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The Effect of Armed Conflict on Drinking Water Quality in Gaza: Laboratory-Based Study of Microbial and Chemical Contaminates

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Abstract: Access to safe drinking water is a fundamental human right, yet it remains critically compromised in conflict zones such as the Gaza Strip. This study provides a quantitative assessment of the microbiological and chemical quality of drinking water in southern Gaza—specifically the Khan Younis and Middle Area governorates—during the period of active military conflict between December 2023 and May 2025. A total of 1116 water samples were collected from various public and health facilities and analyzed based on treatment status and facility type. Water quality was assessed using standard APHA methods, targeting key parameters: Fecal Coliforms, Escherichia coli, Free Residual Chlorine, Salinity, and pH. Statistical analyses, including One-Way ANOVA and correlation testing, revealed significant microbiological contamination—particularly in untreated water sources, where Fecal Coliforms and E. coli exceeded WHO limits. Desalinated and treated sources consistently exhibited better quality; however, residual chlorine levels were suboptimal across both categories (mean = 0.23 mg/L in treated water), indicating insufficient disinfection. Salinity levels in groundwater wells reached critical levels (mean = 2897.71 mg/L), reflecting chronic seawater intrusion. Correlation analysis confirmed a strong positive relationship between salinity and pH (r = 0.63) and a negative correlation between chlorine levels and microbial indicators, suggesting that disinfection failure contributes directly to health risks. Findings underscore the urgent need to protect water infrastructure, ensure continuous chlorination, and enhance emergency WASH services in conflict-affected settings. This study contributes to the global understanding of water insecurity during armed conflict and provides evidence to support humanitarian response planning and international legal advocacy.

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I. INTRODUCTION

Access to safe drinking water is a fundamental public health necessity. In the Gaza Strip, chronic water scarcity and declining quality are well-documented due to excessive groundwater extraction, seawater intrusion, insufficient infrastructure, and pollution (UNICEF & PWA, 2023; WHO, 2022). During armed conflicts, these problems intensify, as wars directly damage water wells, desalination plants, and distribution systems (UN OCHA, 2024). In the most recent escalation, sustained military operations severely affected electricity supplies, disrupting water pumping, chlorination, and treatment processes (Weinthal et al., 2021). Concurrently, damage to sewage systems has increased the risk of groundwater contamination through leakage and infiltration (Abu Amr & Yassin, 2022).

Data from Khan Younis during this period reveal a collapse in basic water safety indicators. Laboratory results show that free residual chlorine levels were consistently 0.0 mg/L, far below the WHO-recommended minimum of 0.2 mg/L (WHO, 2022). In parallel, salinity levels reached up to 1600 mg/L, exceeding acceptable limits and reflecting deep salinization of the coastal aquifer (Al-Agha & Al-Najjar,

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2021). Although pH values remained between 7.0 and 7.8, microbial indicators such as Fecal Coliforms appeared in several samples, suggesting fecal intrusion in the absence of disinfection.

These water quality threats occur alongside reduced water availability. Damage to wells and chlorination systems, fuel shortages, and limited technician access severely restrict water production and delivery (UN OCHA, 2024). As a result, civilians often rely on unsafe sources or face emergency water rations below humanitarian standards (WHO, 2022).

This study aims to evaluate the chemical and microbiological quality of drinking water in Khan Younis during the conflict, using field data collected from health facilities. The results reflect the complex and compounding impact of conflict on public water systems in Gaza.

II. METHODOLOGY

This study adopted a quantitative, laboratory-based approach to evaluate the impact of ongoing armed conflict on the quality of drinking water in the southern Gaza Strip, specifically within Khan Younis and the Middle Governorate. The analysis focused on water samples collected from healthcare facilities between December 2023 and May 2025, a period marked by repeated infrastructure attacks, power outages, and displacement crises.

➢ *Sampling and Parameters*

A total of 1,689 water samples were collected from various departments in hospitals and clinics across the two governorates. Unlike stratification by water source type, all samples originated from institutional taps and tanks within health facilities, representing water actually used by staff and patients.

Each sample underwent testing for microbiological and chemical parameters. The microbiological indicators included Fecal Coliforms (F.C) and Escherichia coli (E. coli), as recommended by the World Health Organization (WHO, 2022) for monitoring fecal contamination.

Chemical testing included Free Residual Chlorine (FRC), Salinity (used as a proxy for total dissolved solids due to the dataset's structure), and pH level. Many samples—especially from Khan Younis—exhibited no detectable chlorine (0.0 mg/L) and high salinity values reaching 1600 mg/L, signaling treatment failure and salinization. All testing adhered to APHA (2017) protocols to ensure standardization and accuracy.

➢ *Statistical Analysis*

To assess the spatial variation in water quality, the study employed descriptive statistics and One-Way Analysis of Variance (ANOVA) using Python (v3.11) and the SciPy statistical library. ANOVA was used to determine whether there were statistically significant differences in mean values of each parameter across the two governorates (Khan Younis vs. Middle Area).

Statistical significance was established at $p < 0.05$. In addition, mean, standard deviation, minimum, and maximum values were calculated for each parameter by governorate and facility, providing insight into variability across locations.

➢ *Ethical and Field Considerations*

Due to the complexity of operating in a conflict-affected setting, sample collection was carried out in collaboration with local health authorities and humanitarian agencies working in Gaza. All samples were analyzed at the central public health laboratory, following ethical procedures that prioritized safety, data integrity, and institutional coordination.

III. RESULT AND DISSECTION

The analysis of water samples collected from various facilities in the South Area of Gaza during the ongoing armed conflict revealed statistically significant differences in both chemical and microbiological water quality parameters depending on facility types (health facilities, IDP centers, water wells, desalination plants, and community kitchens). The application of One-Way ANOVA demonstrated considerable variability among water sources, particularly in terms of Total Dissolved Solids (TDS), Electrical Conductivity (EC), Fecal Coliforms (F.C), and E.Coli.

➢ *Microbiological and Chemical Water Quality Differences by Water Type*

Statistical analysis revealed significant differences in the microbiological and chemical quality of drinking water across various facility types in the Gaza Strip. Using One-Way ANOVA, substantial variability was observed in Fecal Coliform (F.C) concentrations ($p < 0.0001$), Free Residual Chlorine (FRC) ($p \ll 0.0001$), Salinity ($p = 0.00001$), and pH ($p < 0.0001$). However, the variation in E. coli levels was not statistically significant ($p = 0.668$), potentially due to its low detection rate or sampling limitations. The results are summarized in Table 1.

Table 1 ANOVA Results Based on Facility Type

Parameter	F-Statistic	P-Value
Fecal Coliform (F.C)	6.84	3.14e-11
E.Coli	0.77	6.68e-01
Free Residual Chlorine	18.02	2.43e-33
Salinity	3.92	1.35e-05
pH	8.80	3.99e-15

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Facilities such as community kitchens, households, and health centers exhibited the highest levels of microbial contamination, with mean Fecal Coliform counts exceeding 10 CFU/100ml. These findings are concerning, particularly in health settings, and may be attributed to the absence of disinfection, poor internal piping conditions, or contaminated water storage (Abu Amr & Yassin, 2022; WHO, 2022). In contrast, municipal reservoirs, desalination plants, and water trucks reported consistently lower microbial loads, reflecting more controlled water management practices and potentially centralized treatment protocols.

Chemically, salinity levels were most elevated in IDP centers and water wells, with values surpassing 20,000 mg/L in some cases—exceeding WHO's aesthetic guideline of 500 mg/L (WHO, 2022). These extreme values likely result from groundwater salinization due to over-pumping, seawater intrusion, and lack of aquifer recharge (UNEP, 2020; Al-Agha & Al-Najjar, 2021). Desalination plants, as expected, exhibited lower salinity levels, consistent with their treatment capabilities.

Free Residual Chlorine (FRC) was nearly absent across all facility types (mean ~ 0.0 mg/L), indicating a system-wide failure in water disinfection. This aligns with reports of fuel shortages, chlorination system failures, and disrupted supply chains during military operations (UNICEF, 2023; UN OCHA, 2024).

Although pH values showed statistically significant differences, most samples remained within the acceptable WHO range (6.5–8.5). Slightly elevated or reduced pH values—especially in well and truck-distributed water—may reflect inadequate buffering or chemical instability in storage tanks (Tchobanoglous & Schroeder, 1985).

These findings emphasize that facility type is a strong determinant of water quality, particularly under conflict conditions where treatment and monitoring capabilities vary widely. Vulnerable settings such as IDP centers and community-based facilities require urgent WASH interventions to restore safe water access and reduce disease risk.

- *Residual Chlorine Deficiency*

Although residual chlorine did not vary significantly by water source ($p = 0.070$), the absolute values were dangerously low in nearly all samples. This indicates a widespread failure in maintaining adequate chlorination, a problem reported in numerous conflict-affected regions (Ramesh et al., 2021). In Gaza, this can be attributed to: Electricity blackouts, Damage to chlorine injection systems, Delays in supply of disinfectants due to border closures (UN OCHA, 2024). According to WHO guidelines, drinking water should contain at least 0.2–0.5 mg/L of residual chlorine to remain bacteriologically safe up to the point of use (WHO, 2022). The widespread chlorine deficiency increases the risk of waterborne outbreaks, especially in displaced populations relying on tanker-distributed water stored in unsafe conditions.

These findings reinforce the critical relationship between infrastructure stability and water safety. In the context of armed conflict: Desalinated water, though cleaner, is highly dependent on energy and logistical continuity. Municipal and well water are exposed to environmental and infrastructural risks, with contamination levels exacerbated during military operations. Failure in disinfection and monitoring systems further worsens vulnerability. This study aligns with global trends observed in conflict zones such as Yemen, Syria, and South Sudan, where war disrupts WASH (Water, Sanitation, and Hygiene) services and leads to outbreaks of waterborne diseases (Murray et al., 2020; UNICEF, 2023).

- *Microbiological and Chemical Water Quality Differences by Governorate*

Measurable differences in both microbiological and chemical indicators, highlighting the geographic variability of water safety under conflict conditions.

Statistically, Fecal Coliform (F.C) levels were notably higher in Khan Younis, where health facilities and community sites reported mean values exceeding 11 CFU/100ml, compared to lower levels in the Middle Governorate. This aligns with field observations that Khan Younis, having endured more direct infrastructure damage and population displacement, is more vulnerable to microbial contamination (UN OCHA, 2024; Abu Amr & Yassin, 2022).

In contrast, Escherichia coli (E. coli) levels did not vary significantly between the two governorates, with mean values remaining relatively low across the dataset ($p > 0.05$), suggesting either limited detection or consistent exposure risks.

From a chemical perspective, salinity levels were markedly elevated in Khan Younis, with some samples exceeding 1600 mg/L, compared to moderate levels in the Middle Governorate. These high values likely reflect seawater intrusion and groundwater over-extraction in coastal zones (Al-Agha & Al-Najjar, 2021; UNEP, 2020).

Free Residual Chlorine (FRC) was critically low across both regions—often at 0.0 mg/L—indicating a systemic collapse in water disinfection capacity due to fuel shortages, power outages, and broken treatment systems (WHO, 2022; UNICEF, 2023).

pH levels remained within the WHO-accepted range (6.5–8.5) in most cases, with slight variations that did not reach statistical significance.

These findings underscore the compounded risks faced by communities in Khan Younis and emphasize the need for geographically targeted WASH interventions, prioritizing emergency chlorination, mobile treatment units, and sustained water safety monitoring.

- *KhanYounis: The Epicenter of Water System Collapse*

The governorate of Khan Younis emerged as the most critically impacted area during the recent Israeli military

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operations in Gaza. Statistical analysis revealed the highest levels of Fecal Coliform contamination ($p = 2.81\times10^{-8}$) and complete failure in residual chlorine levels ($p = 1.34\times10^{-6}$), with most samples showing 0.0 mg/L, signaling a total collapse in disinfection systems.

The extensive destruction of water infrastructure—due to continuous airstrikes and ground incursions—led to sewage infiltration, disruption of chlorination, and halted pumping operations. This was further exacerbated by prolonged electricity blackouts and fuel shortages across the governorate (UN OCHA, 2024).

Additionally, salinity levels were significantly higher in Khan Younis (p = 0.0291), in part due to over-extraction from aquifers and coastal seawater intrusion, a crisis worsened by limited alternatives during the siege.

These findings underscore the catastrophic impact of the conflict on public health infrastructure, and call for urgent humanitarian action to restore safe water access through mobile treatment units, emergency chlorination, and coordinated WASH responses.

- *Correlation Analysis: Scientific Results and Interpretation*

Chemical parameters of drinking water. The findings are summarized as follows:

Table 2 Correlation Matrix of Key Water Quality Parameters

	Fecal Coliform	**E. Coli**	**Free Residual Chlorine**	**Salinity**	**pH**
Fecal Coliform	1.0	0.45	-0.13	0.03	-0.02
E.Coli	0.45	1.0	-0.07	0.02	0.03
Free Residual Chlorine	-0.13	-0.07	1.0	-0.15	0.11
Salinity	0.03	0.02	-0.15	1.0	0.2
pH	-0.02	0.03	0.11	0.2	1.0

The correlation between Fecal Coliforms and E. coli was moderate (r = 0.45), suggesting a partial co-occurrence of microbial contamination, though not perfectly aligned—possibly due to differences in survival rates or detection limitations under field conditions.

Free Residual Chlorine showed weak negative correlations with both Fecal Coliforms (r = -0.13) and E. coli (r = -0.07), indicating that lower chlorine levels are generally associated with higher microbial loads, although the strength of association was not strong. This may reflect inconsistent or failed disinfection across many sites.

The correlation between Salinity and microbial indicators was nearly nonexistent (F.C: r = 0.03, E. coli: r = 0.02), suggesting that chemical salinization and microbial contamination occur through independent mechanisms—for example, seawater intrusion vs. fecal infiltration.

pH did not exhibit significant correlation with any variable, implying that pH values remained relatively stable across the dataset and did not directly influence microbial or chemical pollution levels.

These correlations highlight the multifactorial nature of water contamination in conflict zones, where different sources of pollution (sewage, saline intrusion, chemical failure) act in parallel. Therefore, effective water safety monitoring requires tracking both microbial and chemical indicators simultaneously.

- *Descriptive Statistics*

A descriptive statistical analysis was conducted on 1116 water samples to evaluate the microbiological and chemical quality of drinking water based on its treatment status (treated vs. untreated) during the ongoing conflict in Gaza. Parameters included Fecal Coliforms, Escherichia coli, Free Residual Chlorine, Salinity, and pH.

The results revealed clear disparities between treated and untreated water:

Fecal Coliforms were significantly elevated in untreated water (mean = 8.71 CFU/100ml) compared to treated sources (mean = 2.74 CFU/100ml), indicating that disinfection processes reduce microbial loads. However, the persistence of F.C in treated samples suggests either incomplete treatment or recontamination during storage or distribution, particularly plausible in areas with damaged or low-pressure infrastructure (Al-Khatib et al., 2019).

Similarly, E. coli, a direct indicator of fecal pollution, averaged 1.49 CFU/100ml in untreated water and 0.43 CFU/100ml in treated sources. Although treatment effectively lowered contamination, the detection of E. coli in treated samples may reflect intermittent disinfection, storage vulnerability, or cross-contamination due to broken pipelines during military operations (UNICEF, 2023).

Free Residual Chlorine levels were critically low in untreated samples (mean = 0.03 mg/L), while treated water showed higher concentrations (mean = 0.23 mg/L). Despite this, both fall around or below the WHO-recommended minimum of 0.2 mg/L, indicating inconsistent or insufficient chlorination, potentially due to electricity cuts, fuel shortages, or lack of chlorination chemicals amid siege conditions.

Salinity was alarmingly high in untreated water (mean = 2897.71 mg/L), far exceeding WHO aesthetic thresholds (500 mg/L). This reflects long-standing seawater intrusion into Gaza's aquifer, exacerbated by over-extraction and absence of freshwater recharge. In contrast, treated water, primarily from desalination, showed a much lower mean salinity of 306.09 mg/L, confirming the effectiveness of desalination plants in mitigating salinity-related risks (UNEP, 2020).

pH levels remained within WHO acceptable ranges (6.5–8.5) in both groups, with slightly higher alkalinity in untreated water (mean = 7.51 vs. 7.11). Elevated pH values may indicate mineral content variations or potential chemical imbalances, which can influence water corrosivity and reduce the efficiency of chlorine-based disinfection (Tchobanoglous & Schroeder, 1985).

In summary, while treated water consistently outperforms untreated sources, the presence of residual contamination and low chlorine levels even in treated samples underscores systemic vulnerabilities. These include interrupted chlorination, damaged distribution infrastructure, and logistical constraints under conflict conditions—highlighting the urgent need for sustainable water treatment interventions and robust WASH systems in Gaza.

- *Limited Differences in Chemical Parameters*

While microbiological parameters showed significant variability across water sources and treatment conditions, the differences observed in chemical parameters—particularly pH and Free Residual Chlorine—were comparatively modest and statistically less robust.

The analysis revealed that pH values, though statistically different ($p = 0.0149$), generally remained within the WHO-recommended range (6.5–8.5) across all samples. The mean pH for treated water was 7.11, while untreated water averaged 7.51. These values indicate that alkalinity is not a major issue in most sources; however, extreme outliers—such as values above 10 or below 5.5—were detected in a few samples, raising concerns about potential measurement errors or local contamination from industrial discharge, improper chemical dosing, or distribution pipe corrosion.

As for Free Residual Chlorine, although treated water samples demonstrated higher averages (0.23 mg/L) than untreated samples (0.03 mg/L), both means hover near or below the minimum effective disinfection threshold of 0.2 mg/L recommended by WHO. This suggests widespread weakness in chlorine dosing systems, likely caused by electricity shortages, limited chemical supplies, and equipment damage—conditions exacerbated during the conflict. The absence of sufficient residual chlorine increases the risk of recontamination during storage and transport, especially in areas with intermittent water supply and damaged infrastructure.

The lack of significant variation in these parameters does not necessarily indicate safe conditions, but rather reflects systemic uniformity in service disruption and treatment limitations. Thus, even when no strong statistical differences are detected, the overall levels themselves may still be inadequate, posing chemical safety concerns that warrant urgent remediation efforts.

IV. CONCLUSION

This study provides empirical evidence of the multifaceted impact of armed conflict on the quality of drinking water in the Gaza Strip. Through laboratory-based analysis and statistical evaluation using One-Way ANOVA, significant disparities were observed in microbiological parameters (particularly Fecal Coliform and E.Coli) across both water sources and governorates.

The findings underscore that municipal network and well water are significantly more contaminated than desalinated water, especially in conflict-affected areas. KhanYounis, in particular, exhibited elevated microbial contamination, coinciding with the timeline of a full-scale military incursion initiated in December 2023, during which water and sanitation infrastructure were severely damaged or rendered inoperative. This highlights a clear link between infrastructure destruction and public health risk, particularly the increased vulnerability to waterborne disease outbreaks in displaced populations.

While chemical parameters (TDS, EC, and pH) did not vary significantly across governorates, their elevated absolute values, especially in groundwater-dependent regions, raise concerns about long-term exposure to saline and mineral-rich water. These values reflect deeper aquifer degradation and salinization processes, as documented in prior environmental studies.

Furthermore, the critical failure of residual chlorine disinfection—evident in nearly all samples—represents a system-wide collapse in microbial control, largely driven by electricity blackouts, damaged chlorination infrastructure, and logistical barriers caused by the conflict.

In sum, this study demonstrates that the ongoing war in Gaza not only disrupts the water supply but severely compromises its safety. The intersection of conflict, displacement, and infrastructure collapse demands urgent WASH-focused humanitarian response, prioritizing microbial safety, emergency chlorination, and sustainable water management strategies, particularly in heavily affected zones such as KhanYounis.

V. RECOMMENDATION

- *Immediate Restoration of Disinfection Infrastructure*

- Urgently rehabilitate chlorination systems in municipal and well water facilities, particularly in conflict-affected areas such as KhanYounis.
- Ensure consistent supply of chlorine disinfectants and other treatment chemicals through coordinated humanitarian corridors.

- *Deployment of Mobile Water Treatment Units*

- Establish mobile purification and chlorination units in areas lacking centralized treatment.

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- Prioritize shelters and displaced communities where microbial contamination is highest.

➢ *Microbiological Surveillance and Early Warning Systems*

- Implement routine microbial monitoring of drinking water supplies (Fecal Coliforms, E.Coli) at the point of use.
- Integrate results into an early warning public health system to prevent waterborne disease outbreaks.

➢ *Public Awareness and Hygiene Promotion*

- Conduct community-level education campaigns on safe water storage, household disinfection methods, and basic hygiene practices.
- Distribute hygiene kits with chlorine tablets and instructions to households reliant on tanker water.

➢ *Long-Term Aquifer Management and Source Protection*

- Regulate groundwater abstraction to reduce over-pumping and seawater intrusion.
- Strengthen pollution control laws targeting agricultural runoff and industrial discharge into the aquifer.

➢ *Infrastructure Resilience Planning*

- Design water and sanitation infrastructure that is resilient to conflict, including decentralized systems, backup power, and protected boreholes.
- Advocate for the protection of civilian water systems under international humanitarian law.

➢ *Integrated WASH-Humanitarian Coordination*

- Enhance coordination among WASH actors, health authorities, and local municipalities to ensure a unified emergency response.
- Align interventions with SPHERE standards for minimum water quantity and quality in humanitarian contexts.

VI. LIMITATION

- While this study provides valuable insights into the effects of armed conflict on drinking water quality in Gaza, several limitations must be acknowledged:
- Sampling was restricted to facilities accessible during military operations, potentially excluding heavily damaged or remote areas.
- Some water parameters such as nitrates and heavy metals were not included due to resource limitations.
- ANOVA assumes normal distribution; although robust, deviations may slightly affect the significance levels.
- Future research should incorporate broader sampling, longitudinal monitoring, and more advanced water quality indicator

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