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Chemical and microbiological quality of drinking water in Gaza Strip, Palestine

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ABSTRACT

Israel and the Gaza Strip shares the southern Mediterranean coastal aquifer with Israel. Long-term overexploitation in the Gaza Strip has resulted in a decreasing water table, accompanied by the degradation of its water quality. Due to high levels of salinity, most of the ground water is not suitable for both domestic and agricultural consumptions. The aim of this paper is to evaluate the chemical and microbiological qualities of the drinking water in Gaza Strip. The rapid rate of population growth in the Gaza Strip and dependence upon ground water as a single water source presents a serious challenge to future development. Data were collected from the Palestinian Ministry of Health on the concentration of total dissolved solids (TDS), chloride (Cl^-) and nitrate (NO_3^-) in drinking water wells, and contamination of total and faecal coliforms in water wells and distribution networks. From the collected data on chemical water analysis, we obtained that the average concentration of TDS (1687 mg/l), Cl^- (577 mg/l) and NO_3^- (131 mg/l) were higher than that of the World Health Organization (WHO) standard, i.e., 1000, 250 and 50 mg/l, respectively. Upon microbiological water analyses, total and faecal coliform contamination percentages were found to exceed that of the WHO standard, i.e., <5% for total coliform and free (0%) for faecal coliform for all water wells and networks distribution system, and the level of contamination in water networks were higher than that in wells. The chemical and microbiological qualities of drinking water thus deteriorated in Gaza Strip, and water demand is increasing rapidly due to rapid population growth and absence of alternative water resources. This may result in adverse human health impacts.

Key words: Chloride; contamination; coliform; Gaza Strip; nitrate; water wells; water quality.

INTRODUCTION

The Gaza Strip is a part of the Palestinian coastal plain located in arid and semi-arid regions. It is bordered by Egypt from the south, the Green Line from the North, Nagev desert from the East and the Mediterranean Sea from the West. The total surface area is 360 km^2, where about 1.5 million of Palestinian people live and work.[1] This figure classifies the Gaza Strip as one of the most densely populated area in the world. It is divided geographically into five Governorates: Northern, Gaza, Mid Zone, Khan Younis and Rafah. The annual average rainfall varies from 400 mm in the north to

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about 200 mm in the south of the Strip.[2] Most of the rainfall occurs in the period from October to March, the rest of the year being dry. However, Wadi Gaza transports water into the Mediterranean Sea for relatively short periods of time during the rainy season.[3] Therefore, the main source of water is the groundwater aquifer. It has no permanent surface water. Over pumping and low rainfall have limited the quantity of water available and have further contributed to the degradation of the water quality.[4]

The entire population is completely dependent on groundwater for agricultural, industrial, and domestic water supplies. The aquifer is continuously over-exploited. The sewage system is incorrectly designed.[5] The total abstraction of groundwater in Gaza Governorates is estimated to be 170 Million Cubic Meter (MCM or Mm^3)/ year.[6] Crop cultivation alone consumes around 85 MCM/year of the groundwater pumped through more than 4000 wells located over all Gaza Governorates, while the remainder (85 MCM/year) is used for industrial and domestic water supplies.[3] The water crisis stems from the growing water deficit as the amount of water exploitation; 170 MCM/year is not balanced by natural or anthropogenic replenishments. The natural replenishment of the aquifer is estimated to be 35 MCM/year, while the anthropogenic replenishment (agricultural return flow, pipe leakage and waste water) is estimated at 40 MCM/year. The lateral inflow from the eastern part of the aquifer is 15 MCM/year. Overall, the Gaza Strip is facing an annual deficit of ~70 MCM/year.[6] Because of the water deficit, regional water levels have lowered, and deep hydrological depressions have formed in the urban areas including Gaza City in the north and Rafah in the south.[7-10]

The concentration of chemical pollutants, including Cl^- and NO_3^- has exceeded the recommended WHO standards. The quality of the groundwater in Gaza Strip is generally poor; water quality has deteriorated due to infiltration of sewage, solid waste leaching and agricultural fertilizers. The drinking water distribution system is relatively old and requires frequent maintenance. Interruption of the water supply and use of roof tanks are common in the Gaza Strip, and the sewage system is improbably designed. Although the microbiological quality of drinking water has deteriorated, few studies have discussed the problem. Recent work revealed that total and faecal coliform contamination exceeded the World Health Organization's (WHO) limits for water wells and networks in Gaza Governorates. However, the contamination percentages were higher in networks than in wells. Bacterial contamination of water wells and networks has been reported in developed and developing countries.[11] The aim of this paper is to present the chemical and microbiological quality of drinking water in Gaza Strip. The objectives of this study were to answer the following research questions: (1) What is the contamination level of total dissolved solids (TDS), Cl^- and NO_3^- for each Gaza Strip Governorates? (2) What is the contamination level of total and faecal coliforms in water wells and networks distribution system during the year 2009?

MATERIALS AND METHODS

Data collection

Following the monitoring cooperative program between Palestinian Ministry of Health and Coastal Municipalities Water Utility (CMUW), water samples were collect from 164 drinking water wells distributed in five governorates of Gaza Strip during the period from 1 April to 30 October 2009 for chemical and microbiological examinations. With regard to monitoring program, one sample was collected for chemical examinations from each drinking water wells, while samples for microbiological examinations were collected monthly from the drinking water wells and from the representative points of water distribution networks.

Data on TDS, Cl^- and NO_3^- were obtained from the records of water control department at the Palestinian Ministry of Health. According to the records, samples were collected for chemical examination in the year 2009 for 164 drinking water wells distributed in all Governorates in the Gaza Strip.

Data on total and fecal coliform contaminations in water wells and network distribution systems were obtained from the records of water control department at the Palestinian Ministry of Health. According to the records, samples were collected in the year 2009 for 164 water wells distributed for all governorates of Gaza Strip. For networks, samples were collected at random from representative points serving water to consumers (households, schools, hospitals and clinics).

Data analysis

Data were analysed using Microsoft Excel to calculate the average concentration of TDS, Cl^- and NO_3^- for each governorates in Gaza Strip and compared with the WHO standard, and also the bacterial contamination percentage was calculated by total and faecal coliforms on monthly basis for water wells and networks. In addition the monthly contamination percentages in water wells and networks distribution system were calculated for each Governorate in the Gaza Strip in the year 2009.

RESULTS AND DISCUSSION

Chemical contamination (TDS, Cl^- and NO_3^-) of drinking water wells

The data of chemical water analysis were obtained from the records water control department at the Palestinian Ministry of Health in 2009. TDS and Cl^- used in this paper as an indicator of groundwater salinity contamination in Gaza Strip and Nitrate was used as an indicator of anthropogenic contamination of groundwater. High levels of Cl^- and TDS in the groundwater cause high salinity in the water supply.[12] Table 1 summarize the average concentration of TDS, Cl^- and NO_3^- for drinking water wells in each Governorates of the Gaza Strip. The average TDS concentration ranges from 720 mg/l in the North to 2709 mg/l in Gaza Governorate. Cl^- concentration ranges from 181 mg/l in the North to 772 mg/l in Gaza Governorate. The average concentration of NO_3^- ranges from 97 mg/l in the North to 139 in Gaza Governorate. As shown in table 1, level of TDS, Cl^- and NO_3^- were higher than WHO standard, i.e, 1000, 250 and 50 mg/l, respectively, for the entire Gaza strip Governorates, except in the North Governorate where the concentration of TDS were less than standards. Table 2 presents the percentages of drinking water wells that exceeds WHO standards of TDS, Cl^- and NO_3^-. For TDS, about 49% of drinking municipal water wells exceed WHO standard (1000 mg/l). The percentage ranges from 4% in the North Governorate to 81% in Mid Zone. Like TDS, the concentrations of Cl^- in 58% of municipal water wells were higher than WHO standard (250 mg/l) and range from 8% in the North to 94% in Mid Zone Governorates.

The major source of salinity in the aquifer in the Gaza Strip is derived from the flow of natural saline ground water from the eastern part of the aquifer toward the Gaza Strip. The long-term reduction of the water tables due to over-

Table 1. Average concentration of chemical parameters in drinking water in Gaza Strip in the year 2009.

Governorate	No. of wells	Total flow (m3/h)	TDS (mg/l)	NO_3^- (mg/l)	Cl^- (mg/l)
Rafah	17	1505	1196.13	113.62	428.59
Khan Younis	32	2470	1602.7	205	637.43
Middle	39	2308	1494.61	80.17	634.26
Gaza	44	4562	1695.5	139.24	772.35
North	32	3904	720.37	96.53	180.64
WHO standard	NA	NA	1000	50	250
Total	164	14749	NA	NA	NA

exploitation has increased the water gradients and rate of water flow toward the Gaza Strip. Sea water intrusion has also resulted in salinization of ground water in the western part of the aquifer. Sources of high Cl^- content have been determined to be sea water intrusion, lateral flow of brackish water from east in the middle and southern area and up-coning of the brine water from the base of the aquifer.[13] Seawater intrusion and uplift of the deep brine water are the direct consequences of over pumping, and represent the greatest threats to municipal and agricultural water supplies in the Gaza Strip. According to data collected by Amiruddin *et al*.[14] in Malacca Strait showed significant low salinity input from West coast Peninsular Malaysia in Northeast Monsoon season. During southwest Monsoon period, there was an intrusion of high saline water from Andaman Sea to the Strait. The blowing of Southwesterly wind may push seawater from Indian Ocean and Andaman Sea intrudes the Strait from the Northern sector. The Strait also was found to be more stratified in warmer condition.

The lateral inflow of brackish water from the east is believed to be groundwater from the Eocene rocks that underlie the coastal aquifer in the east and is therefore of natural origin. Cl^- concentrations in the monitored, shallow portions of the coastal aquifer are generally better in the north of the Gaza Strip than in the south. The relatively low values of Cl^- in the north, and demonstrates the shallow nature of wells that are sampled. This suggests that brackish water from Israel is flowing toward the northern well fields in Gaza City and Jabalya. The increasing Cl^- trends in the Khan Younis municipal well field were demonstrated by the deeper wells. Al Harbi *et al*.[15] in Al-Mendasah area, North-West of Al-Madinah Al-Munawarrah concluded that the soil infiltration rate will not be affected either by well water or drainage water irrigation. Only 12% of well waters are safe for irrigation directly without serious soil and crop production problems.

An additional source of pollution in the Gaza Strip is NO_3^- concentration was used in this paper for indicate of groundwater contamination by wastewater, solid waste infiltrate and agriculture fertilizers. In contrast to salinity, groundwater flowing from east has relatively low NO_3^- levels. The groundwater quality in the study site in Thanjavur city, Tamil Nadu, India, is impaired by surface contamination sources, mineral dissolution, ion exchange, and evaporation. NO_3^-, Cl^-, and sulfate concentrations strongly express the impact of surface contamination sources such as agricultural and domestic activities, on groundwater quality.[16]

Table 2. Comparison of TDS, NO_3^- and Cl^- concentration of drinking water wells comparing with WHO standard in Gaza Strip Governorates at the year 2009.

Governorates	TDS	NO_3^-	Cl^-
North	4%	71%	8%
Gaza	62%	90%	66%
Mid Zune	81%	69%	94%
KhanYounis	72%	90%	72%
Rafah	25%	75%	50%
Average	49%	79%	58%
WHO Standard	1000 mg/l	50 mg/l	250 mg/l

As shown in Table 2, about 79% of municipal wells in the Gaza Strip have NO_3^- concentrations that exceed WHO guidelines of 50 mg/l. The level of NO_3^- contamination has been rising so rapidly that most of Gaza's drinking water wells are no longer suitable for human consumption. Nevertheless, domestic wells continue to supply ground water of poor quality to local communities for drinking water.[17,18] Dissimilar data accrued by Curly *et al.*[19] indicate that leaching losses were closer to those recorded under arable land than extensively managed grassland; slurry application on an establishing *Miscanthus* crop does not appear to contribute adversely to levels of NO_3^- in groundwater when compared to other more extensive cropping systems between fertilize and unfertilized crop.

Microbial contamination (Total and fecal coliform)

Table 3. Total coliform sample contamination examined for water wells and networks at monthly basis throughout the year 2009 in the Gaza Strip.

Month	Wells			Networks		
	n	**C. s**	**C.%**	***n***	**C. s**	**C.% of**
January	95	10	11	213	8	4
February	62	4	6	266	61	23
March	87	64	74	255	199	78
April	102	58	57	201	96	48
May	81	8	10	174	26	15
June	109	6	6	282	51	18
July	114	13	11	193	23	12
August	98	16	16	356	90	25
September	40	5	13	157	22	14
October	65	5	8	150	24	16
November	82	15	18	160	24	15
December	35	3	9	128	24	19
Total	970	207	Aver. 21	2535	648	Aver. 26

n = number of samples, **C .s:** Contaminated samples, **C%:** Contamination percentage.

Assessment of water wells and networks distribution system of total and fecal coliform contamination was made on monthly basis in 2009 as shown in Table 3. The groundwater wells and water networks included in this paper were selected in such a way as to cover all the possible sources of drinking water purposes for all Governorates in Gaza Strip. Coliform organisms used in this study as indicators for water contamination were the most commonly used indicators for monitoring water quality.[20,21] The monthly collected samples in term of population size fulfilled the minimum limit of samples according to monitoring program that was applied by the Palestinian ministry of health. In general, the percentage of total coliform contamination in wells is lower than that in networks all over the various months of the year. The contamination values vary from 6-74% and from 4-78% in wells and networks, respectively. Like wells, the level of total coliform contamination in the networks across the most months exceeded that of the WHO standard (5%), except in January which was 4%. The highest contamination values for both wells and networks were recorded in March and Aril. The ranges were 11-74% and 4-78% in wells and networks, respectively. However, high contamination percentages of 74 and 78% were detected in March in wells and networks, respectively.

The fecal colifrom samples contamination recorded for water wells and networks is illustrated in Table 4. The samples were considered to fulfil the minimum limit of samples according to monitoring program that was applied by the Palestinian Ministry of Health. According to the WHO standard, fecal coliform contamination is based on forming ≥ 1 colony per 100 ml of sample examined. Like total coliform, the fecal coliform contamination in the wells is generally lower than that in the networks. The range of fecal coliform contamination was from 0-10% in wells and from 1-14% in networks. However, the level of contamination generally exceeded that of the WHO standard, except for wells in December when the samples were free of contamination. In general, higher fecal coliform contamination values in water wells were registered in August, September and November. However, in networks the higher percentages of fecal coliform were recorded accrues the months in summer in March, August and November.

As a general guide, the WHO (1996)[20] recommends that one sample per 1,000 persons served should be examined each month for supplies serving up to 100,000 persons. For supplies serving populations over 100,000, it is considered justifiable to reduce the sampling

Table 4. Fecal coliform sample contamination examined for water wells and networks at monthly basis throughout the year 2009 in the Gaza Strip.

Month	Wells			Networks		
C.% of	*n*	C.s	C.% of	*n*	C.s	C.% of
1	248	2	1	248	2	1
9	266	23	9	266	23	9
13	255	32	13	255	32	13
7	201	14	7	201	14	7
8	174	14	8	174	14	8
8	320	26	8	320	26	8
3	193	5	3	193	5	3
14	356	50	14	356	50	14
6	157	10	6	157	10	6
5	150	7	5	150	7	5
11	198	22	11	198	22	11
7	128	9	7	128	9	7
Aver. 8	2646	214	Aver. 8	2646	214	Aver. 8

n = number of samples, **C .s:** Contaminated samples, **C%:** Contamination percentage.

increment to one per 10,000 persons per month. In systems serving populations of this size, the interval between successive samples will be very short. The samples should be taken at regular intervals throughout the month. In water supplies with a history of high-quality water production, it may be possible to reduce the number of samples taken for bacteriological analysis. Therefore, the water-monitoring program in Gaza Strip should be applied to increasing the monitoring of supplies and number of samples. However, the monitoring processes are restricted by the complexity of water distribution system.[22]

Comparison between the total coliform contamination in the wells and water networks of the five Governorates of Gaza Strip is summarized in Table 5. The contamination percentages exceeded that of the WHO limit for both wells and networks all over Gaza Strip Governorates. In general the total coliform contamination percentages in networks were higher than that in wells. The contamination percentages ranges from 17-28% and from 23-32% in wells and networks, respectively.

Table 6 summarizes the levels of fecal coliform contamination in the wells and water networks of the five Governorates of Gaza Strip. The fecal coliform contamination exceeded the WHO limit for both water wells and networks, and its ranges from 0-8% and from 0-12 percentages, respectively. Uncontaminated samples

Table 5. Total coliform contamination percentages in water wells and networks for each governorate in Gaza Strip in the year 2009.

	Wells			Networks		
Governorates	*n*	C.s	C.%	*n*	C.s	C.%
North	285	49	17	367	87	24
Gaza	506	114	22	1022	297	29
Mid Zone	62	12	18	793	184	23
Khan Younis	15	3	20	179	60	33
Rafah	102	29	28	174	56	32
Total	970	207	Aver. 5	2535	684	Aver. 8

n = number of samples, **C .s:** Contaminated samples, **C%:** Contamination percentage.

Table 6. Comparison between the fecal coliform contamination in wells and water networks of the five Governorates of Gaza Strip in 2009.

	Wells			Networks		
Governorates	***n***	**C. s**	**C.%**	***n***	**C .s**	**C.%**
North	285	10	3.5	367	37	10
Gaza	506	28	5.5	1070	109	10
Mid Zone	62	5	8	831	45	5
Khan Younis	15	0	0	189	0	0
Rafah	102	8	8	189	23	12
Total	970	51	Aver. 5	2646	214	Aver. 8

n = number of samples, **C .s:** Contaminated samples, **C%:** Contamination percentage.

were recorded for both water wells and networks in Khan Younis Governorate. Coliform contamination in water networks was higher than that in wells throughout the study period.

In spite of regulations to protect groundwater and the distribution system from microbial contamination, the annual bacteriological analysis of drinking water for each Governorate in the Gaza strip revealed that the total and fecal coliform contamination in wells and water distribution networks was generally higher than that of the WHO limit. The drinking water source and its delivery system (casing, pump, pipes and other appurtenances) must be free of contamination from either surface (e.g. waste infiltration) or subsurface (e.g. cesspools) source. Particularly, the water must meet the guideline criteria of microbiological quality.[18]

Melad *et al*.[23] mentioned that the infiltration of wastewater in Beith Lahia - Gaza Strip directly affects the microbial quality of groundwater. Beith Lahia has a very sever chemical and biological contamination problems due to the flooding of the existing wastewater treatment plant to the nearest sand dunes. The same problems are tangible in all the surrounding areas of wastewater treatment plant in Rafah. Khanyounis Governorate has no sewer system and the residents use cesspits which finally infiltrate to the groundwater. The percentage contamination will be representative because the number of collected samples was dependent on the population size, the quantity of water supplied and the frequent monitoring of the water source in a definite period. Accordingly, percentage increase in contamination will increase the risk on human health. Heavily contaminated water networks and groundwater wells were registered for total and faecal coliforms, particularly in developing countries.[24,25]

The main problem in Gaza Strip is the lack of spare parts and professional to repair and maintain water distribution system. Leakage from nodes and joints, interruption of water supply for many hours a day increase the possibilities of wastewater seepage to water network. In addition, the problems of networks contamination will exacerbated due to the destruction of the infrastructure including water and wastewater networks by the Israeli militant activities. Obtaining clean drinking water is a constant challenge in many countries. Often the only water available is rife with disease-causing bacteria and must be disinfected to make it safe. The lack of money needed to develop the elaborate drinking water infrastructure in addition to the difficulty or impossibility associated with importing materials and expertise necessary for sustainable operation of such facilities demand techniques capable of eliminating or neutralizing water-borne pathogens using little or no external input such as capital, material, expertise, etc.[26] WHO 1996 reported that deterioration of the bacteriological quality of water during distribution can occur and there where are a number of places contamination can be introduced. In addition many wells have damage chlorination units. Chlorination chemical compounds in many cases are not in the market due to the Israeli restriction and closure.

The major factors contributing to the coliform problem in Gaza Strip may include: (1) sewage infiltration through incorrectly designed sewage systems or through cesspools and wastewater treatment facilities in Gaza Strip, [5,27] and cross contamination of pipeline systems. Schmitz[28] reported that cross contamination of pipeline systems is one of the more common ways in which drinking water supply system is contaminated by sewage. (2) Interruption of water supply that may cause inverse pumping of wastewater or other contaminants from the surrounding system. This may be due to breakage in the distribution system, thus promoting bacterial bio-film growth. Bio-films were reported to develop in water distribution systems.[29,30] (3) Improper operation and inadequate or interrupted disinfection and problem with system maintenance. El-Mahallawi[31] concluded that the disinfection efficiency is not sufficient and the chlorination processes are not well implemented in most of the cases. (4) Availability of sufficient nutrients in standpipe or storage reservoir that is not used for some period of time. It was indicated that in the drinking water of the Barcelona distribution system the factor that controls the growth of bacteria is organic carbon. Moreover, bacteria from the biofilm growing on the surface of the pipes may cause the problems of bacterial growth.[28]

CONCLUSION

For chemical quality of drinking water, the average concentration of TDS, Cl and Nitrate were higher than WHO standard for all Governorates of the Gaza Strip; while, TDS and Cl in the North Governorate were less than WHO standard. Moreover, the highest level of TDS, Cl and Nitrate were in Gaza and Khan Younis Governorates. Moreover, 79% of drinking water wells in Gaza Strip have Nitrate level higher than WHO limit (50 mg/l). The concentration of TDS and Chloride in (49% and 58%) in water wells were exceeds than WHO limits (1000 mg/l and 250 mg/l) in Gaza Strip, respectively. For microbial water quality, the total level of total and fecal coliform contamination in both water wells and networks generally exceeded that of WHO limit. The level of total and fecal coliform contamination in water networks was higher than that in wells in Gaza Strip Governorates.

Recommendations

- Implementation of protection system for water wells and networks distribution system.
- Frequent maintenance of the sewage water networks to reduce wastewater flooding events.
- Raise the monitoring level of all water resources near the source of pollution such as septic tanks, cesspools and wastewater treatment plants and decentralizing of monitoring program.
- Controlled the resources of water pollution, throw setting up designs and a good maintenance for water network.
- Awareness programe for water consumption and conservation should be developed.
- improvement of wastewater treatment plants to product adequate effluent quality for reuse.
- Co-operation between all ministries which works in the water field to put an inclusive water law.

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