Desalination 249 (2009) 1165–1170

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Chemical and microbiological quality of desalinated water, groundwater and rain-fed cisterns in the Gaza strip, Palestine

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ARTICLE INFO

Article history:
Accepted 19 January 2009
Available online 8 October 2009

Keywords:
Water quality
Desalinated water
Gaza Strip
Palestine

ABSTRACT

The aim of this study was to assess the physiochemical and microbiological quality of the domestic water through one-year long surveillance in Gaza Strip, Palestine. Water samples were taken from rain-fed cisterns, groundwater from the water network, and desalinated water. For certain chemical parameters, such as nitrate, a high percentage of water samples from all sources exceeded the limits of the Palestinian Standard Institution and the World Health Organization (WHO). Total dissolved solid (TDS) readings were non-compliant for most samples from groundwater and water from rain-fed cisterns, but the TDS quality was far better in desalinated water. As far as microbiological quality is concerned, high percentages of non-compliance were observed for total *Coliform* and fecal *Coliform* in most water samples, which was also reflected by the high incidence of water-borne diseases in Gaza Strip. The study reveals a clear superiority of quality for desalinated water, but also the need to adopt better practices (maintenance and pre- and post-treatment) in the desalination plants.

1. Introduction

With the pollution of water caused by human activities, serious health problems and other economic costs related to water treatment, remediation and locating a new water supply, become evident [1]. In the Middle East, the increasing deterioration in quality of available water and water deficiency are looming, while in the Palestinian context the problems of both water deficiency and contamination are obvious and acute [2–4]. Water could be chemically, physically, or microbiologically contaminated. Each of which is linked to various sources and health related problems and consequences. Two main factors determine the chemical and microbiological composition of water quality: artificial and natural contamination. Any microbiological or chemical analysis of water reveals the joint effects of both sources of contamination, and it is usually impossible to fully identify and separate these sources [5].

The main source of microbiological contamination is microorganisms from human or animal excreta, which reaches humans through contaminated water from wastewater, landfills, or wastewater treatment stations, causing serious health problems. For example, according to the UN, diarrhea accounts for 80% of all diseases and over one third of deaths in developing countries, which are caused by the patients' consumption of contaminated water [1,5]. Most of the gastrointestinal infections that may be transmitted through drinking water are transmitted via fecal–oral pathway [6]. Hence, the effects of improvements in the quality of water were felt on the combat against endemic diseases such as typhoid and cholera in adults, and diarrhea in children [7]. The most commonly used indicators for microbiological contamination are the *Coliforms*: total and fecal *Coliforms*. *E. coli* is a subgroup of total *Coliform* group [8]. Detection of bacterial indicators in drinking water signifies the presence of pathogenic organisms that are the source of water-borne diseases.

Chemical pollution, the other type of water contamination, could be organic or inorganic. Organic chemicals include leachate (e.g., from solid waste), synthetic organic compounds, and chlorinated compounds like Trihalomethans (THM), which are associated with poisoning, cancer, liver, kidney and Central Nervous System problems. Inorganic compounds, on the other hand, consist of substances resulting from water treatment and pesticides or pollution resulting from industry (e.g.: Cd, Ba, Hg, Mo and B). Many diseases are associated with these elements including, poisoning, cancer, hypertension and infantile cyanosis. The latter is associated with nitrate toxicity [8].

Various sources are suspected of causing water pollution in the Gaza Strip, Palestine. These primarily include wastewater, overuse of fertilizers and agricultural pesticides, and solid waste that might produce toxic substance, e.g. nitrate [3,4]. The aim of this study was to shed light on drinking water quality in Gaza Strip. Different sources of water, including desalinated water, groundwater, and harvested rainwater were studied and water related problems were assessed in terms of potential sources of water pollution, and the impact of water pollution on the health of the inhabitants of Gaza Strip.

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0011-9164/$ – see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.desal.2009.01.038

2. Material and methods

2.1. Study area

The Gaza Strip area is part of Palestine. It is a small area of about 365 km^2 located at the eastern coast of the Mediterranean, about 35 km long and between 6 and 12 km wide (Fig. 1) 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 area consists of a littoral zone, a strip of dunes from the Quaternary era situated on the top of a system of older Pleistocene beach ridge, and more to the east, gently sloping alluvial and loess plains [9]. The total population of GS was 1,202,756 persons in 2004 as extrapolated from the data of 1997 census by the Palestinian Central Bureau of Statistics [10].

The three sources of domestic water supply in Gaza Strip are 1) groundwater from the coastal aquifer, 2) desalinated water utilizing brackish and, less commonly, seawater as feed, and 3) rainwater harvesting wells [11–14]. Groundwater from the coastal aquifer supplies the Strip with 90% of its domestic (i.e., municipal and agricultural) water needs [11]. The aquifer in the Gaza Strip is part of the coastal aquifer, which extends from Mt. Carmel in the north to the Sinai desert in the south with a variable width and depth. The total area of the coastal aquifer is about 2000 km^2 with 400 km^2 beneath the Gaza Strip [15]. The aquifer media are composed mainly of alluvial sandstone with gravel from the Tertiary era covered with Quaternary sand dunes. These dunes extend along the shoreline up to few kilometers inland. The depth of the aquifer varies from about 170 m at the shoreline to a few meters at the eastern boundary (Fig. 2). This makes it vulnerable for pollutants mainly from untreated wastewater in the area [3,11,12]. There is a very thick impermeable clay layer underneath the aquifer, the Saqiya formation. This 400 to 1000 m layer forms the bed of the aquifer. Some clay layers of different thicknesses up to 20 m divide the aquifer into three main sub-aquifers. These sub-aquifers were classified into sub-aquifer A, which is at the top; sub-aquifer B; and sub-aquifer C beneath (Fig. 2) [9].

Salinity of the coastal aquifer's groundwater has been constantly increasing over time, due to seawater intrusion and the excessive withdrawal of water, far exceeding the natural recharge [11,12]. In many areas of the Gaza Strip, salinity in groundwater extracted from the aquifer has exceeded 1000 mg/L, and even 3000 mg/L in some

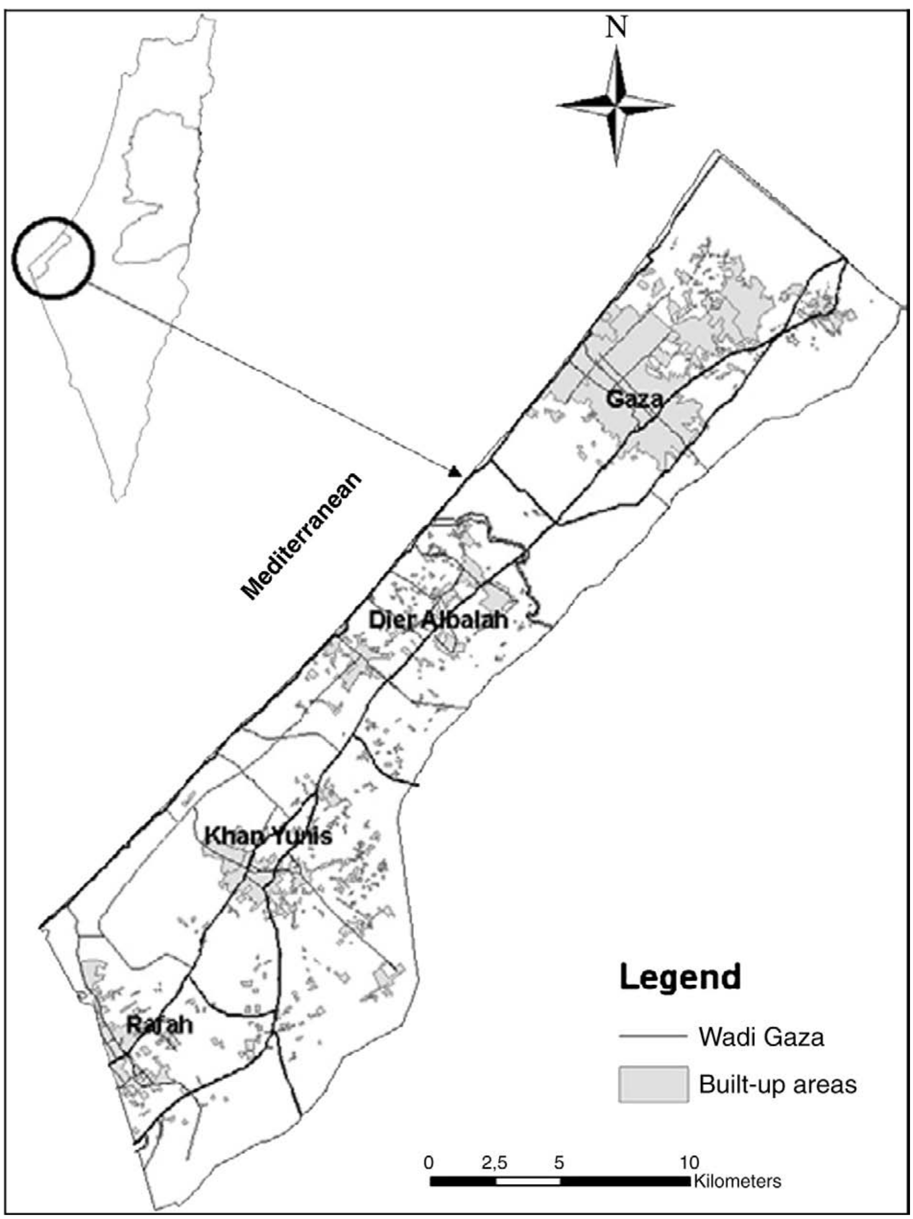

Fig. 1. Location map of the Gaza Strip.

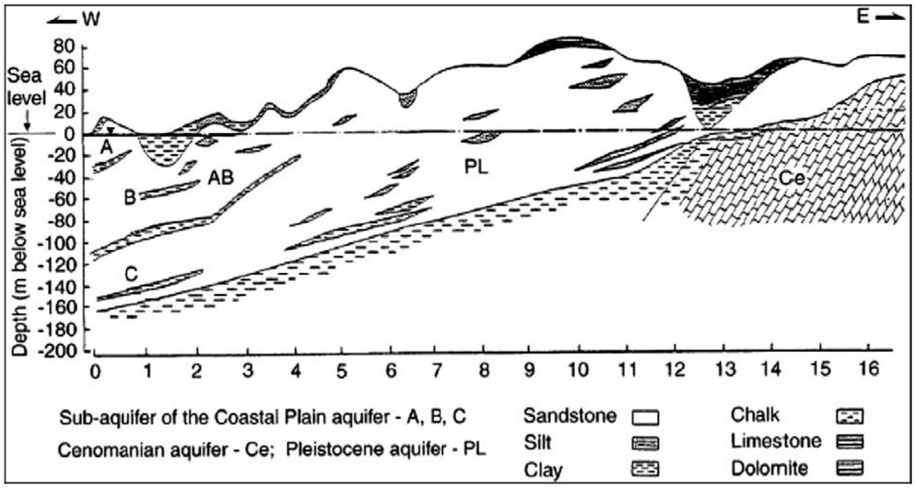

Fig. 2. Typical geological cross-section in the Gaza Strip [9].

areas [11]. Although water with such salinity can be used for certain domestic applications, such as irrigation and household cleaning, it is deemed unacceptable for drinking purposes [16]. As a result, desalination became the alternative source for drinking water, supplying the Gaza Strip with 90% of its drinking water needs [11]. So far, there is no major desalination plant to supply the whole Gaza Strip with its need of desalinated water, although such project has been planned for [12,13]. Instead, desalinated water comes from an array of government-owned small plants, plants owned by non-for-profit non-governmental organizations, and commercial desalination plants [11,12]. Table 1 provides some details on the seven governmental desalination plants operating in Gaza Strip [11]. Additionally, about 17% of the Gaza Strip residents use small Reverse Osmosis (RO) units in their homes, producing about 20 L/day [11]. Residents in Gaza Strip obtain desalinated water either by distribution tankers, or directly from the desalination plants (using plastic containers, etc). In the city of Khan Younis, as a unique case, desalinated water is pumped through the water network for few hours every day [11].

2.2. Data collection and analysis

Data on the physical, chemical and microbiological quality of water samples from different sources was obtained from the records of the Central Public Health Laboratories (CPHL) of the Palestinian Ministry of Health (MoH) in Gaza city. The data was the result of random water sampling for routine inspection conducted during the period from January to December of 2004. The physical and chemical tests performed by CPHL to assess water quality included turbidity, pH, conductivity, total dissolved solids (TDS), nitrite, nitrate, chloride, sulfate, calcium, magnesium, fluoride, potassium, sodium, ammonia, and color. Microbiological tests included total *Coliform* (TC), fecal *Coliform* (FC), fecal *Streptococcus*, *Pseudomonas*, and cholera. All analyses (physical, chemical and microbiological) were carried out in accordance with the procedures described by the American Public Health Association [17]. CPHL, which is accredited by Palestinian Standard Institution (PSI), follows the ISO standard No. 17025 in its tests. Internal and external proficiency tests are carried out to assure the accuracy and precision of sample results.

Water samples were collected by CPHL from three origins in Gaza Strip. These are; 1) groundwater pumped through the water network (sampled at the customers taps, storage tanks, etc), 2) desalinated water (sampled at exit points of desalination plants, customers taps during pumping hours of desalinated water, water selling stations, distribution tankers, etc), and 3) water from the rain-fed cisterns. In accordance with standard procedures [17], CPHL personnel who performed the sampling treated the water samples in situ (when needed), stored them at 4 °C, held them in sterile boxes, and sent them to the laboratory within 1–2 h of collection. Ultimately, compliance statistics for all three types of water (ground, desalinated, rain) were produced, reviewed, sorted, tabulated, and categorized by the authors with the help of the Environmental Health Department personnel of the MoH as well as the CPHL technicians. The data was coded and entered into the computer and the averages for the different parameters were found using SPSS software (Statistical Package for Social Sciences). Decisions regarding whether water samples were deemed acceptable or not acceptable for drinking or bathing were based on the World Health Organization [6,16] and/or Palestinian [18] guidelines.

3. Results and discussion

3.1. Physiochemical water quality

Table 2 shows a summary of compliance rates of tested water samples in Gaza Strip for fifteen physiochemical parameters. Clearly, water quality varies significantly depending on the source of water. Desalinated water samples had a high percentage (44%) of non-compliance in terms of their pH value compared to water from rain-fed cisterns (1%) or groundwater (11%). Almost all non-compliant samples

Table 1
Government-owned desalination plants in Gaza Strip [11].

Plant name	Feed water	Feed water TDS (mg/l)	Plant capacity (m^3/h)	Plant productivity (m^3/h)
Industrial Zone (north)	Brackish water	1400	95	75
Beit Lahia (north)	Beach wells	1300	60	50
Deir El Balah (1)	Beach wells	3100	78	45
Deir El Balah (2)	Seawater	35,000	30	20
Deir El Balah (3)	Seawater	35,000	–	2000
Khan Younis El-Sharqi	Beach wells	2500	60	50
Khan Younis Al-Sa'ad	Beach wells	2000	80	65

Table 2
Physiochemical quality of drinking water samples in Gaza Strip.

Tests	Source of water						Compliance limit and reference
	Water from rain-fed cisterns		Desalinated water		Groundwater(network-distributed)		
	Number of samples	Percentage of non-compliant samples (%)	Number of samples	Percentage of non-compliant samples (%)	Number of samples	Percentage of non-compliant samples (%)	
Turbidity	294	0.3	122	0	168	8.9	5 NTU [16]
pH[a]	297	1.0	158	44.3	108	11.1	6.5–8.5 [6]
Conductivity	297	55.6	147	2.0	108	88.0	1500 μS/cm [6]
TDS	298	52.7	159	4.4	127	52.8	1000 mg/l [16]
Nitrite	250	0.8	64	1.6	52	1.9	0.3 mg/l [16]
Nitrate	298	76.8	149	12.8	111	84.7	50 mg/l [16]
Chloride	298	56.7	159	0	116	67.2	250 mg/l [16]
Sulfate	295	18.6	123	0	80	18.8	250 mg/l [16]
Calcium	295	0	122	0	83	0	100 mg/l [18]
Magnesium	295	0	122	0	79	0	100 mg/l [18]
Fluoride	203	43.4	61	4.9	36	25.0	1.5 mg/l [16]
Potassium	295	0	122	0	77	0	10 mg/l [18]
Sodium	295	54.9	122	0	77	45.5	200 mg/l [16]
Ammonia	237	0.4	73	0	44	0	1.5 mg/l [16]
Color	294	0	122	0	77	0	15 TCU [16]

[a] All non-compliant samples registered pH values below the lower compliance limit of 6.5.

had pH values below the WHO limit of 6.5. It is known that, in membrane desalination, the pH of the permeate (the desalinated water) is usually below 6. This is because carbon dioxide passes through the membranes and hydrogen carbonate is rejected. Since the pH is governed by the logarithm of the ratio of hydrogen carbonate to carbon dioxide, the pH of the permeate water is always low. As a consequence, the water is very corrosive towards several materials, such as asbestos, cement, galvanized steel, steel, cement lining, copper and brass. So, post treatment is required, such as mixing with other water or filtration through limestone grains. As such post treatment of desalinated water is not conducted in Gaza Strip, the low pH values were observed.

Another major aspect of non-compliance is the nitrate content. A shocking 88% non-compliance percentage for nitrate content was observed in the network water from groundwater origin, and a similarly high 77% non-compliance percentage was observed for water from rain-fed cisterns. Untreated domestic and industrial wastewater is considered one of the most important pollutants in the Gaza Strip, contaminating both ground and surface water. This, along with the excessive use of fertilizers, have impacted the quality of water in the Strip as the infiltration of wastewater into groundwater in the Strip causes the high nitrate concentration, which was also reported by others [3,11]. This is further complicated by the fact that intermittent pumping of water in the network causes negative pressure in the pipes during no-pumping periods, which sucks polluted wastewater from the ground into the old leaky water pipes. It is important to keep in mind that about 36.6% of the households in the Gaza Strip are not connected to a sewage network and use cesspits for wastewater disposal. Moreover, about 50% of all wastewater in the Strip flows in open valleys from both cities and villages [19]. Nitrate non-compliance is significantly lower for desalinated water (12.8%), but is still high. Nitrate is usually not very well rejected in RO, with rejection rates of 80–90%, depending on the type of the RO membrane used and its condition. Moreover, the high nitrate concentration in the permeate of RO systems might be due to poor performance of the RO (e.g. damaged membranes or leakages in O-rings). The fact that nitrate concentration in the feed water to the desalination units (mostly brackish water in Gaza) is high, will contribute to the nitrate concentration in the permeate.

Salinity is another cause of non-compliance in water samples. Total dissolved solids (TDS) non-compliance rate was 56% and 88% for rain-fed cisterns and groundwater samples, respectively, compared to only 4% in desalinated water. Similar trends are also observed for sodium, chloride, sulfate, and conductivity readings, as seen in Table 2. Once again, water samples from rain-fed cisterns and groundwater origins registered a much higher non-compliance rate than desalinated water for all these parameters. In fact, all desalinated water samples were 100% compliant with standards in terms of their chloride, sulfate, and sodium content. These observations reveal two things: first, the horribly deteriorated quality of groundwater and water from rain-fed cisterns, which was also reported in other studies [11,12]. It is clear, beyond doubt, that the increasing unbalanced withdrawal of water from the coastal aquifer of Gaza Strip is causing serious problems with seawater intrusion into the aquifer. Moreover, it is clearly causing soil salinity and that also is impacting the rain-fed cisterns, most of which are underground excavations, supported by clay walls, allowing salt ions to infuse them. Secondly, a clear advantage is observed here for desalination, where the water quality is far better than groundwater and water from rain-fed cisterns. The reverse osmosis (RO) process applied in the desalination units allows for a high salt rejection rate, enabling excellent control of the desalinated water in terms of its salt content. As these RO units become overused, especially under poor maintenance conditions (e.g., lack of proper anti-scalant dosing, pretreatment, etc.), fouling of the membrane could lead to poor salt rejection, which could explain the small percentage of non-compliant desalinated water samples (about 4%), with respect to TDS results. Another factor to keep in mind is that in the Khan Younis city, desalinated water is pumped into the water network for few hours daily. Prior to this pumping period, the water pipes will have residuals of salty groundwater in them, which gets mixed with the desalinated water. This also may cause high salinity in the desalinated water samples in this case, mainly at the beginning of the pumping period.

Fluoride is another key water quality that is of importance in our case. About 43% and 25% of rain-fed water and groundwater samples, respectively, had fluoride content exceeding the allowable limit, compared to 5% only in desalinated water. High fluoride concentrations were found to lead to skeletal fluorosis and paralysis, yellow staining of teeth, as well as kidney malfunction. Teeth discoloration and mottling is at the present time vividly observed in the teeth of adult Palestinians in the central and southern Gaza Strip [12].

Finally, it is interesting to observe that the two physical quality parameters, turbidity and color, were very good (i.e., total or very high compliance rate in samples) for all sources of water in Gaza Strip. The only exception is the above-limit turbidity in about 9% of the samples of groundwater pumped through the network. Due to the shortage of water supply, water is pumped intermittently in the network in Palestine (and also in many neighboring countries, like Jordan). As a result, residents in Gaza Strip install water tanks to collect water during pumping periods for use during no-pumping times. Solid particles in the water settle and accumulate at the bottoms of these tanks, then become suddenly stirred and suspended when the water flow to the tank is re-started, especially at high water pressure. If water is drawn from the tank during that time (i.e., when water from the network is re-filling the tank), it is likely to be visibly turbid, as commonly observed by the residents in Palestine.

3.2. Microbiological water quality

Out of 1056 water samples from rain-fed cisterns tested in Gaza Strip for total *Coliform* (TC) and fecal *Coliform* (FC), 8.6% and 3.9% of the samples exceeded the WHO limits for TC and FC, respectively, as shown in Table 3. These percentages were up to 15.5% and 7.1%, respectively, for water samples taken from water networks, and to 15.2% and 7%, respectively, for desalinated water samples. All the samples tested were free of cholera (Table 3). A smaller number of water samples were tested for *Pseudomonas* from hospitals and swimming pools fed by groundwater (113 samples) and desalinated water (184 samples). 21.2% of the network water samples and 6.5% of the desalinated water samples were found to exceed the WHO guidelines for *Pseudomonas* (Table 3). As shocking as the latter result may sound, it is not un-precedented. In another study [20] on the prevalence of *Legionella* species and their possible association with *Pseudomonas* in hot water distribution systems in West Bank (Palestine) hospitals, *L. pneumophila* was isolated from 62% of the 53 samples tested, and *P. aeruginosa* were isolated from 21% of 81 samples.

These results indicate a contamination of the domestic water supply in the water network in Gaza Strip by wastewater. This could be due to leakage from the wastewater sewage system, openly flowing sewage, and seepage pits into the water pipelines, as some of the pipes in the water networks are old and cracked. This would particularly happen during the cease periods of water pumping in these pipes, as negative pressure develops inside them. It could also be due to breakage in the water distribution system, thus promoting bacterial biofilm growth. Biofilms were reported to develop in water distribution systems [21]. Besides being subject to the conditions of the water network in localities where it is pumped through it, desalinated water is also prone to contamination thanks to the other methods by which it is distributed in Gaza Strip. Namely; plastic containers, distribution tankers, filling taps at the desalination plants, and several other primitive methods, reported elsewhere [11]. This manual handling of water significantly increases the risk of water contamination, especially if proper hygienic practices are not followed by the handlers of water. Sadly, this strips the desalinated water from one of its main advantages, that is, being microorganisms-free as it permeates through the RO membranes.

As for residents who use rain-fed cisterns in Gaza Strip, water disinfection is clearly inadequate in some of these households, as they depend on water collected in the winter season in their cisterns. Lack of proper disinfection could lead to suitable conditions for biofilm bacterial re-growth, thus increasing the possibility of water contamination. Lack of public awareness about the issues that are important to maintaining good microbiological water quality is another key reason that contributes to water contamination in these cases. For example, in a study conducted in another Palestinian locality, the Tubas district, it was found that 63.7% of the households did not test the drinking water from their rain-fed cisterns, despite the short distance between these cisterns and the sewage pits and the presence of animals near the water cisterns, which increases the possibility of rain-fed cisterns contamination and the risk of water-related diseases [22].

As an indication of the health complications that can be caused by such poor microbiological water quality, Table 4 provides statistics on some water-borne diseases, reported in Gaza Strip in 2004 [23]. The results on intestinal parasitic diseases were as follows: ascariasis (round worm) was found in 1492 cases; oxyuriasis was found 109 cases; strongyloidiasis was found 54 cases; and amebiasis (trophozoite) was found in 11,360 cases in the Strip.

4. Conclusions and recommendations

Based on Palestinian Water Authority records, the domestic water demand in Gaza Strip for the year 2000 was 55 million m^3. This demand is projected to increase to 182 million m^3 in the year 2020 [24]. Water quality in the Strip is deteriorating. Groundwater from the coastal aquifer is currently the main source of water, and its depletion and increasing salinity are becoming urgent problems. Despite the current utilization of desalination to supplement the water needs of Gaza Strip, a significant percentage of this desalinated water does not comply with standard limits for chemical (especially nitrate, pH, and TDS) and microbiological quality. The non-compliance rate, on the other hand, is much higher for groundwater pumped through the network and for water from rain-fed cisterns. The key reasons identified behind this non-compliance include 1) the contamination of water by domestic and industrial wastewater, which flows openly in many parts of Gaza Strip, 2) the poor conditions of the water network, allowing diffusion of polluted water into it, especially when negative pressure develops inside the pipes, 3) the insufficient disinfection of water in the network and the rain-fed cisterns, and 4) the manual and non-hygienic handling and distribution methods of the desalinated water. This situation has resulted in a threat to public health and the spread of water-borne diseases. From the analysis of the results in this study, the following key recommendations are made:

- Dependence on desalinated water should increase, which means that the desalination capacity of the current plants should be boosted or new plants should be built. This will reduce the water withdrawal rate from the coastal aquifer and allow it to rehabilitate itself and reduce its salinity. Moreover, this will guarantee a high-quality water supply in the Gaza Strip. Distribution of desalinated water, then, should be totally done through the water network.

Table 3
Microbiological quality of drinking water samples in Gaza Strip.

Test	Water from rain-fed cisterns		Groundwater (network-distributed)		Desalinated water	
	Number of samples	Percentage of non-compliant samples (%)	Number of samples	Percentage of non-compliant samples (%)	Number of samples	Percentage of non-compliant samples (%)
Total *Coliform*	1056	8.6	2802	15.5	525	15.2
Fecal *Coliform*	1056	3.9	2802	7.1	515	7.0
Fecal streptococcus	150	0.7	378	4.8	197	1.0
Pseudomonas[a]	NA[b]	NA	113	21.2	184	6.5
Cholera	NA	NA	51	0.0	NA	NA

[a] *Pseudomonas* test is carried out for drinking water samples from hospitals and swimming pools only.
[b] NA: No tested samples.

Table 4
Water related diseases in the Gaza Strip [23].

Disease	Number of cases in Gaza Strip in 2004
Intestinal parasitic diseases	
Ascariasis (round worm)	1492
Oxyuriasis	109
Strongyloidiasis	54
Amebiasis	
Trophozoite	11,360

- Frequent maintenance and upgrading of water and wastewater networks should occur, and open over-ground dumping of wastewater should cease.
- Proper water disinfection must be constantly implemented and the collection surfaces of rain-fed cisterns must be frequently cleaned.
- The desalination plants, including the private ones, must be professionally operated according to global standards to protect the quality of desalinated water. This includes implementing necessary pre- and post-treatment of water, as needed, and maintenance of the desalination units.
- The public's awareness of health risks associated with poor disinfection, operation, and maintenance of the widely-used rain-fed cisterns should be increased.

Acknowledgement

The authors would like to thank the Central Public Health Laboratories (CPHL) of the Palestinian Ministry of Health (MoH) in Gaza city for providing the data and for their help. The authors also would like to thank Prof. Jan Schippers, from UNESCO-IHE in the Netherlands, for useful discussions.

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