Case Study

Water quality and its role in waterborne disease outbreaks during the war on the Gaza Strip

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Abstract

Background: Contaminated drinking water poses a major threat to public health and well-being worldwide. There are growing concerns about the issue in developing countries, especially in conflict areas like the Gaza Strip. The aim of this study is to assess the quality of water in public supplies, focusing on displaced people's shelters and healthcare facilities in Khan Younis and the Middle Area in the Gaza Strip, and to understand the role of the Ministry of Health (MoH) in waterborne disease outbreak control during the war on the Gaza Strip.

Methods: In this case study we utilized secondary data obtained from the Health Information Unit at the MoH. The dataset comprises results from both microbial and chemical analyses of water samples collected between May and June 2024. Healthcare facilities and displaced people's shelters are primary sources of these samples, which were collected from various points, including drinking water and water intended for personal and household hygiene. Microbial testing looked for *fecal coliform* (FC) and *Escherichia coli* (E. coli). Chemical analyses were conducted, including measurements of free chlorine levels and total dissolved solids (TDS). The results were compared with the World Health Organization (WHO) guidelines for drinking water quality to assess the overall water safety and identify potential health risks.

Results: The findings indicate a widespread contamination across different water sources in Khan Younis and the Middle Area of the Gaza Strip, with 41% of samples testing positive for FC and 20% for E. coli in public water supplies and shelters. In healthcare facilities, the contamination rates were 39% and 25% for FC and E. coli, respectively. Additionally, chemical tests revealed that 42% of samples did not meet WHO standards for total dissolved solids (TDS) and 79% had critically low levels of free chlorine.

Conclusion: The contamination levels in drinking water in the Gaza Strip exceed the threshold values of the WHO guideline for safe drinking water, and the severe scarcity in the chlorination process further complicates the situation. Therefore, strategies to protect water sources and improve treatment must be implemented immediately. This research highlights the crucial need for international intervention to reinstate safe water access and prevent deterioration in public health.

Keywords*: E. coli, fecal coliform, Gaza Strip, microbial contamination, waterborne disease, war impact.*

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Ethics statement: Ethical approval is obtained from the Palestinian Ministry of Health (MoH)
Authors contributions: The first three authors (Turkman, Alfarra and Assi) contributed equally.

Introduction

Access to clean water and sufficient sanitation are essential human rights and critical determinants of public health. However, during the ongoing war, the Gaza Strip faces an unprecedented humanitarian crisis due to the systematic destruction of its water, sanitation, and hygiene (WASH) infrastructure (1–3). The infrastructural destruction, combined with humanitarian aid restrictions and fuel deficiencies, caused over 97% of Gaza's water to be undrinkable, contaminated with sewage, chemicals, and high salt levels, which created risks of dehydration and disease for all the people of the Gaza Strip (4). The WHO and the Environmental Protection Agency (EPA) establish microbiological water quality standards to regulate contamination and ensure safe drinking water, limiting fecal coliform (FC) and E. coli in water sources (5,6). The presence of E. coli in drinking water indicates serious sanitation failures and signifies the widespread presence of other harmful pathogens that pose a direct threat to public health. (7–10).

The coastal aquifer is the key water source in the Gaza Strip, but 97% of the groundwater is unfit for consumption due to contamination and the intrusion of seawater. (4). The Israeli military forces have further exacerbated this crisis by systematically targeting critical water infrastructure, including pipelines, desalination plants, and sewage treatment systems, which has significantly worsened the availability and quality of water resources (1,3). Compounding this issue is the inability to repair damaged water systems, as restrictions on the import of construction materials impede necessary maintenance and reconstruction efforts (11). Consequently, untreated sewage continues to contaminate drinking water supplies, further intensifying the public health crisis and heightening the risk of waterborne diseases (3,12). Moreover, logistical challenges hinder the assessment and management of water quality. Transportation restrictions, insufficient laboratory services, and equipment shortages create significant barriers to conducting thorough and timely water quality evaluations. These limitations undermine the ability to effectively monitor contamination levels, thereby restricting efforts to safeguard water resources and mitigate escalating public health risks (3,13).

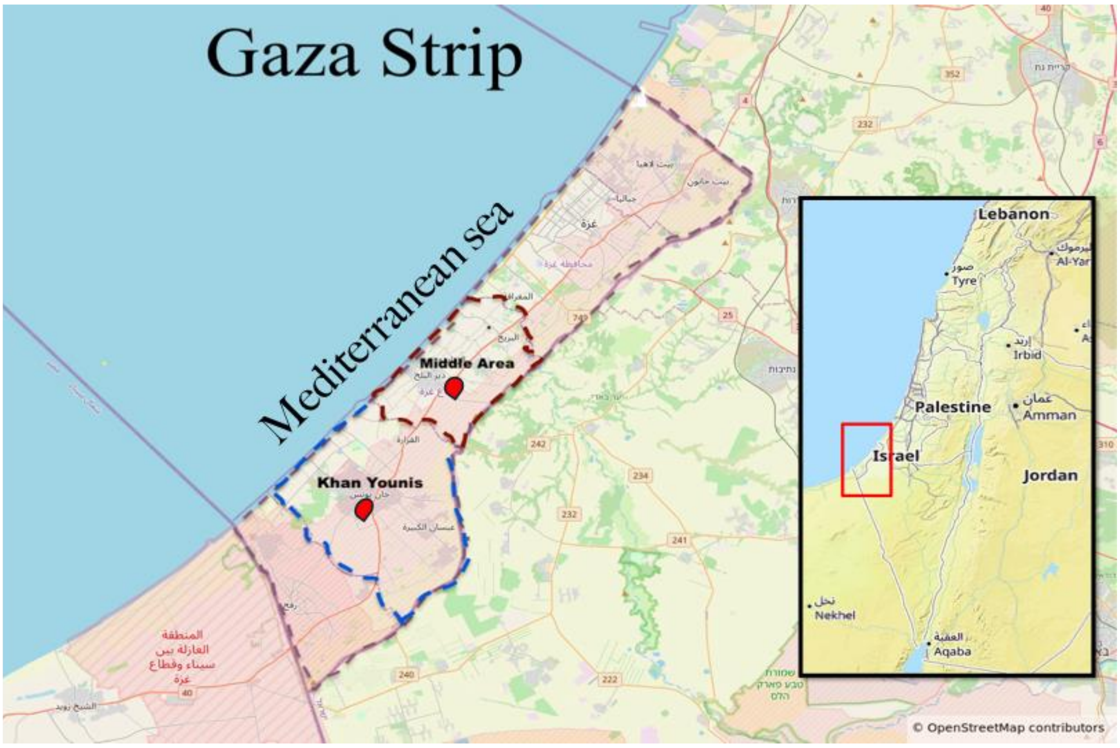
Water contamination affects public health in the Gaza Strip and stays behind the high prevalence rates of typhoid, diarrhea, and hepatitis A, particularly among children, as documented in numerous studies (14,15). Furthermore, microbial contamination renders coastal water unsafe, putting swimmers at risk (16). Drinking water in the Gaza Strip also fails to meet WHO standards, as it exhibits elevated levels of E. coli contamination (17,18). Therefore, growing concern after the current war and insufficient attention is being given to the rising cases of waterborne diseases in the Gaza Strip, and many areas lack proper water safety plans to mitigate the risks (19,20). This case study aims to assess the quality of water in the Gaza Strip, which is crucial for determining the extent of contamination, identifying health risks, and informing both emergency and long-term policy responses. Given the current conflict, reliance on secondary data sources provides the most feasible approach to evaluating water quality trends to support emergency interventions.

Study setting

This case study was conducted in Khan Younis and the Middle Area Governorates in the Gaza Strip between May and June 2024 (Figure 1). Khan Younis Governorate is located in the southern Gaza Strip, approximately 4 kilometers east of the Mediterranean Sea, with an area around 108 km² (21). In 2022, the governorate had a population of 427,000 as reported by the Palestinian Central Bureau of Statistics (22). The area primarily relies on the Coastal Aquifer Basin as its main water source, supplemented by desalination plants, tanker-delivered water, and local reservoirs (23). Notwithstanding these resources, the governorate encounters difficulties related to compromised infrastructure and aquifer contamination (24).

The Middle Area Governorate, also known as Deir al-Balah, is located in the center of the Gaza Strip, with an area around 56 km² (21). The population is approximately 311,000 residents (22). The region's water supply comes from the coastal aquifer, managed by the Coastal Municipalities Water Utility (CMWU), and is bolstered by desalination efforts.

Figure 1. Khan Younis and Middle Area Governorates



Source: Base map © OpenStreetMap contributors (25).

Data collection

This case study utilized secondary data obtained from the Health Information Unit at the Palestinian Ministry of Health (MoH) in the Gaza Strip. The dataset comprises random water samples collected from multiple sites across the Khan Younis and Middle Area governorates in the Gaza Strip. Those samples were collected by the Environmental Health and Occupational Safety Department between May and June 2024 and were tested in the Public Health Laboratory branches at Nasser Medical Complex in Khan Younis and Al-Aqsa Martyrs Hospital in the Middle Governorate. The source of samples includes health facilities, shelters, water networks, wells, and desalinated water sources, based on field inspections and public health priorities. This targeted approach allowed for a focused assessment of water quality in vulnerable settings during the emergency period.

Microbial and chemical tests

The Environmental Health and Occupational Safety Department carried out microbial tests on 103 water samples collected from shelters and 75 from healthcare facilities to test for the presence of FC and E. coli, following the ISO 9308-1:2014 standards (26). Additionally, field testing was conducted on 457 samples to measure total dissolved solids (TDS) and free residual chlorine levels, using TDS meters for solid content and DPD (N, N-diethyl-p-phenylenediamine) colorimetric tests for chlorine, with results recorded in milligrams per liter (mg/L) (27).

Data processing and quality control

To ensure data reliability, the lab technicians followed quality assurance and quality control protocols, which were based on WHO standards, including: i) Calibration of devices before sample analysis ii) Utilization of field blanks and duplicates to identify contamination iii) Adherence to international protocols for assessing water quality: the concentration of microbial contamination in water samples was measured in colony-forming units (CFU)/100 ml (28). The raw data was cleaned and preprocessed to eliminate missing or erroneous values, then further analyzed using descriptive statistics and contrasted with national and international standards of drinking water quality.

Data analysis

We used Microsoft Excel to calculate the bacterial contamination rate of E. coli and FC and perform figures. We used descriptive and trend analyses to assess the concentration of E. coli and FC bacteria and investigate chemical parameters. The water quality results were systematically compared against the World Health Organization (WHO) guidelines for drinking water quality to evaluate overall safety and identify potential health risks (28).

Ethical considerations

Ethical approval was received from the MoH in the Gaza Strip. The study prioritizes public health impact by sharing findings with relevant authorities to facilitate emergency interventions and improve water safety for affected communities.

Results

Microbial contamination assessment

The microbial analysis of 103 water samples from different sources in public supplies and shelters, including wells, desalinated water, public tanks, and public networks, reveals significant contamination levels of FC and E. coli. Table 1 illustrates that 42 out of 103 samples (41%) tested positive for FC contamination, whereas 21 samples (20%) exhibited E. coli contamination, resulting in an overall contamination rate of 61% across samples. The highest contamination rate of E. coli was observed in wells (25%), followed by the public networks (22%). While FC contamination was most prevalent in public networks (44%), desalinated water and the public network had a higher contamination rate compared to wells and public tanks. In contrast, public tanks exhibit 100% FC contamination, but the sample size is too small (n=1) to draw definitive conclusions.

Table 1. Microbial water assessment in public supplies and shelters

Samples Sources	Samples			Contamination (%)	
	Total N	FC*	E. coli*	FC	E. coli
Wells	16	6	4	38%	25%
Desalinated Water	50	19	9	38%	18%
Public Tank	1	1	0	100%	0%
Public Network	36	16	8	44%	22%
Total	103	42	21	41%	20%

FC*: Fecal coliform contaminated samples. E. coli*: E. coli contaminated samples

A total of 75 water samples were collected from different sources within healthcare facilities to assess microbial water quality. As presented in Table 2, the FC contamination rate across all samples was 39%, while E. coli was detected in 25% of the samples. This suggests that, on average, a higher percentage of samples contain FC compared to E. coli. Among the different water sources, Networks water shows the highest contamination rates, with 52% of its samples containing FC and 28% containing E. coli. In contrast, wells exhibited moderate contamination, with 33% of samples containing FC and 25% E. coli. Desalinated water had slightly lower contamination levels, with 29% of samples testing positive for FC and 24% for E. coli. Overall, FC contamination (39%) was more prevalent than E. coli (25%) across all samples.

Table 2. Microbial water assessment in healthcare facilities

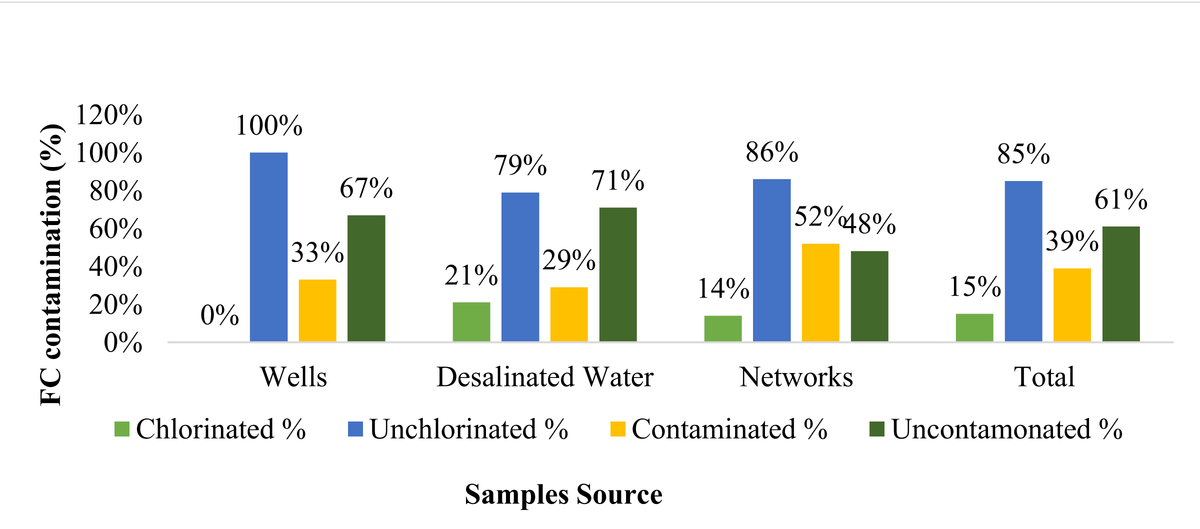
Samples Sources	Samples			Contamination (%)	
	Total N	FC*	E. coli*	FC	E. coli
Wells	12	4	3	33%	25%
Desalinated Water	34	10	8	29%	24%
Networks	29	15	8	52%	28%
Total	75	29	19	39%	25%

FC*: Fecal coliform contaminated samples. E. coli*: E. coli contaminated samples

Chemical analysis

A further assessment was performed on 75 water samples from health facilities to assess the effectiveness of the chlorination process. As shown in Figure 2, the results demonstrate a significant disparity in FC contamination levels based on chlorination status. Unchlorinated water sources were predominant, representing 85% of the total samples, while only 15% were chlorinated. Among the different sources, wells had the highest proportion of unchlorinated samples (100%), followed by network water (86%) and desalinated water (79%). Correspondingly, FC contamination rates were highest in network water (52%), followed by well water (33%) and desalinated water (29%). In contrast, the proportion of uncontaminated samples was greatest in desalinated water (71%), followed by wells (67%) and network water (48%). Overall, 39% of the total health facilities' water samples were found to be contaminated, whereas 61% were uncontaminated. These findings indicate a strong association exists between the lack of chlorination and increased FC contamination.

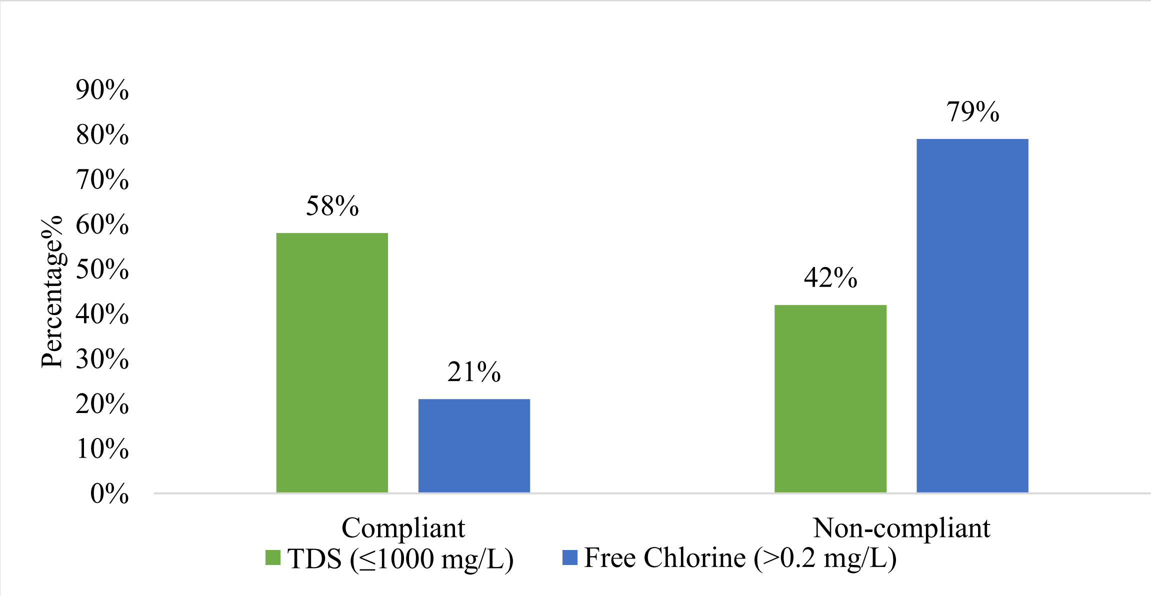
Figure 2. FC contamination rate in healthcare facilities based on chlorination



Measurements of Total Dissolved Solids (TDS) and Free Chlorine levels were conducted in 457 field tests. The results indicate a significant failure to meet the World Health Organization

(WHO) standards (28). In Figure 3, of the 121 samples analyzed for TDS, 70 samples (58%) complied with the WHO recommendation for TDS levels (≤1000 mg/L). 51 samples (42%) surpassed the threshold. A free chlorine concentration test was performed on 175 samples; the results indicate 36 (21%) of the samples had acceptable chlorine levels. 139 samples (79%) did not meet the WHO standard levels of free chlorine (>0.2 mg/L).

Figure 3. PH, TDS, and free chlorine levels compliant to WHO standards



Microbial contamination of water in the Gaza Strip varied over time and across different water sources. The microbial quality has been documented through numerous studies and routine monitoring by the Public Health Laboratories of the MoH. As illustrated in Table 3, the percentage of water samples exceeding WHO limits for FC (0 CFU/100 mL) ranged from 2% to 12% for wells and networks between 1999 and 2003. A significant increase was observed from 2009 onward, particularly in household storage tanks and tanker trucks, where FC contamination reached 40.3% and 6.7%, respectively. Small-scale desalination plants also exhibited FC contamination, with rates ranging from 5.3% to as high as 27%. E. coli was detected in up to 9.9% of groundwater samples in 2003 and in 28.3% of desalinated water samples in 2012. While a 2018–2019 study reported E. coli in 6.9% of water samples. These results reflect a rising trend in microbial contamination over time, particularly in vulnerable settings and non-piped water sources.

Table 1. Microbial assessment of water sources between 1991-2024 in the Gaza Strip

Year	Sample Source	Total samples (N)	Contaminated Samples	FC contamination (%)*	E. coli contamination (%)*	Source
1999	Wells	743	60	8	-	(27)
1999	Networks	1393	170	12	-	(27)
2000	Wells	780	18	2	-	(27)
2000	Networks	1213	74	6	-	(27)
2001	Wells	872	54	6	-	(27)
2001	Networks	1288	144	11	-	(27)
2002	Wells	823	50	6	-	(27)
2002	Networks	364	60	4	-	(27)
2003	Wells	767	18	2	-	(27)
2003	Networks	974	57	6	-	(27)
2003	Groundwater	152	18	13	9.9	(29)
2004	wells	5	0	0	-	(30)
2004	Networks	189	0	0	-	(30)
2005	Wells	61	0	0	-	(30)
2005	Networks	243	9	4	-	(30)
2006	Wells	76	4	5	-	(30)
2006	Networks	426	23	5	-	(30)
2009	Small-Scale Desalination Plants	19	1	5.3	-	(31)
2009	Tanker Trucks	15	1	6.7	-	(31)
2009	Household Water Storage Tanks	226	91	40.3	-	(31)
2012	Desalination Plants (Inlet)	88	10	11.4	-	(32)
2012	Desalination Plants (Outlet)	88	12	13.8	-	(32)
2012	Desalinated Plants	81	22	27	28.3	(33)
2016	Small-Scale Desalination Plants	50	7	13	-	(34)
2016	Tanker Trucks	50	14	28	-	(34)
2018-2019	Various Water Sources	1317	91	-	6.9	(35)
2024	Different sources in shelters	103	42	41	20	Our case study
2024	Different sources in healthcare facilities	75	29	39	25	Our case study
	*WHO guidelines for drinking water: FC and E. coli must not be detectable in any 100-ml sample (0 CFU/100 mL). FC: Fecal coliforms					

Discussion

Microbial contamination assessment

The levels of FC and E. coli in water are essential indicators for evaluating water quality and the likelihood of waterborne diseases (8,10). The findings revealed significant microbial contamination in the primary water sources, including public water supplies and healthcare facilities in Khan Younis and the Middle Area Governorate. Table 1 indicates that Wells demonstrates apprehension regarding contamination, with a FC rate of 38% and an E. coli rate of 25%. This finding is troubling, as wells frequently serve as a primary water source in rural or underserved regions where alternatives are scarce. Although desalinated water has lower contamination rates (38% for FC and 18% for E. coli), these rates still indicate significant contamination. Since desalination processes are designed to eliminate harmful pathogens, the presence of contamination suggests potential issues with the treatment and post-treatment stages due to power shortages and damage caused by Israeli forces (36). The most alarming finding pertains to the public water network, which exhibits the highest levels of contamination: 44% for FC and 22% for E. coli. Public water systems are meant to provide safe drinking water to large populations, so these findings point to serious failures in maintaining water quality standards due to inadequate disinfection and damaged infrastructure (3). These findings highlight significant levels of microbial contamination across various sources of water. However, the statistical analysis shows no significant association between water source and contamination rates for both FC and E. coli. In addition to the correlation coefficient between FC and E. coli contamination being 0.99, which indicates a very strong positive relationship. This suggests that water sources with high FC contamination are also likely to have high E. coli contamination. The finding confirms that contamination might be widespread rather than localized to water sources.

Significant contamination rates in healthcare facilities were noted, as demonstrated by the data in Table 2, with 41% of public water samples and 39% of water samples from healthcare facilities testing positive for FC. Additionally, 20% and 25% of these samples were found to contain E. coli, respectively. This finding indicates severe deterioration in water quality. Beyond superficial contamination, chemical contamination introduces an additional dimension of risk. In 2014, evaluations by the Palestinian Water Authority indicated that 90–95% of the aquifer's water is unsuitable for human consumption, chiefly due to high levels of nitrates and chlorides (37). The presence of high nitrate levels in drinking water is of particular concern, as it has been associated with a range of adverse health outcomes, including methemoglobinemia (blue baby syndrome) and long-term risks such as thyroid dysfunction and gastrointestinal illnesses. Another report from RAND Corporation analysis found that almost a quarter of all reported diseases in the Gaza Strip were linked to inadequate water quality and access (38). Therefore, the findings in this research are consistent with previous research that underscores Gaza's ongoing water quality crisis, which is heavily influenced by infrastructure damage due to the impacts of war (14,33).

Overview of microbial contamination of water in the Gaza Strip

The Gaza Strip has long suffered from severe water contamination, intensified by ongoing political instability, deteriorating infrastructure, and restricted access to water treatment technologies (16,17,27). This crisis worsened following the 2023 war, which severely damaged water infrastructure and obstructed the delivery of sanitation and hygiene supplies (3). Numerous studies, along with regular monitoring by the Public Health Laboratories of the Palestinian MoH, have documented the microbial quality of Gaza's water. As shown in Table 3, levels of FC and E. coli were higher than the WHO guidelines (0 CFU/100 mL) in various sources like wells, water networks, desalination plants, tanker trucks, and household storage tanks. These data reflect both spatial and temporal variability in microbial contamination.

According to the MoH water assessments, between 1999 and 2003, wells and networks exhibited FC contamination rates ranging from 2% to 12% (27). A temporary decline in contamination was observed between 2004 and 2005, where some samples showed 0% FC contamination (30). However, due to the small sample sizes and the detection of contamination in subsequent years, these improvements were not system-wide or sustainable. The highest levels of microbial contamination were detected in household storage tanks and tanker trucks, which serve as fallback sources during water shortages. In 2009, 40.3% of household tank samples and 6.7% of tanker truck samples exceeded FC limits (31). By 2016, tanker truck contamination had surged to 28% (34). These trends likely stem from prolonged water supply interruptions, inadequate tank maintenance, and lack of chlorination, factors that increase the risk of secondary contamination. Although desalination plants are widely promoted as a sustainable solution, their microbial quality has proven inconsistent. Small-scale desalination units in 2009 and 2016 recorded FC contamination rates of 5.3% and 13%, respectively (31,34). Two studies from 2012 found even more contamination: 11.4% at the (inlet) and 27% at the (outlet) of the desalination plants, indicating problems with the treatment process or recontamination after treatment (32,33).

Earlier studies rarely reported E. coli contamination, but when they did, they revealed serious public health concerns. For instance, in 2003, Sharif found E. coli in 9.9% of groundwater samples, likely from sewage infiltration into aquifers (29). While desalinated plants reported an even higher rate of 28.3% in 2012, it suggests potential post-treatment contamination, perhaps due to poor maintenance or recontamination during storage and distribution (33). Although a 2018–2019 study reported a reduced contamination rate of 6.9% across various sources, this figure still violates WHO standards and highlights the chronic fragility of Gaza's water sector (14).

TDS Levels and Chlorination Impact

Total Dissolved Solids (TDS) and free chlorine levels are crucial parameters to identify the quality of water. Proper regulation is essential to ensure both public health and system efficiency (28). The WHO recommends that TDS levels less than 300 mg/L are excellent, whereas levels exceeding 1200 mg/L are considered unacceptable. While the minimum concentration of free chloride is 0.2 mg/L, it is often required at the farthest point in the distribution system to ensure effective disinfection. The results from the chemical analysis in Figure 3 showed that 58% of water samples meet the WHO standard for TDS, defined as ≤1000 mg/L, while 42% of samples exceeded this threshold, indicating significant deviations from the recommended water quality guidelines. More concerning is the finding that 79% of samples failed to meet the standards for acceptable free chlorine levels.

To assess whether there was a statistical association between TDS compliance and chlorine presence, a chi-square test was conducted. The test yielded $p < 0.05$, indicating a significant association between TDS compliance and free chlorine levels. The results suggest that samples with high TDS levels may also struggle with chlorine retention, possibly due to chlorine demand from dissolved organic and inorganic matter. Microbial data further reinforce these concerns. Chlorination status was strongly correlated with microbial contamination: 79% of unchlorinated samples tested positive for FC contamination, whereas only 15% of chlorinated samples were contaminated. In addition to that, the situation in healthcare facilities is particularly critical in relation to the effectiveness of chlorination practices (Figure 2). The predominance of unchlorinated water sources (85%) is alarming, as it correlates strongly with the presence of higher FC contamination rates. Water sourced from networks and wells both exhibited low chlorination levels and had the highest contamination percentages (52% and 33%, respectively). Conversely, desalinated water, which showed relatively higher chlorination coverage (21%), had the lowest contamination rate (29%). The overall contamination rate of 39% concerns healthcare settings, where safe water is essential to prevent healthcare-associated infections and ensure patient safety. Therefore, these findings strongly advocate enhancing chlorination practices.

These results underscore the essential role of chlorination in improving microbial safety. Comparatively, historical studies conducted before the escalation of conflict in the Gaza Strip reported significantly lower levels of bacterial contamination. For instance, E. coli O157:H7 was found in only 6.9% of 1,317 samples (35). In contrast, the current study reports contamination rates as high as 39–40%, signaling a dramatic deterioration in water quality. This finding suggests systemic failures in both disinfection protocols and severe infrastructural damage. Besides the risks of microbial contamination, the high levels of TDS found in many samples make us worry about the water's chemical safety (39). Elevated TDS levels mean the presence of various minerals and salts in the water, which can lead to health problems and hinder the effectiveness of chlorine (5,33,40). These findings collectively point to the urgent necessity of implementing a comprehensive emergency response plan, which should prioritize enhanced disinfection practices, especially through expanded chlorination efforts. The WHO (28) recommends immediately increasing the concentration of free chlorine to at least 0.5 mg/L if there is a waterborne disease outbreak or confirmed FC contamination in a drinking water supply.

Water Contamination and Public Health

A comparison between current and past studies suggests that military aggression and systematic destruction of Gaza's water and sanitation infrastructure have directly contributed to increased contamination rates (2). According to United Nations reports, the destruction of desalination plants and water distribution networks has led to wastewater leakage into drinking water sources, increasing contamination and the spread of waterborne diseases (20,41). The list includes cholera. Diarrhea, skin infections, typhoid, and antimicrobial resistance (AMR) are particularly prevalent (15). Studies documented high prevalence rates of typhoid, diarrhea, and hepatitis A, mainly among children (35). In 2019, a study conducted an examination of coastal recreational water in the Gaza Strip, revealing unsafe levels of microbial contamination that pose a risk of infection for swimmers (16). This finding reflected the significant contamination of sources for both potable and swimming. Another study conducted in 2012 (17) discovered that advertised drinking water in the Gaza Strip did not meet the standards of microbial safety of the WHO, with high levels of E. coli contamination. The study underscored that desalinated and bottled water were also at contamination risk due to poor transportation and storage conditions. However, regarding our finding, there is an increase in the contamination rate compared to previous studies before the war in 2023. This finding explains the widespread prevalence of waterborne diseases among the population (41). Furthermore, dehydration and malnutrition, aggravated by scarce water supplies, deteriorate immune systems, making people more vulnerable to infections (36). The WHO has recognized an increase in acute gastroenteritis cases in the Gaza Strip, with hospitals struggling to provide acceptable care due to shortages of clean water, medical supplies, and electricity (42,43). Beyond bacterial contamination, chemical pollution adds another layer of danger. Nitrate levels in Gaza's drinking water are six times higher than the safe limit, posing serious health risks, especially for infants, who are at risk of developing "blue baby syndrome," a potentially fatal condition caused by oxygen deprivation (44). Long-term exposure to high salinity (TSD) could potentially lead to kidney and cardiovascular diseases (40).

Limitations

Reliance on secondary data presents significant challenges because real-time verification of contamination levels is not possible. Additionally, the ongoing war has created logistical constraints, affecting both sample collection and laboratory processing. The lack of a stable infrastructure for water quality monitoring has resulted in inconsistencies in data collection methods across various agencies, potentially impacting the accuracy of reported contamination levels. Furthermore, restricted access to certain areas due to security concerns limits the ability to conduct a comprehensive assessment of water sources across the Gaza Strip.

Conclusion and Recommendations

The findings highlight the destitute water quality in Khan Yunis and the Middle Area of the Gaza Strip during the ongoing conflict and its severe impact on public health. The findings point out the importance of both immediate and long-term interventions. Emergency measures should focus on improving water quality through desalination, chlorination, and securing alternative water sources. Meanwhile, long-term strategies should prioritize restoring infrastructure, expanding wastewater treatment, and enforcing policies to prevent contamination.

International support remains critically important for guaranteeing the availability of essential materials such as water treatment supplies, fuel, and laboratory equipment necessary for environmental safety and public health. Given the reliance on secondary data, future research should prioritize longitudinal health studies to evaluate the long-term effects of water contamination on the population. Moreover, efforts are required to standardize data collection processes across different agencies to improve the reliability and validity of the results.

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Appendix 1. The FC contamination rate in healthcare facilities based on chlorination

Samples Source	Samples (N)	Chlorinated	Unchlorinated	Uncontaminate	FC contaminated	Chlorinated (%)	Unchlorinated (%)	Uncontaminated (%)	FC contaminated (%)

Wells	12	0	12	8	4	0	100	67	33
Desalinated Water	34	7	27	24	10	21	79	71	29
Networks	29	4	25	14	15	14	86	48	52
Total	75	11	64	46	29	15	85	61	39
FC: Fecal coliform									