

Original Article

Drinking Water Quality at Industrial Supply Points and Its Association with Gastrointestinal Morbidity in Adjacent Communities

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ABSTRACT

Background: Unsafe drinking water remains an important environmental and public health concern, particularly in communities located near industrial areas where microbiological and chemical contamination may coexist. **Objective:** To assess the microbiological, physicochemical, and selected chemical quality of drinking water from industrial-area supply points in Multan, Pakistan, and examine its association with recent gastrointestinal morbidity among adjacent communities. **Methods:** A community-based analytical cross-sectional study was conducted from January to June 2025 among 300 adult residents. Sixty drinking-water samples were assessed for total coliforms, *Escherichia coli*, physicochemical parameters, nitrate, lead, and arsenic. Gastrointestinal symptoms during the preceding 14 days were collected using a structured interviewer-administered questionnaire. Descriptive statistics, chi-square testing, and logistic regression were used for analysis. **Results:** Total coliforms were detected in 35/60 samples (58.3%) and *E. coli* in 25/60 (41.7%). High turbidity and TDS occurred in 30.0% and 36.7% of samples, respectively; nitrate, lead, and arsenic exceeded reported limits in 15.0%, 13.3%, and 8.3%. Gastrointestinal morbidity was reported by 96/300 participants (32.0%), with diarrhea reported by 21.3%. Reported morbidity among participants classified as exposed to *E. coli*-contaminated water was 47.1% ($p < 0.001$). **Conclusion:** Microbiological contamination was common in sampled industrial-area water supplies and was associated with greater reported gastrointestinal morbidity. The cross-sectional findings support strengthened water-safety surveillance but do not establish causality. **Keywords:** Drinking water quality; *Escherichia coli*; Coliform bacteria; Gastrointestinal morbidity; Industrial areas; Environmental health; Pakistan.

INTRODUCTION

Safe drinking water is fundamental to population health because microbiological and chemical contamination can increase the risk of acute and chronic adverse health outcomes. Contaminated drinking water remains an important contributor to preventable disease, particularly in low- and middle-income settings where deficiencies in source protection, treatment, distribution infrastructure, sanitation, and routine surveillance may increase human

exposure (1). Globally, inadequate water, sanitation, and hygiene continue to contribute substantially to diarrheal disease and other gastrointestinal morbidity, with a disproportionate burden in resource-constrained populations (2,3).

Pakistan faces persistent challenges in ensuring the microbiological and chemical safety of drinking water. Rapid urbanization, population growth, aging water-distribution infrastructure, inadequate wastewater treatment, and expanding industrial activity have placed increasing pressure on surface-water and groundwater resources (4,5). Studies from different regions of Pakistan have documented bacterial contamination, elevated physicochemical parameters, and potentially hazardous chemical constituents in drinking-water supplies (4,6,7). Communities located near industrial areas may be particularly important for environmental-health surveillance because their water sources can be influenced by multiple contamination pathways, including inadequately treated wastewater, leakage from drainage systems, compromised distribution networks, and contamination of shared groundwater or surface-water sources (5). However, the presence of contaminants in water collected from industrial-area supply points does not by itself establish that industrial activity is the direct source of contamination.

Microbiological contamination is of immediate public health importance because ingestion of fecally contaminated water can facilitate transmission of enteric pathogens and gastrointestinal infection (8). Total coliforms are commonly used as indicators of the sanitary condition of water systems, whereas the detection of *Escherichia coli* provides more specific evidence of recent fecal contamination and signals the possible presence of enteric pathogens (9,10). Household drinking water in developing settings frequently becomes contaminated at the source, during distribution, or after collection and storage, and such contamination can increase the likelihood of diarrheal and other gastrointestinal illnesses (11). Evidence from water, sanitation, and hygiene interventions further demonstrates that improving the microbiological safety of drinking water can reduce diarrheal disease burden (12).

Chemical contamination represents an additional concern in industrial and urban environments. Drinking water may contain excessive concentrations of nitrate, dissolved solids, arsenic, lead, and other inorganic or organic pollutants as a consequence of natural geochemical processes, agricultural inputs, industrial discharges, or deficiencies in water-treatment and distribution systems (5,13–15). In Pakistan, drinking water has been identified as a potential source of lead and other hazardous contaminants in some settings (13). Arsenic contamination of groundwater is also an internationally recognized public-health problem because prolonged exposure can produce serious chronic health effects (14). Although chemical pollutants are more commonly associated with long-term toxicity than with acute gastrointestinal illness, their detection is relevant when evaluating the overall safety of drinking-water supplies in environmentally vulnerable communities (15).

Previous Pakistani investigations have largely characterized municipal, groundwater, filtration-plant, or community drinking-water quality, while relatively limited evidence has simultaneously linked measured water-quality conditions at supply points located in industrial areas with gastrointestinal morbidity among nearby residents (4,6,7). Environmental water testing alone cannot determine whether contamination is producing illness in the population, while community symptom surveys without contemporaneous water-quality assessment provide limited information regarding environmental exposure. Integrating microbiological and physicochemical water assessment with household-level health information may therefore provide a more informative evaluation of the relationship between water safety and gastrointestinal morbidity. Nevertheless, because such evidence is observational and cross-sectional, identified relationships should be interpreted as associations rather than proof of causation.

Multan is a rapidly urbanizing and industrializing city in Punjab, Pakistan, where residential communities may depend on water supplies located within or adjacent to industrial areas. Evidence describing the microbiological and chemical quality of these supplies together with gastrointestinal health outcomes among nearby residents remains limited. Characterizing this relationship is relevant for identifying potentially unsafe supply points, informing environmental-health surveillance, and guiding priorities for water-quality monitoring and risk reduction. Accordingly, this community-based analytical cross-sectional study aimed to assess the microbiological, physicochemical, and selected chemical characteristics of drinking water obtained from industrial-area supply points in Multan and to determine whether exposure to contaminated drinking-water sources was associated with recent gastrointestinal morbidity among residents of adjacent communities.

MATERIALS AND METHODS

A community-based analytical cross-sectional study was conducted to characterize the microbiological, physicochemical, and selected chemical quality of drinking water supplied from points located in industrial areas and to examine its association with recent gastrointestinal morbidity among residents of adjacent communities. The study was carried out in communities surrounding industrial zones of Multan, Punjab, Pakistan, through the Department of Community Medicine, Nishtar Medical University, Multan, in collaboration with local environmental health authorities. Data collection, environmental sampling, laboratory assessment, data entry, and statistical analysis were conducted over six months from January to June 2025. The analytical cross-sectional design enabled contemporaneous assessment of environmental water-quality indicators and gastrointestinal morbidity within the defined study population.

The target population comprised adult residents of communities located near industrial water supply points in Multan. Individuals were eligible if they had resided in the selected area for at least six months, thereby ensuring an established period of residence within the local water-supply environment. Temporary visitors, individuals unwilling to participate, and persons with a known gastrointestinal disorder considered unrelated to the drinking-water exposure under investigation were excluded. Industrial areas with adjacent residential communities were first identified, after which households within the selected communities were sampled using a multistage approach. Systematic random sampling was used to select households, and one eligible participant from each selected household was interviewed. The required participant sample was estimated using the conventional single-proportion approach for cross-sectional studies, based on an anticipated prevalence of gastrointestinal symptoms, a 95% confidence level, and an acceptable margin of error. A total of 300 community residents were ultimately included in the study.

Participant information was collected through an interviewer-administered structured questionnaire developed after review of previous work on drinking-water safety and gastrointestinal morbidity. The instrument covered demographic characteristics, including age, sex, educational level, occupation, household size, and duration of residence; water-related characteristics, including the principal drinking-water source, household storage and treatment practices, and water-consumption patterns; and recent gastrointestinal symptoms. Before the main survey, the questionnaire was pretested in a small group to identify unclear wording and improve comprehensibility. Field investigators received training in standardized interviewing, study procedures, ethical conduct during community data collection, and water-sample handling. Completed data-collection forms were reviewed regularly for missing or inconsistent entries as part of field-level quality control.

Recent gastrointestinal morbidity was assessed using participant-reported symptoms experienced during the preceding 14 days. Symptoms recorded included diarrhea, loose stools, abdominal pain or cramps, nausea, and vomiting. Participants reporting one or more of the gastrointestinal symptoms defined in the study questionnaire were classified as having recent gastrointestinal morbidity. Information on the duration of symptoms, medication use, and healthcare attendance was also recorded. Water-use practices, including household water treatment, were captured because they could modify the relationship between source-water quality and reported gastrointestinal illness.

Environmental assessment was conducted using 60 drinking-water samples collected from selected supply points serving the study communities. Sampling locations included water-storage tanks, distribution points, and commonly used community collection sites. Samples were collected in sterile sampling containers, transported to the laboratory under controlled conditions, and analyzed within the recommended holding period. Microbiological assessment included testing for total coliforms and *Escherichia coli*, with membrane filtration used as the principal microbiological procedure. Total coliforms were evaluated as indicators of sanitary water quality, while detection of *E. coli* was interpreted as evidence of fecal contamination and potential microbiological risk (9,10). Physicochemical assessment included pH, turbidity, electrical conductivity, total dissolved solids, hardness, chloride, and nitrate. Chemical assessment additionally included selected heavy metals, particularly lead and arsenic. Water-quality findings were interpreted in relation to established drinking-water safety principles and guideline values applicable to microbiological and chemical contaminants (1).

Measures were taken throughout environmental sampling and laboratory assessment to improve data quality and reproducibility. Sampling personnel followed standardized collection and handling procedures, laboratory

equipment was calibrated before analytical use, and established operating procedures were applied during testing. Selected samples were analyzed in duplicate as part of laboratory quality control. Microbiological and chemical findings from sampled supply points were subsequently examined in relation to gastrointestinal morbidity reported among residents using the studied water-supply environment.

Data were initially entered into Microsoft Excel and subsequently analyzed using IBM SPSS Statistics version 26.0. Continuous variables were summarized using means and standard deviations, whereas categorical variables were presented as frequencies and percentages. Associations between categorical water-quality indicators and recent gastrointestinal morbidity were initially evaluated using the chi-square test. Logistic regression analysis was then performed to examine factors associated with gastrointestinal morbidity. The adjusted analysis included age, sex, household size, educational status, and household water-treatment practices as potential confounding variables, together with relevant water-quality exposure indicators. Statistical significance was defined as a two-sided p-value <0.05.

RESULTS

A total of 300 community residents were included in the analysis. The mean age was 34.6 ± 12.8 years; 164 (54.7%) participants were male and 136 (45.3%) were female. The largest age group was 30–50 years, comprising 126 (42.0%) participants, followed by those aged <30 years (112, 37.3%) and >50 years (62, 20.7%). Most participants had lived in the study area for more than five years (186, 62.0%). Industrially supplied water was reported as the principal drinking-water source by 214 (71.3%) participants, while 98 (32.7%) reported household water treatment (Table 1).

Table 1. Demographic and Water-Use Characteristics of Study Participants (n=300)

Characteristic	n(%)
Age, years, mean $\pm$ SD	34.6 $\pm$ 12.8
Age group	
<30 years	112 (37.3)
30–50 years	126 (42.0)
>50 years	62 (20.7)
Sex	
Male	164 (54.7)
Female	136 (45.3)
Educational status	
No formal education	45 (15.0)
Primary education	86 (28.7)
Secondary education	103 (34.3)
Graduate	66 (22.0)
Duration of residence	
<5 years	114 (38.0)
>5 years	186 (62.0)
Principal drinking-water source	
Industrial supply	214 (71.3)
Other source	86 (28.7)
Household water treatment	
Yes	98 (32.7)
No	202 (67.3)

SD, standard deviation.

Sixty drinking-water samples were analyzed. Total coliforms were detected in 35/60 samples (58.3%; 95% CI 45.7–69.9), while *Escherichia coli* was detected in 25/60 (41.7%; 95% CI 30.1–54.3). The mean pH was 7.4 ± 0.6 . High turbidity was reported in 18/60 samples (30.0%; 95% CI 19.9–42.5) and high total dissolved solids in 22/60 (36.7%; 95% CI 25.6–49.3). Nitrate concentrations above the reported recommended limit occurred in 9/60 samples (15.0%; 95% CI 8.1–26.1). Lead and arsenic above the reported permissible limits were identified in 8/60 (13.3%; 95% CI 6.9–24.2) and 5/60 (8.3%; 95% CI 3.6–18.1) samples, respectively (Table 2).

Table 2. Microbiological, Physicochemical, and Chemical Findings in Drinking-Water Samples (N=60)

Water-quality parameter	Summary	95% CI (%)
pH, mean $\pm$ SD	7.4 $\pm$ 0.6	—
Total coliform detected	35/60 (58.3)	45.7–69.9
<i>E. coli</i> detected	25/60 (41.7)	30.1–54.3

Water-quality parameter	Summary	95% CI (%)
High turbidity	18/60 (30.0)	19.9–42.5
High TDS	22/60 (36.7)	25.6–49.3
Elevated nitrate	9/60 (15.0)	8.1–26.1
Lead above limit	8/60 (13.3)	6.9–24.2
Arsenic above limit	5/60 (8.3)	3.6–18.1

CI, confidence interval; SD, standard deviation; TDS, total dissolved solids. Confidence intervals for proportions were calculated using the Wilson method.

Recent gastrointestinal morbidity was reported by 96/300 participants (32.0%; 95% CI 27.0–37.5). Diarrhea was the most frequently reported individual symptom, occurring in 64 (21.3%; 95% CI 17.1–26.3), followed by abdominal pain in 54 (18.0%; 95% CI 14.1–22.7), nausea in 38 (12.7%; 95% CI 9.4–16.9), and vomiting in 28 (9.3%; 95% CI 6.5–13.2). The summed frequencies of individual symptoms exceeded the number classified with overall gastrointestinal morbidity, consistent with participants reporting more than one gastrointestinal symptom (Table 3).

Table 3. Gastrointestinal Morbidity Reported During the Previous 14 Days (n=300)

Outcome	n/N (%)	95% CI (%)
Any gastrointestinal morbidity	96/300 (32.0)	27.0–37.5
Diarrhea	64/300 (21.3)	17.1–26.3
Abdominal pain	54/300 (18.0)	14.1–22.7
Nausea	38/300 (12.7)	9.4–16.9
Vomiting	28/300 (9.3)	6.5–13.2

CI, confidence interval. Confidence intervals for proportions were calculated using the Wilson method.

The reported bivariate analyses indicated the strongest association for microbiological contamination. Gastrointestinal morbidity was reported in 47.1% of participants classified as exposed to *E. coli*-contaminated water, with $p < 0.001$. Morbidity was reported in 41.8% of those classified as exposed to total-coliform-positive water ($p = 0.002$). The corresponding morbidity proportions were 38.9% for high turbidity ($p = 0.041$), 36.4% for high TDS ($p = 0.048$), 44.4% for elevated nitrate ($p = 0.030$), and 50.0% for lead above the reported permissible limit ($p = 0.019$) (Table 4).

Table 4. Reported Associations Between Water-Quality Indicators and Gastrointestinal Morbidity

Water-quality indicator	Water samples, n/N (%)	Gastrointestinal morbidity (%)	p-value
<i>E. coli</i> detected	25/60 (41.7)	47.1	<0.001
Total coliform detected	35/60 (58.3)	41.8	0.002
High turbidity	18/60 (30.0)	38.9	0.041
High TDS	22/60 (36.7)	36.4	0.048
Elevated nitrate	9/60 (15.0)	44.4	0.030
Lead above limit	8/60 (13.3)	50.0	0.019

TDS, total dissolved solids. Reported p-values were based on chi-square analyses.

Overall, the descriptive findings showed frequent microbiological contamination of sampled water supplies alongside a 32.0% prevalence of recent gastrointestinal morbidity in the surveyed population. The manuscript-reported bivariate analyses showed the smallest p-values for *E. coli* and total-coliform exposure. Because the supplied results do not contain the participant-level exposed and unexposed denominators, regression coefficients, standard errors, or confidence intervals, no additional crude or adjusted effect estimates are presented.

DISCUSSION

This study identified substantial microbiological contamination of drinking-water samples collected from industrial-area supply points in Multan and a corresponding burden of recent gastrointestinal morbidity among nearby residents. Total coliforms were detected in 58.3% of samples and *Escherichia coli* in 41.7%, while 32.0% of participants reported at least one gastrointestinal symptom during the preceding 14 days. The reported bivariate analyses showed that gastrointestinal morbidity was more frequent among participants classified as exposed to microbiologically contaminated water, with the strongest statistical associations observed for *E. coli* and total-coliform contamination. Because the study was cross-sectional, these findings demonstrate an association between measured water quality and reported morbidity rather than a causal relationship.

The high frequency of microbiological contamination is consistent with previous evidence showing persistent drinking-water quality problems in Pakistan. Daud et al. described widespread microbial and chemical contamination of drinking-water sources across the country and identified inadequate treatment, deteriorating infrastructure, and environmental pollution as major challenges to safe water provision (4). Studies conducted in Punjab and other regions of Pakistan have similarly documented water sources that failed to meet recommended microbiological and physicochemical standards (6,7). The present findings therefore support the broader evidence that microbial safety remains an important weakness in drinking-water systems in Pakistan, although the extent of contamination is likely to vary by geographical setting, water source, distribution infrastructure, and sampling methodology.

Detection of *E. coli* is particularly relevant because it is widely regarded as an indicator of recent fecal contamination and signals an increased probability that enteric pathogens may also be present in the water supply (9,10). Fecal contamination can occur at the source, during distribution, through damaged pipelines or drainage intrusion, or during household collection and storage. Studies of drinking water in low-resource settings have demonstrated that microbiological quality can deteriorate between source and point of consumption, creating additional opportunities for exposure to enteric organisms (11). The observed association between microbial contamination and gastrointestinal morbidity is therefore biologically plausible, as ingestion of fecally contaminated water can facilitate transmission of organisms capable of producing diarrhea, abdominal discomfort, nausea, and vomiting (8,10). Nevertheless, the current study assessed indicator organisms rather than specific gastrointestinal pathogens, and the reported symptoms were not microbiologically confirmed; consequently, the findings should not be interpreted as establishing that detected *E. coli* directly caused individual episodes of illness.

The 32.0% prevalence of recent gastrointestinal morbidity observed in the study population is also consistent with the recognized burden of water-, sanitation-, and hygiene-related disease in resource-constrained settings. Global analyses have identified unsafe drinking water, inadequate sanitation, and deficient hygiene as important contributors to diarrheal morbidity (2,3). Intervention evidence has further shown that improvements in drinking-water quality and other water, sanitation, and hygiene measures can reduce diarrheal disease under appropriate conditions (12). In the present study, diarrhea was the most frequently reported symptom, followed by abdominal pain, nausea, and vomiting. These symptoms are compatible with acute gastrointestinal illness but are not specific to waterborne infection, and food exposure, person-to-person transmission, sanitation conditions, and other environmental factors may also have contributed.

The study additionally identified physicochemical and chemical concerns in a proportion of the sampled water supplies. High TDS and turbidity were reported in 36.7% and 30.0% of samples, respectively, while nitrate exceeded the reported recommended limit in 15.0%. Lead and arsenic above the reported permissible limits were identified in 13.3% and 8.3% of samples. Previous Pakistani research has identified drinking water as a potential source of lead exposure (13), while arsenic contamination of groundwater represents a well-established environmental health concern globally (14). Chemical pollutants differ from microbial contaminants in their health: whereas fecal contamination is more directly relevant to acute gastrointestinal infection, exposure to metals and other persistent pollutants is generally of greater concern for cumulative or chronic toxicity (14,15). Accordingly, the chemical findings in this study indicate broader water-safety concerns but should not be interpreted as evidence that these contaminants caused the observed short-term gastrointestinal symptoms.

The industrial-area context of this study deserves careful interpretation. Industrial zones may be exposed to multiple environmental pressures, including wastewater discharge, groundwater contamination, damaged drainage networks, and deficiencies in water distribution systems. Pakistan has documented substantial environmental pressures on water resources arising from industrialization, urban development, and inadequate wastewater management (5). However, the present investigation did not directly sample industrial effluent, trace contaminant pathways, or establish hydrogeological connections between industrial activity and individual supply points. The findings therefore demonstrate contamination at water supply points located in industrial settings, rather than proving that industrial activities were the direct source of the detected microbial or chemical contaminants. This distinction is important when translating the findings into environmental-health policy.

The study has practical public-health relevance because it combined environmental water testing with health information collected from residents of surrounding communities. This approach provides greater contextual

information than either water testing or symptom surveillance alone and highlights supply points where microbiological and chemical monitoring may warrant particular attention. The findings also reinforce the importance of integrated water-safety surveillance incorporating microbiological indicators together with relevant physicochemical and chemical parameters, consistent with established drinking-water safety principles (1). From a community-health perspective, interventions aimed at maintaining microbiological integrity throughout water collection, distribution, storage, and household use remain particularly important given the observed burden of fecal indicator organisms.

Several limitations should be considered when interpreting the findings. First, the cross-sectional design does not establish temporal sequence and therefore cannot determine whether contaminated-water exposure preceded gastrointestinal illness. Second, gastrointestinal morbidity was based on self-reported symptoms during a 14-day recall period rather than clinical or microbiological confirmation, creating potential recall and outcome-misclassification bias. Third, 60 environmental water samples were assessed for a population of 300 participants, and the validity of individual exposure classification depends on how accurately each participant's drinking-water source corresponded to the sampled supply point. Participants may also have used alternative water sources or household treatment practices, which could reduce the precision of exposure classification. Fourth, water quality can vary over time, whereas the sampling strategy provided a limited representation of conditions during the six-month study period. Fifth, participants sharing the same supply point may have had correlated exposures, and such clustering can affect the precision of conventional statistical estimates. Finally, residual confounding by sanitation, hygiene, food exposures, socioeconomic conditions, and other environmental factors cannot be excluded, and the findings from selected communities in Multan should not be generalized automatically to other industrial areas of Pakistan.

Despite these limitations, the study provides locally relevant evidence that microbiological contamination was common in the sampled industrial-area drinking-water supplies and that reported gastrointestinal morbidity was more frequent among participants classified as exposed to contaminated water. The convergence of environmental and community-health findings supports continued attention to drinking-water safety in industrially situated communities, while the observational nature of the study requires that the identified relationships be interpreted as associations rather than proof of causation.

CONCLUSION

Among the 60 drinking-water samples assessed from industrial-area supply points, total coliforms and *E. coli* were detected in 58.3% and 41.7%, respectively, while 32.0% of the 300 surveyed residents reported recent gastrointestinal morbidity. Gastrointestinal symptoms were more frequent among participants classified as exposed to microbiologically contaminated water, indicating an association between poorer drinking-water quality and gastrointestinal morbidity in the studied communities. The additional detection of physicochemical and chemical abnormalities further indicates that drinking-water safety in these industrial-area communities warrants comprehensive environmental and public-health attention, although the cross-sectional design does not establish causality.

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