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Linking water quality, health risks, and community responses in urban drinking water systems of a lower-middle-income city: Evidence from Bangladesh

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Abstract

Access to safe drinking water remains a public health concern in urban Bangladesh. This study assessed the quality, risks, and public perception of public water points (PWPs) in Kushtia Municipality. Seven water samples were analyzed for 13 physicochemical and 5 microbiological parameters. Six parameters (alkalinity, hardness, dissolved oxygen, BOD_5, temperature, and iron) exceeded national standards. Water Quality Index values (195.03–228.68) classified all sources as unfit for drinking, while Pollution Index and Nemerow Pollution Index identified BOD_5, hardness, and alkalinity as dominant pollutants. Fecal coliforms were detected in 71.4% and *Pseudomonas spp.* in 57.1% of samples. Chemical health risks from iron and arsenic were negligible, but the Quantitative Microbial Risk Assessment indicated a 100% annual infection risk in five of seven PWPs for both adults and children. A cross-sectional Knowledge, Attitude, and Practice (KAP) survey of 305 users revealed high knowledge (0.57), high attitudes (0.58), and borderline high but comparatively lower safe practices (0.50). Regression analysis showed education, occupation, and duration of water use influenced KAP scores, though associations were weak. Respondents emphasized regular maintenance, water testing, and treatment upgrades. The study emphasizes the need for integrated environmental management strategies, including routine microbial monitoring, infrastructure upgrades, and community-engaged interventions, to advance safe and equitable urban water access in low- and middle-income settings in line with SDG 6, SDG 3, and SDG 11.

Keywords: KAP survey, Microbial contamination, Municipal water, Physicochemical quality, Quantitative microbial risk assessment, Water Quality Index, Water safety

Abbreviations

- BOD_5 – Biochemical Oxygen Demand (5-day)
- CDI – Chronic Daily Intake
- CFU – Colony Forming Unit
- DO – Dissolved Oxygen
- EC – Electrical Conductivity
- FC – Fecal Coliform
- HQ – Hazard Quotient
- KAP – Knowledge, Attitude, and Practice
- MLR – Multiple Linear Regression
- NPI – Nemerow Pollution Index

- ORP – Oxidation-Reduction Potential
- Pi – Pollution Index
- PCA – Principal Component Analysis
- PWP – Public Water Point
- QMRA – Quantitative Microbial Risk Assessment
- TC- Total Coliform
- TDS – Total Dissolved Solids
- WQI – Water Quality Index
- WHO – World Health Organization
- WTP – Water Treatment Plant

1. Introduction

Drinking water quality encompasses the physical, biological, and chemical characteristics that determine its safety and suitability for human consumption [1]. Access to safe drinking water is a fundamental human right and a cornerstone of public health and sustainable development [2]. Globally, 5.8 billion people (73%) rely on safely managed drinking water, with over 90% of urban populations depending on piped systems [3]. In Bangladesh, although 60–70% of the urban population has access to piped water, only 15–20% rely on municipal supply systems, including public water points (PWPs) [4,5]. Rapid urbanization, industrialization, and inadequate infrastructure have contributed to contamination of water sources, posing serious threats to both water quality and public health [6].

This challenge is particularly acute in urban municipalities in Bangladesh, such as Dhaka District, Kushtia District, Sirajganj District, and Chattogram District, where residents rely on aging and poorly maintained piped water systems that are highly vulnerable to microbial and chemical contamination [1,7,8]. National data indicate that 41% of piped sources and more than 60% of small-town supplies contain *E. coli*, alongside high prevalence of iron (66.2%), bacterial (11.7%), and arsenic (6.5%) contamination [6,9]. Recent studies in Bangladesh and neighboring countries further report widespread contamination with *E. coli*, iron, arsenic, and other pollutants, underscoring the dual risks of chronic chemical exposure and acute microbial infections. For instance, Prithibi et al. [10], Shathi et al. [11], and Tanvir et al. [12] assessed drinking water quality in Dhaka District's municipal supply and confirmed bacterial contamination. In Pakistan, Nawaz et al. [13] and Alamgir et al. [14] evaluated municipal water quality in Lahore District and Karachi District, respectively, identifying multiple contaminants, assessing associated health risks, and highlighting heavy metal and microbial vulnerabilities in piped water systems. Similar challenges have also been documented in other developing regions: Luvhimbi et al. [15] in Thulamela Municipality, South Africa, reported microbial and chemical contamination linked to poor storage and distribution.

Despite these risks, health risk assessments in Bangladesh have primarily focused on heavy metals such as lead, arsenic, and iron on municipal water supply [6,16,17], while microbial risks remain largely underexplored. Quantitative Microbial Risk Assessment (QMRA) has been applied in other contexts [18,19], but its application in Bangladesh remains limited. Integrating QMRA with chemical risk assessments provides a more comprehensive framework

for evaluating water safety, particularly in freely accessible PWPs where microbial contamination and community vulnerability are high [10,11].

Another critical dimension is public perception. Perceived issues with water taste, odor, or color can reduce trust in municipal systems, prompting households to use expensive bottled water or unsafe alternatives, increasing economic and health risks [20-22]. This perception gap between actual water quality and community understanding directly affects usage behavior and policy outcomes [23]. Addressing both scientific quality and public perception is therefore essential for sustainable water management.

Groundwater levels in Kushtia Municipality are declining [24], and during the dry summer, tubewell water often becomes unavailable, making PWPs the primary drinking water source. With 39 unmonitored PWPs [69] and no prior comprehensive assessments, this situation presents a critical opportunity to fill existing knowledge gaps. Accordingly, this study has three objectives: (i) to evaluate the physicochemical and microbiological quality of freely accessible PWPs; (ii) to estimate health risks, particularly from heavy metals and microbes, using HQ and QMRA; and (iii) to assess community KAP regarding PWP use. By integrating scientific water quality data with public perception, this study provides the first multidimensional assessment of PWPs in Kushtia and in Bangladesh, generating evidence to guide water management, public health interventions, and policy development in Kushtia and similar urban contexts across the country.

2. Materials and methods

2.1 Study area

Kushtia Municipality, located in Kushtia District of Khulna Division, Bangladesh (23°54′10″ N, 89°7′9″ E), spans 42.79 km² (Fig. 1) and has a population of approximately 226,800 [25]. Since 2011, it has expanded from 12 to 21 wards [26]. The area is served by four WTPs and overhead tanks, primarily covering the older municipal zones. These WTPs are designed mainly for the removal of arsenic and iron [25]. Water is distributed through 10,158 private pipeline connections and 56 PWPs, of which 39 are currently operational and primarily serve low-income communities [69].

2.2 Study design

This mixed-method study was conducted in two phases. Phase 1 involved physicochemical and microbial analysis of water samples (Section 2.3), while Phase 2 comprised a cross-sectional KAP survey (Section 2.4). The phases were designed to complement each other: Phase 1 provided objective measurements of pipeline water safety, and Phase 2 explored community perceptions and behaviors regarding the same sources. Together, these approaches enable triangulation of risks from both scientific and social perspectives.

2.3 Phase 1: Physicochemical and microbial analysis

2.3.1 Sample collection

Seven water samples (n=7) were collected from seven PWPs in Kushtia Municipality from March 11 to March 12, 2025. These sites were selected from all available PWPs (**Table S1**) in the study area, with consideration of budget constraints, spatial distribution, and usage patterns to ensure representative coverage. The sampling locations are illustrated in **Fig. 1**. Polypropylene plastic bottles were used for sample collection. Prior to use, the bottles were thoroughly washed, rinsed with deionized water, autoclaved, and dried in a laminar flow hood to ensure sterility [1]. Samples were stored at 4°C until laboratory analysis [27].

2.3.2 Laboratory analysis

All seven water samples were analyzed for thirteen physicochemical parameters using standard analytical procedures and calibrated instruments, as detailed in **Table S2**. These included alkalinity, hardness, chloride, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), iron, arsenic, total dissolved solids (TDS), electrical conductivity (EC), pH, temperature, oxidation-reduction potential (ORP), and turbidity. For microbiological assessment, five parameters were analyzed: total coliforms (TC), fecal coliforms (FC), and *Pseudomonas* spp. were quantified using the membrane filtration method, where 100 mL of water was passed through a 0.45 μm membrane filter, then incubated on selective media, m-Endo agar for coliforms and cetrimide agar for *Pseudomonas*, at appropriate temperatures for 24–48 hours. *Salmonella* spp. and *Shigella* spp. were detected using culture-based methods involving pre-enrichment in buffered peptone water, selective enrichment in selenite or tetrathionate broth, and isolation on XLD or SS agar, followed by biochemical confirmation. All analyses were conducted in accordance with [28] and [29] protocols. Quality assurance and control procedures, including the use of blanks, duplicates, and calibration standards, were maintained throughout the testing process to ensure data reliability [1].

2.3.3 Data analysis

For data analysis, the single-factor pollution index (P_i), NPI, and WQI were used. The P_i and NPI were calculated to assess key pollutant contributions in PWP water samples using Eqs. 1 and 2 [30]:

$$P_i = \frac{C_i}{S_i} \quad \text{.....(Eq. 1)}$$

where P_i represents the pollution index of the single water quality index i; C_i is the measured value of pollutant content (mg/L); S_i is the standard value of environmental quality (mg/L).

$$NPI = \sqrt{\frac{(P_1)^2+(P_{imax})^2}{2}} \quad \text{..... (Eq. 2)}$$

where NPI is the comprehensive pollution index of the sampling point; P_{imax} is the maximum value of the single-item pollution index of the pollutants at the sampling point; $P_1 = \frac{1}{n}\sum_{i=1}^{n} P_i$ is the average value of the single-factor index.

A parameter was considered non-polluting when Pi and the NPI value were ≤ 1 [30].

The WQI was computed using the Weighted Average Method [69], following three steps:

(i) Unit weight:

$$W_n = \frac{k}{S_n},\ k = \left(\sum \frac{1}{S_n}\right) \quad \text{(Eqs. 3-4)}$$

(ii) Subindex:

$$q_n = \frac{V_n - V_{id}}{S_n - V_{id}} \times 100 \quad \text{(Eq. 5)}$$

where V_n is the observed value of the *n*th water quality parameter and V_{id} is its ideal value. The V_n is 7 for pH, 14.6 mg/L for DO, and typically zero for other parameters [70].

(iii) Aggregated WQI:

$$WQI = \frac{\sum q_n W_n}{\sum W_n} \quad \text{(Eq. 6)}$$

2.3.4 Health risk assessment

While WQI and NPI provide integrated indices of overall water quality, Hazard Quotient (HQ) and Quantitative Microbial Risk Assessment (QMRA) were applied to translate chemical and microbial contamination into health risk terms. Chemical risks from PWP water were evaluated using Chronic Daily Intake (CDI) and HQ for iron and arsenic, following the same equations and exposure parameters as Hossain et al. [1]. CDI via ingestion and dermal exposure was calculated as:

$$CDI_{Ingestion} = \frac{C_w \times IR \times EF \times ED}{BW \times AT} \quad \text{(Eq. 7)}$$

$$CDI_{Dermal} = \frac{C_w \times SA \times K_p \times ET \times EF \times ED \times CF}{BW \times AT} \quad \text{(Eq. 8)}$$

where all parameters follow Hossain et al. [1] (**Table S3**). HQ was then computed as:

$$HQ_{ingestion/dermal} = \frac{CDI}{RfD} \quad \text{(Eq. 9)}$$

with RfD = 700 µg/kg/day for iron and 0.3 µg/kg/day for arsenic. HQ < 0.1 = negligible risk; 0.1–1 = low; 1–4 = moderate; >4 = high risk [70].

Microbial risks were assessed through a QMRA framework to estimate the probability of infection from fecal contamination, following the standard four-step USEPA procedure [31,32]. The four steps are summarized below:

Step 1: hazard identification

FC, commonly used as indicators of fecal pollution, were used as proxies for enteric pathogens, particularly *E. coli*. Their presence suggests potential contamination by disease-causing organisms and reflects inadequate sanitation or water treatment [33].

Step 2: exposure assessment

Human exposure occurs through the ingestion of contaminated drinking water. The daily ingested dose (D) was calculated using the following Eq. 10:

$$D = \frac{C \times V}{100} \quad \text{(Eq. 10)}$$

where C = FC concentration (CFU/100 mL), V = daily water ingestion volume (mL/day), and 100 converts units from per-100mL to per-mL. Water intake was stratified for adults (2.0 L/day) and children (1.0 L/day) based on USEPA [34] and WHO [32] guidelines.

Step 3: dose–response assessment

The Beta-Poisson model was applied to estimate the probability of infection from the ingested dose of fecal coliforms (*E. coli* as an indicator). This model was chosen because fecal coliforms reflect general enteric pathogen contamination, and strain-specific data were not available [35]. The probability of infection (P_{inf}) was calculated using the following Eq. 11:

$$P_{inf} = 1 - \left(1 + \frac{D}{N_{50}}\left(2^{1/\alpha} - 1\right)\right)^{-\alpha}$$

(Eq. 11)

where N_{50} = 1120, the median infectious dose and, α=0.21, a fitted parameter for *E. coli.*

Step 4: risk characterization

To estimate long-term health risks, the annual probability of infection was computed assuming daily exposure:

$$P_{annual} = 1 - \left(1 - P_{inf}\right)^{365} \quad \text{(Eq. 12)}$$

Results were compared against the WHO and USEPA benchmark risk of 10^{-4} per person per year [31,32]. A sensitivity check was performed for the *E. coli* model, considering a 20% variation in fecal coliform concentration and daily water ingestion.

Together, the Pi, NPI, WQI, HQ, and QMRA metrics provide quantitative measures of water quality and health risks, which are subsequently compared with KAP survey results to assess alignment between observed water quality and public perceptions.

2.4 Phase 2: KAP survey

The KAP survey was conducted after the water quality and risk assessments to contextualize the findings. By integrating technical water quality indices with community knowledge, attitudes, and practices, the study provides a multidimensional understanding of drinking water safety. This sequencing ensures that behavioral and perceptual data are interpreted in light of measured water quality and associated health risks.

2.4.1 Survey design and population

A cross-sectional survey was conducted in Kushtia Municipality to assess the community's KAP concerning PWPs, following initial physicochemical and microbial assessments. The target population included 305 PWP users representing diverse socio-economic and institutional backgrounds. Participants were selected using a multistage sampling strategy, where all PWPs (**Fig. 1**) were treated as clusters and eight respondents were randomly chosen per cluster [36], ensuring geographic and demographic representativeness.

2.4.2 Data collection and scoring

A structured questionnaire **(Appendix C)** was administered to collect responses related to water quality perception, usage behavior, and associated health risks. The questionnaire incorporated yes/no, Likert scale, concern-based, and frequency-based items. These were quantitatively scored as shown in **Table 1**, where responses such as "Yes" = 1, "No" = 0, and intermediate values (e.g., "Maybe" = 0.5) were used for consistency. Frequency-based practices were scored from 1 (Regularly) to 0 (Never), while willingness and concern-based items followed a similar gradation.

This unified 0–1 scaling, adapted from Razak et al. [37], ensured that responses across all question types could be aggregated consistently and interpreted on a common scale. Final mean domain scores were then categorized as Low (0.00–0.25), Moderate (0.25–0.50), High (0.50–0.75), or Very High (0.75–1.00). Average domain scores were computed for Knowledge (12 items), Attitude (10 items), and Practice (10 items) using Eqs. 13–15. This approach allowed direct comparison across domains and facilitated interpretation of the overall KAP levels in the study population.

$$\text{Knowledge score} = \frac{1}{12}\sum_{i=1}^{12} Knowledge_i \quad \text{(Eq. 13)}$$

$$\text{Attitude score} = \frac{1}{10}\sum_{i=1}^{10} Attitude_i \quad \text{(Eq. 14)}$$

$$\text{Practice score} = \frac{1}{10}\sum_{i=1}^{10} Practice_i \quad \text{(Eq. 15)}$$

2.4.3 Composite KAP score using Principal Component Analysis (PCA)

PCA was performed on individual-level KAP scores to assign objective weights to each domain. The weights were calculated using Eq. 16 [38]:

$$Weight_i = \frac{|Loading_i|}{\sum|Loadings|} \quad \text{(Eq. 16)}$$

These PCA-derived weights were used in the final score calculation (Eq. 17):

$$\text{Overall KAP score} = W_k \times Knowledge\ score + W_a \times Attitude\ score + W_p \times Practice\ score \quad \text{(Eq. 17)}$$

where W_k, W_a, and W_p are the respective weights for the knowledge, attitude, and practice components, and $W_k + W_a + W_p = 1$ as the weights are normalized.

2.4.4 Regression analysis

Multiple Linear Regression (MLR) models were applied to explore predictors of Knowledge, Attitude, Practice, and the combined KAP index. Data were preprocessed using Microsoft Excel and Python, with categorical variables converted into binary dummy codes and continuous variables checked for outliers and missing values before analysis [39]. Four ordinary least squares (OLS) regression models were developed: Model 1 for knowledge, Model 2 for attitude, Model 3 for practice, and Model 4 for the combined KAP index using the same set of independent variables. Model performance was evaluated using the coefficient of determination (R^2), adjusted R^2, F-statistics, and p-values to assess overall significance [40]. All statistical analyses were performed at a 95% confidence level.

3. Results

3.1 Physicochemical characteristics

3.1.1 Water quality parameters at different PWP

Analysis of water samples from Kushtia Municipality PWPs revealed considerable variation in compliance with national drinking water standards (**Fig. 2**). Of 13 parameters assessed, seven exceeded permissible ranges, alkalinity (470–510 mg/L), total hardness (380–400 mg/L), BOD_5 (1.9–2.2 mg/L), dissolved oxygen (3.0–3.4 mg/L), iron (1.08–1.67 mg/L), temperature (30.1–30.3°C), and ORP (38–46 mV), indicating notable water quality concerns. Other parameters remained within standard limits: chloride (40–100 mg/L), arsenic (≤0.01 mg/L), TDS (310–320 mg/L), EC (650–670 µS/cm), pH (7.85–8.10), and turbidity (≤10 NTU). Collectively, the results reveal that water quality at PWPs was compromised, with several key parameters exceeding safe limits. The national standard values for all parameters can be found in **Table S2**.

3.1.2 WQI

WQI assessment confirmed severe water quality impairment across all PWPs. Scores ranged from 195.03 to 228.68, well above the acceptable threshold of 100 (**Fig. 3**). The highest WQI was recorded at PWP-25 (228.68), followed by PWP-1 (219.87) and PWP-19 (219.45), indicating that all sampled points are unsuitable for human consumption. These results highlight the cumulative impact of multiple physicochemical deviations on overall water quality.

3.1.3 Responsible pollutants analysis

Pi and NPI analyses highlighted the severity and sources of contamination across PWPs (**Fig. S1**, **Fig. 4**). BOD_5 emerged as the most critical pollutant, exceeding standards by up to 11 times (Pi = 9.5–11.0; NPI = 10.61), followed by hardness (Pi = 3.8–4.0; NPI = 3.94) and alkalinity (Pi = 2.4–2.55; NPI = 2.50). Iron (Pi = 1.08–1.67; NPI = 1.47) and temperature (Pi = 1.003–1.010; NPI = 1.01) contributed moderately, while other parameters, including DO, chloride, arsenic, TDS, EC, pH, ORP, and turbidity, remained within acceptable limits (Pi < 1.0), with chloride (Pi = 0.067–0.167), turbidity (0.08), and ORP (0.06) posing minimal risk. These results indicate that BOD_5, hardness, and alkalinity are the primary drivers of systemic water quality impairment in Kushtia PWPs.

3.2 Microbiological analysis

Microbiological analysis of the drinking water samples revealed significant fecal contamination, with FC concentrations ranging from 0 to 268 CFU/100ml (**Fig. 5**). Five of seven samples (71.4%) exceeded the WHO guideline of 0 CFU/100ml for fecal indicators. *Pseudomonas spp.* was detected in four samples (57.1%), peaking at 171 CFU/100ml (PWP-5). *Salmonella* and *Shigella* were absent in all samples.

3.3 Health risk assessment

Health risk assessment showed negligible risk from iron and arsenic in all PWPs. $CDI_{ingestion}$ for iron ranged from 29.59–45.75 µg/kg/day, and for arsenic, it remained low (**Table S4**). Dermal CDI values were minimal, with zero exposure at PWP-34. All HQ values for arsenic (ingestion and dermal) were <1, indicating a negligible health risk (**Table S5**). However, iron HQ_{dermal} (0.913) reached nearly the row risk threshold at six sites.

On the other hand, the QMRA results showed that out of the seven PWPs assessed, only PWP-7 and PWP-34 presented no health risk, with zero FC detected and corresponding infection probabilities of 0% for both children and adults (**Table 2**). In contrast, PWP-1, PWP-5, PWP-19, PWP-25, and PWP-37 exhibited varying levels of fecal contamination, leading to significant infection risks. For children, daily infection risks ranged from 5.04% (PWP-5) to 40.47% (PWP-25), while adults had higher daily risks between 9.38% and 62.99%. In all contaminated PWPs, the annual infection risk reached 100% for both groups. A sensitivity

329 analysis revealed that a 20% increase or decrease in fecal coliform concentration or water
330 ingestion volume could markedly change the estimated annual infection probabilities. This
331 indicates that while some PWPs show near-100% risk, these values reflect model sensitivity
332 and potential exposure rather than absolute certainty of infection.

333

334 **3.4 KAP analysis**

335 **3.4.1 Demographic characteristics**

336 **Table 3** summarizes the socio-demographic and household characteristics of respondents (N =
337 305). The mean age was 43 ± 14 years, with 67.54% male and 32.46% female. Regarding
338 education, 36.63% had no formal schooling, while only 4.29% completed undergraduate or
339 higher degrees. Occupations were diverse, with the largest groups being unemployed (29.57%),
340 business (23.58%), and self-employed/professionals (17.94%). The most reported secondary
341 water sources were tube wells (75.08%) and bottled water (13.77%). Average monthly income
342 was Tk 13,990 ± 15,737. Respondents had lived in the area for 29.44 ± 18.49 years on average
343 and used pipeline water for 10.29 ± 10.93 years. Each household/institution relied on PWP
344 water for an average of seven individuals (±18), with 69.18% including children or other
345 vulnerable groups, averaging three per household.

346 Community perceptions of PWP water use are shown in **Fig. 6**. Currently (**Fig. 6a**), the most
347 common uses were DBHU (28.5%), DHU (22.6%), and BHU (14.8%), with smaller
348 proportions using water for DCU (8.9%), CU (6.9%), B (6.9%), DW (9.2%), and other
349 purposes (2.3%). For perceived potential uses (**Fig. 6b**), APU (40.8%) was the largest category,
350 followed by DBHU (24.3%), BCU (10.5%), BHU (9.5%), BHCU (7.6%), and CU (7.2%),
351 suggesting that respondents see scope for broader applications beyond current practices.

352

353 **3.4.2 Knowledge level**

354 Respondents' knowledge of PWP water safety is shown in **Table 4**. While 46.23% (mean =
355 0.54) knew how water was treated and only 27.54% (mean = 0.41) recognized microbial risks,
356 awareness of chemical (70.82%, mean = 0.75) and physical contaminants (57.05%, mean =
357 0.60) was higher. Despite this, 60.98% (mean = 0.65) considered the water safe for drinking,
358 yet fewer than half (43.28%, mean = 0.46) knew the government water quality standards. About
359 half recognized general health risks (51.15%, mean = 0.59), with slightly more aware of risks
360 to children and vulnerable groups (59.02%, mean = 0.65). Most reported that their knowledge
361 influenced water usage (64.59%, mean = 0.73) and understood who managed water quality
362 (65.9%, mean = 0.67). However, only 28.85% (mean = 0.31) had actively sought to improve
363 their knowledge, highlighting a gap between awareness and proactive learning. Overall, the
364 mean Knowledge score was 0.57, reflecting high understanding across respondents (**Fig. 7**).

365

366 **3.4.3 Attitude level**

Table 5 represents respondents' attitudes toward PWP water safety and contamination risks. While 44.59% (mean = 0.50) considered the water safe to drink without treatment, nearly the same proportion (43.93%) disagreed. Most respondents (82.95% combined; mean = 0.82) valued contaminant-free water as important or very important. Trust in local authorities was mixed (46.89% trusting, 34.43% not trusting, 18.69% uncertain; mean = 0.56), and willingness to pay for water improvements was low (mean = 0.47). Over half (53.77%, mean = 0.62) perceived current water quality as a health risk, with high concern and confidence in protecting against waterborne diseases (means 0.59 and 0.53, respectively). Discussion of water safety within families or neighbors was limited (mean = 0.37), yet a majority (67.54%, mean = 0.77) believed community awareness programs were effective. The overall Attitude score was 0.58, indicating a high perception of risk and importance (**Fig. 7**).

3.4.4 Practice level

Water safety practices also varied (**Table 6**). Only 35.08% (mean = 0.35) used additional filtration or treatment, but over 70% cleaned storage tanks regularly (mean = 0.74) and 45.9% cleaned containers (mean = 0.73). Most respondents (73.77%, mean = 0.74) checked water by color, taste, or smell before use, treating it when cloudy or unusual (67.87%, mean = 0.63). However, 41.97% always drank directly from the pipeline (mean = 0.38), and reporting issues was less common (39.67%, mean = 0.40). Only 15.41% actively educated others (mean = 0.18), and community initiative participation was low (9.18%), although willingness to join was high (80.66%). Overall, Practice scored slightly lower (mean = 0.50; **Fig. 7**), highlighting a gap between knowledge/attitudes and actual behavior.

3.4.5 PCA-Weighted combined KAP

The PCA-weighted combined KAP score summarized respondents' overall knowledge, attitude, and practice regarding PWP water safety. Knowledge and Attitude were the primary contributors to the first principal component (PC1), with high loadings of 0.68 and 0.71, respectively, jointly explaining 53.16% of the variance, while Practice had minimal influence (loading = 0.16) but dominated PC2 (loading = 0.96), which explained 34.14% of the variance. PC3 accounted for 12.70% of the variance, reflecting contrasting effects between Knowledge and Attitude (**Fig. S2**). Based on PC1-derived weights, Attitude (0.46) and Knowledge (0.44) were the most influential factors, whereas Practice contributed less (0.10; **Table 7**). Using these weights, the final combined KAP score was 0.57, indicating a moderate overall level of knowledge, positive attitudes, and water safety practices.

3.4.6 Factors affecting Knowledge, Attitude, Practice, and combined KAP scores

Multivariate regression analysis (**Table 8-9**) revealed that socio-demographic and contextual variables had varying influences on Knowledge, Attitude, Practice, and combined KAP scores. The Knowledge model was significant (R^2 = 0.0911, p = 0.0352), with self-employed or

professional respondents showing a positive association with knowledge ($\beta = 0.0659$, $p < 0.05$). The Attitude model ($R^2 = 0.0987$, $p = 0.0178$) showed weak associations with being unemployed and female, but no individual predictor reached significance. In contrast, the Practice model exhibited stronger explanatory power ($R^2 = 0.1508$, $p < 0.001$), with longer residence ($\beta = -0.0021$, $p < 0.01$), years using pipeline water ($\beta = 0.004$, $p < 0.001$), and primary education ($\beta = -0.1094$, $p < 0.05$) significantly influencing practices. Similarly, the Combined KAP model ($R^2 = 0.1176$, $p = 0.0028$) indicated that residence duration ($\beta = -0.0014$, $p < 0.05$) and years using pipeline water ($\beta = 0.0024$, $p < 0.05$) were significant predictors, while primary education had a non-significant negative effect. Overall, occupation, education, and residence duration had modest but statistically significant associations with water-related KAP, although most of the variance remained unexplained.

3.4.7 Community priorities and suggestions

Community priorities and suggestions regarding PWP water are summarized in **Fig. 8**. For operational improvements, regular maintenance (29.32%) and ensuring water quality (26.21%) were the top concerns, followed by extending supply hours (22.33%), enhancing water pressure (13.01%), and expanding coverage (9.13%). Regarding water safety, the most frequently suggested measures were regular water quality testing (30.49%), upgrading treatment facilities (21.36%), implementing community awareness programs (15.73%), prompt leak repairs (10.29%), and introducing advanced filtration systems (7.77%), while 14.37% of respondents selected "don't know," reflecting uncertainty or lack of specific preferences.

4. Discussions

In this study, several critical concerns regarding PWPs in Kushtia Municipality were identified through physicochemical, microbiological, and KAP assessments. Among 13 parameters, it was found that alkalinity, hardness, DO, temperature, and iron exceeded national standards. Similar trends have been reported in other parts of the Kushtia district [41.42]. Elevated alkalinity and hardness were likely caused by natural minerals [43], contributing to scaling and water quality degradation [1]. In contrast, high BOD_5 levels suggested organic pollution from sewage or decaying matter [44]. The proximity of PWP pipelines to drainage networks (**Fig. S3**) may explain the elevated BOD_5 in this study. Pollution indices (Pi and NPI) confirmed BOD_5, alkalinity, and hardness as major pollutants (**Fig. S1** and **Fig. 4**). Low DO and high temperatures are likely due to inadequate aeration or exposed pipelines, which may not pose an immediate health risk but reflect the overall condition of the supply system [45]. Excess iron, possibly from pipe corrosion or natural sources, led to staining, turbidity, and biofilm formation [46]. These findings highlight key risks to water quality and infrastructure performance.

The WQI assessment indicated that PWP water was unfit for direct consumption. However, the survey data showed that 61% of respondents believed the water was suitable for drinking (**Table 4**). In contrast, a study in Old Dhaka found that 100% of respondents perceived the

water as unsafe for drinking [47]. Notably, 42% of participants in this study reported drinking water from PWPs without boiling or filtering (**Table 6**), consistent with national-level statistics showing limited use of water treatment, particularly among lower-income households [48]. This disparity between perceived and actual water quality reveals a significant gap in public awareness, heightening the risk of waterborne illnesses and underscoring the urgent need for community-based education and effective water safety interventions [49].

Microbiological analysis (**Fig. 5**) revealed fecal contamination in 71.4% of drinking water samples, likely resulting from poor sanitation practices and the close proximity of water sources to drainage systems (**Fig. S3**). Previous studies reported microbial loads beyond permissible limits (0 CFU/ml) in Chattogram [50], with TC and E. coli present in Rajshahi WASA [51], while 66.67% (TC) and 100% (EC) samples exceeded limits in Khulna WASA [52]. Coliform bacteria remain among the most frequently reported microbial contaminants affecting potable water across Bangladesh [53]. The detection of *Pseudomonas spp.* in this study indicated possible biofilm formation and contamination within the pipeline network [54]. Although *Salmonella* and *Shigella* were not detected, microbial pollution still poses risks to water infrastructure by promoting corrosion and biofilm growth, which can degrade water quality and reduce the operational lifespan of the distribution system [55].

The health risk assessment, integrating CDI, HQ, and QMRA, revealed significant concerns regarding the use of PWP water in Kushtia Municipality. All contaminated sources exceeded the WHO's tolerable annual infection risk threshold of 10^{-6}, indicating a high probability of waterborne infections, particularly among children, who are more susceptible to microbial pathogens, a pattern consistent with Amha et al. [56]. Chemical risks from iron and arsenic were found to be negligible, aligning with Hossain et al. [1] in the same area. However, the widespread presence of fecal contamination compromises water safety and increases the local disease burden. These findings were validated by the KAP survey, where 39.3% of respondents reported health issues (**Fig. 9**), including gastrointestinal (35.1%) and infectious (5.6%) symptoms, consistent with microbiological results. Although 58.0% of participants believed the water was safe, the high percentage of self-reported illness highlights a mismatch between perception and experience, pointing to gaps in awareness rather than contradiction. The high rate of uncertainty (52.2% responded "Don't know") and dermal complaints (e.g., rashes, hair fall, itching) suggested underrecognized health effects (**Fig. 10**), warranting further investigation. These insights support the quantitative risk findings and echo concerns raised by [57] about limited health literacy in affected populations.

The respondents for the KAP survey were predominantly from a low-education, low-income community heavily reliant on PWPs, with many vulnerable users and increasing health risks. Despite long-term use, trust in piped water remained limited, with tube wells still the primary source. The gap between current use and perceived potential (**Fig. 6**) highlights unmet demand and the need for safer, more versatile water systems.

KAP analysis revealed a moderate overall score (0.57), driven by relatively high knowledge and attitude but low practice, contrasting with prior research reporting high scores across all domains [58]. This disparity between awareness and behavior, confirmed by PCA results (**Fig.**

S2, **Table 7**), reflects patterns in other low-resource settings. For example, in Ethiopia, 45% of the population lacked basic hygiene education, limiting the translation of knowledge into practice [59]. Similarly, in India, positive attitudes toward water hygiene coexisted with limited access to safe water (18%) and high rates of open defecation (86%), indicating persistent risky behaviors [60]. In Kushtia Municipality, only a few respondents engaged in protective behaviors such as filtering or reporting issues, and willingness to pay for service improvements remained low, contrasting with Dhaka, where 77% expressed readiness to pay for guaranteed safe water [61]. These findings highlight structural and behavioral barriers, including limited access, ineffective communication, and low motivation, constraining safe water practices, as observed in Ethiopia and India. As Sari. [62] emphasized, knowledge alone does not ensure action, underscoring the need for targeted interventions.

The MLR analysis indicated that occupation and prior experience with piped water supply were positively associated with higher KAP scores, while longer duration of residence and attainment of only primary-level education were negatively associated. However, the explanatory power of the models was limited. Previous research has consistently identified education as a key determinant of water safety behavior; individuals with higher educational attainment tend to place greater trust in scientific information and are less influenced by sensory perceptions [63, 64]. In contrast, individuals with only primary education have not consistently demonstrated protective behaviors. Additionally, long-term residents often exhibit a sense of complacency regarding water-related risks, which may contribute to lower KAP scores [65]. The limited explanatory power of the models suggests that other sociocultural or psychological factors affect behavior, highlighting the need for targeted, multifaceted interventions combining education, communication, and trust-building to improve safe water practices.

The community's focus on maintenance and water quality highlights persistent operational challenges related to reliability and safety, consistent with this study's findings. Concerns over supply hours, pressure, and coverage indicate infrastructural limitations critical for maintaining adequate flow and preventing contamination through backflow, microbial growth, and pipe corrosion [66, 67]. Although natural flooding is rare in Kushtia, occasional drainage failures can cause temporary flooding, increasing contamination risks at PWPs. Emphasis on testing and upgrades reflects awareness of water quality issues but also reveals gaps in behavioral and technological mitigation, as indicated by low prioritization of awareness programs and filtration practices. "Don't know" responses further underscore user uncertainty and the need for improved communication [68]. To reduce contamination during temporary floods, infrastructure modifications such as elevated taps, sealed reservoirs, proper drainage, and routine monitoring are recommended.

The contamination pathways, infrastructural constraints, and community practices are interconnected, as illustrated in our conceptual framework (**Fig. 11**), and jointly shape health risks at Kushtia PWPs, highlighting the need for integrated, multi-faceted interventions. These findings illustrate how systemic water quality issues interact with human behaviors and infrastructure limitations, creating cumulative risks that single interventions cannot address. Effective strategies must therefore combine routine water quality monitoring, infrastructure

upgrades, and community-driven awareness programs to reduce microbial and chemical hazards while promoting safe water practices.

This study's multidimensional approach, integrating physicochemical, microbiological, and community-based assessments, offers a comprehensive picture of drinking water quality and related public health risks at PWPs in Kushtia Municipality. The methods and findings are relevant not only to Kushtia but also to other Bangladeshi cities and similar low- and middle-income settings facing water supply challenges. However, the study has limitations. Sampling was restricted to the pre-monsoon period with a small sample size, limiting assessment of seasonal variation. Reliance on fecal coliforms as a proxy for *E. coli* and other pathogens may also overlook pathogen-specific risks. Future research should include year-round monitoring and more targeted microbiological analyses. Collaboration with NGOs and local stakeholders will be vital for sustainable solutions.

5. Conclusion

This study provides an integrated assessment of physicochemical quality, microbial contamination, health risks, and community perceptions of drinking water from public water points in Kushtia Municipality, Bangladesh. The findings reveal severely compromised water quality, with WQI values classifying all sources as unfit for consumption and BOD_5, hardness, and alkalinity identified as dominant pollutants, indicating systemic deficiencies in treatment and distribution infrastructure. Widespread microbial contamination and Quantitative Microbial Risk Assessment results demonstrating near-universal annual infection risks, particularly among children, underscore an urgent public health concern. Although chemical health risks from arsenic and iron were generally minimal, the potential for localized dermal exposure to iron highlights the importance of continued surveillance within urban water systems. The observed disconnect between relatively high community knowledge and attitudes and comparatively lower safe practices indicates that awareness alone is insufficient in the absence of reliable infrastructure, consistent water quality monitoring, and behavioral support mechanisms. Importantly, strong community demand for improved maintenance, supply reliability, and treatment upgrades suggests both the urgency and feasibility of intervention. From an environmental management and policy perspective, the results emphasize that achieving safe and equitable urban water access requires an integrated approach that combines infrastructure investment, routine microbial and chemical monitoring, risk-based management tools such as QMRA, and community-driven engagement strategies. Strengthening institutional capacity for water quality surveillance, prioritizing upgrades to treatment facilities, and embedding public water point management within urban sustainability planning are essential steps toward advancing SDG 6, SDG 3, and SDG 11 in rapidly urbanizing settings of low- and middle-income countries.

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CRediT author statement

Md. Inzamul Haque: Writing – review & editing, Validation, Supervision, Investigation, Methodology, Conceptualization. **Md. Anik Hossain**: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Abu Reza:** Writing – review & editing, Data curation. **Md. Asikur Rahman**: Writing – review & editing, Data curation. **Most. Atia Parvin**: Writing – review & editing, Data curation. **J S M Mahedi**: Writing – review & editing, Data curation. **Md. Ashraful Islam Dewan**: Writing – review & editing, Data curation.

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Clinical trial number

Not applicable.

Ethics declarations

Ethics approval and consent to participate

The study was conducted in accordance with the ethical standards approved by the Department of Geography and Environment at the Islamic University, Kushtia (Ref: 141/Edu/IU-2024/31). The approval document is available at: Islamic University Ethics Approval Notice. Verbal informed consent was obtained from all participants prior to data collection. Participation was voluntary, and confidentiality and anonymity were strictly maintained. Participants were informed of their right to withdraw at any time without any consequences.

Consent for publication

Not applicable.

Data availability statement

Data will be made available on request.

Conflict of interest statement

The authors declare there is no conflict.

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Figures

Fig. 1. Study area map showing seven sampling locations (red) and all public water points (black dots). Inset (A) shows Kushtia Sadar Upazila. The map was produced in ArcGIS 10.8 using ESRI's Topographic basemap, with additional buildings and roads data extracted from BBBike (https://extract.bbbike.org/)

Fig. 2. Physicochemical parameters of water samples collected from different PWPs in Kushtia Municipality

Fig. 3. WQI scores of PWPs in Kushtia Municipality, all above 100, indicating poor water quality across all sampling sites

Fig. 4. NPI scores for key water quality parameters across sampling sites. Parameters with NPI ≥ 1 (highlighted in red) indicate significant pollution sources affecting overall water quality

Fig. 5. Microbiological quality of PWPs in Kushtia Municipality. (a) Total and Fecal coliform counts (CFU/100 mL) across PWPs. (b) *Pseudomonas spp.* counts (CFU/100 mL). (c) Detection status of *Salmonella spp.* and *Shigella spp.*, showing absence in all samples.

Fig. 6. Current and potential uses of PWP water in Kushtia Municipality

Fig. 7. Boxplots of Knowledge, Attitude, and Practice (KAP) scores related to PWP water use

Fig. 8. Community-perceived priorities for improving the PWP water system in Kushtia Municipality. (a) system improvement and (b) water safety in water service management

Fig. 9. Public perception of (a) ingestion-related health risks and (b) self-reported symptoms associated with PWP water use

Fig. 10. Public perception of (a) health impacts and (b) reported dermatological symptoms associated with PWP water use

Fig. 11. Linkage between water quality, health risk, and community awareness. The diagram illustrates the relationships between key factors influencing water safety, including water quality issues, the WQI, health risks (infections), and community knowledge, attitude, and practices. The arrows represent how water quality issues, such as contaminants, influence health risks, which in turn affect community awareness and water treatment practices. Finally, community priorities, such as maintenance and treatment improvements, are linked to the overall water safety system.

Fig. 1

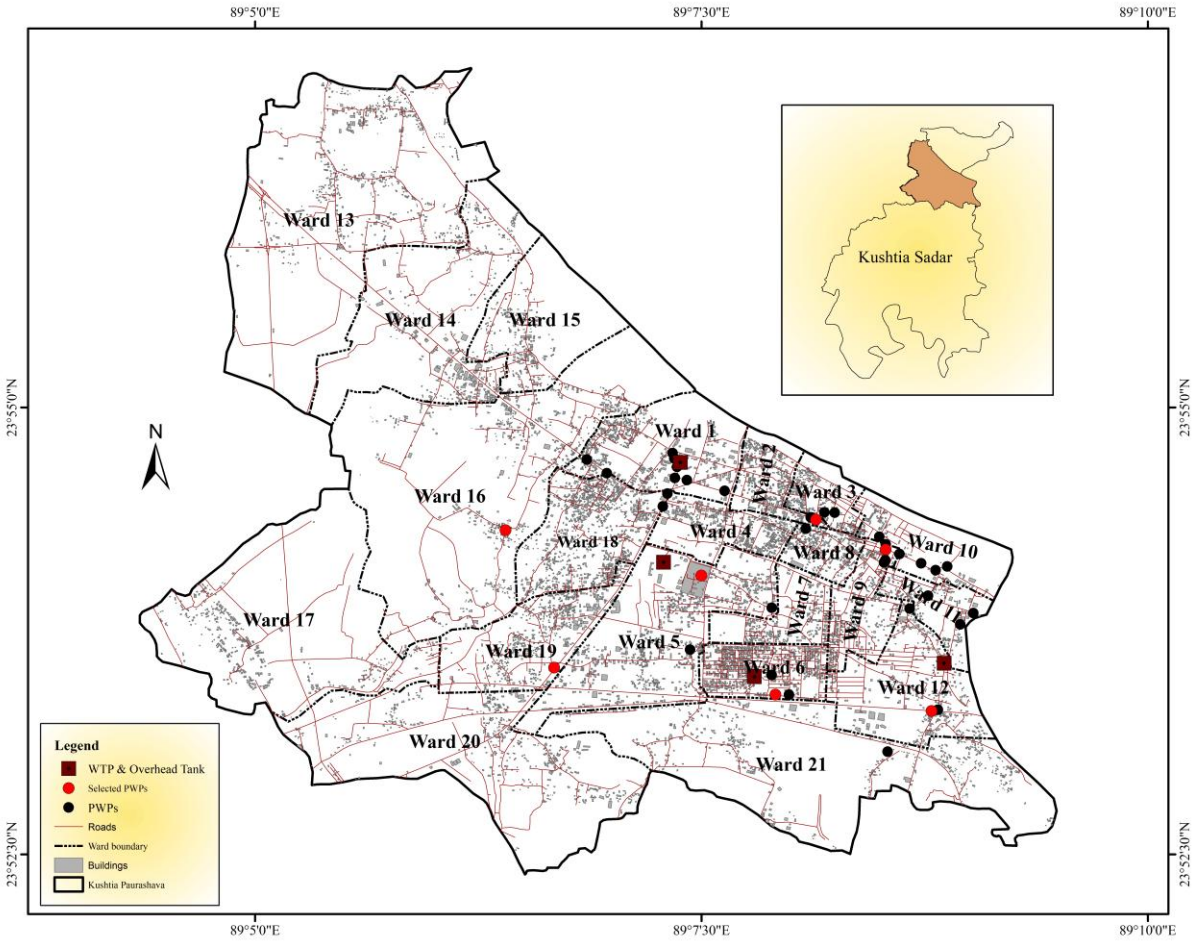
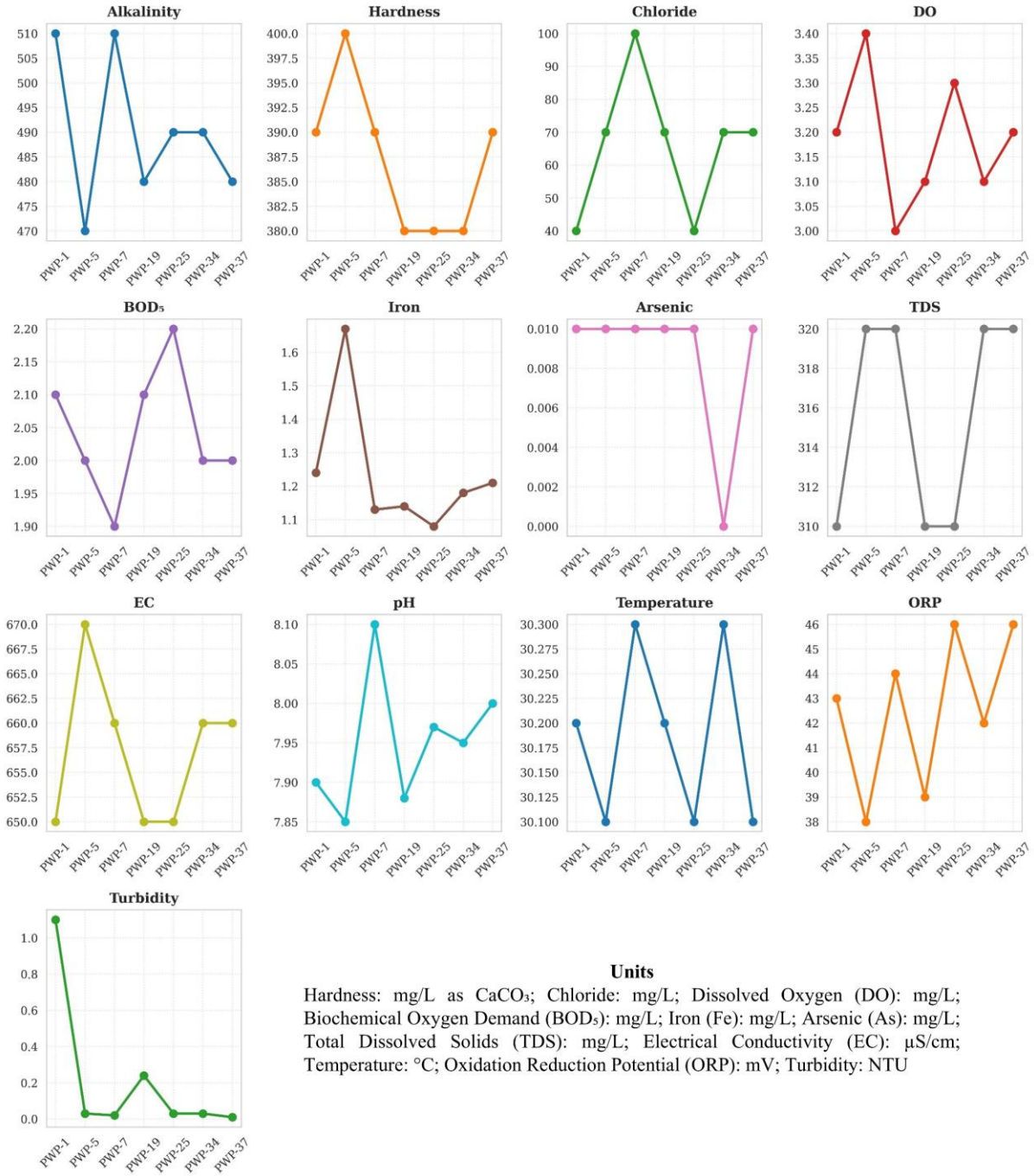

89°5'0"E
89°7'30"E
89°10'0"E
23°55'0"N
23°52'30"N
Ward 13
Ward 14
Ward 15
Ward 16
Ward 17
Ward 18
Ward 19
Ward 20
Ward 21
Ward 1
Ward 2
Ward 3
Ward 4
Ward 5
Ward 6
Ward 7
Ward 8
Ward 9
Ward 10
Ward 11
Ward 12
N
Kushtia Sadar
Legend
WTP & Overhead Tank
Selected PWPs
PWPs
Roads
Ward boundary
Buildings
Kushtia Paurashava

Fig. 2



Units

Hardness: mg/L as $CaCO_3$; Chloride: mg/L; Dissolved Oxygen (DO): mg/L; Biochemical Oxygen Demand (BOD_5): mg/L; Iron (Fe): mg/L; Arsenic (As): mg/L; Total Dissolved Solids (TDS): mg/L; Electrical Conductivity (EC): µS/cm; Temperature: °C; Oxidation Reduction Potential (ORP): mV; Turbidity: NTU

Fig. 3


All values exceed WQI threshold (100)
WQI Score
230
220
210
200
190
180
219.87
211.97
200.57
219.45
228.68
195.03
210.28
PWP-1
PWP-5
PWP-7
PWP-19
PWP-25
PWP-34
PWP-37

Fig. 4

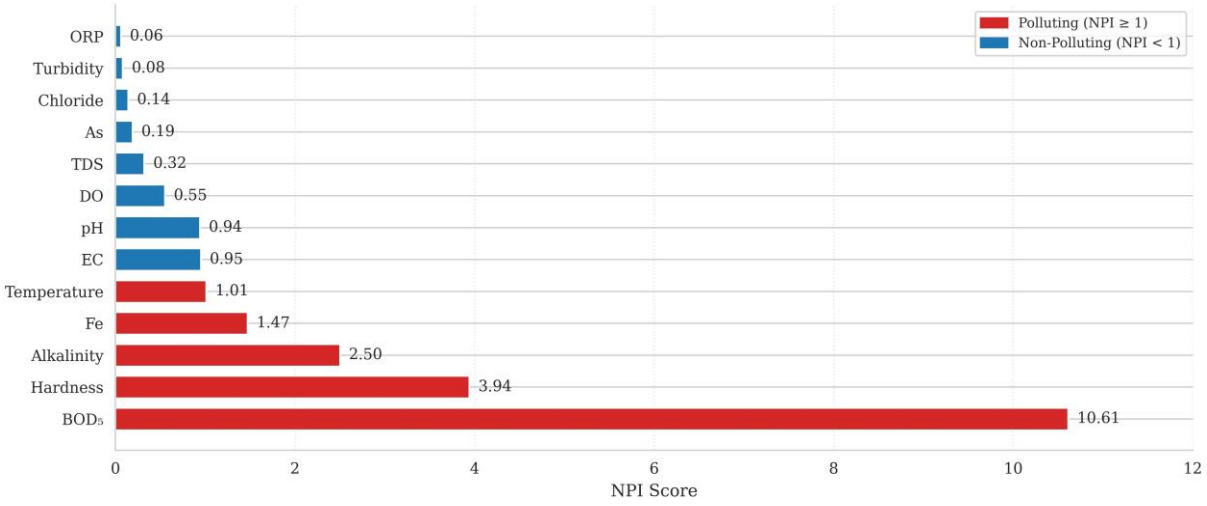

Polluting (NPI ≥ 1)
Non-Polluting (NPI < 1)
ORP
Turbidity
Chloride
As
TDS
DO
pH
EC
Temperature
Fe
Alkalinity
Hardness
BOD5
0.06
0.08
0.14
0.19
0.32
0.55
0.94
0.95
1.01
1.47
2.50
3.94
10.61
0
2
4
6
8
10
12
NPI Score

Fig. 5

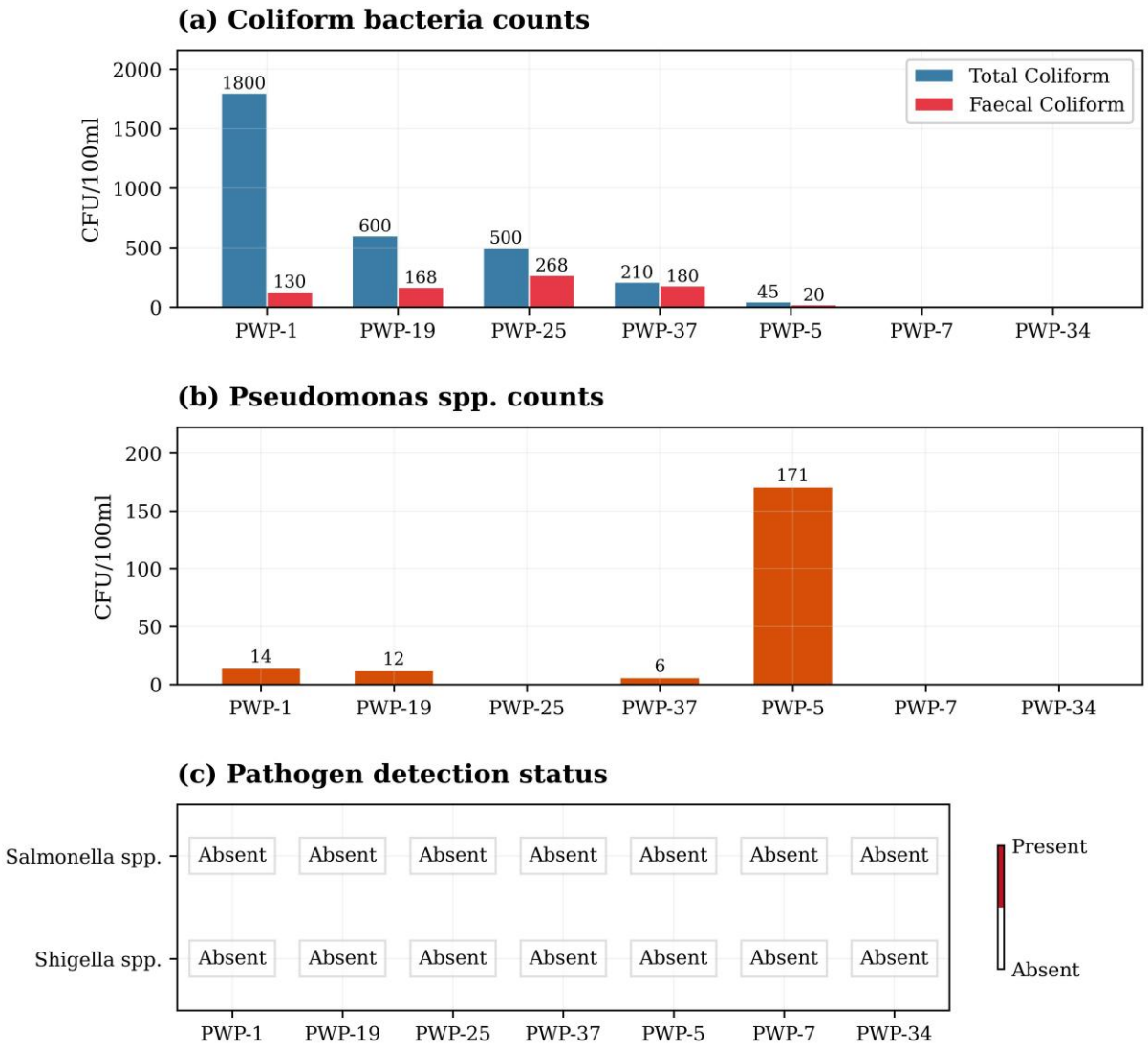
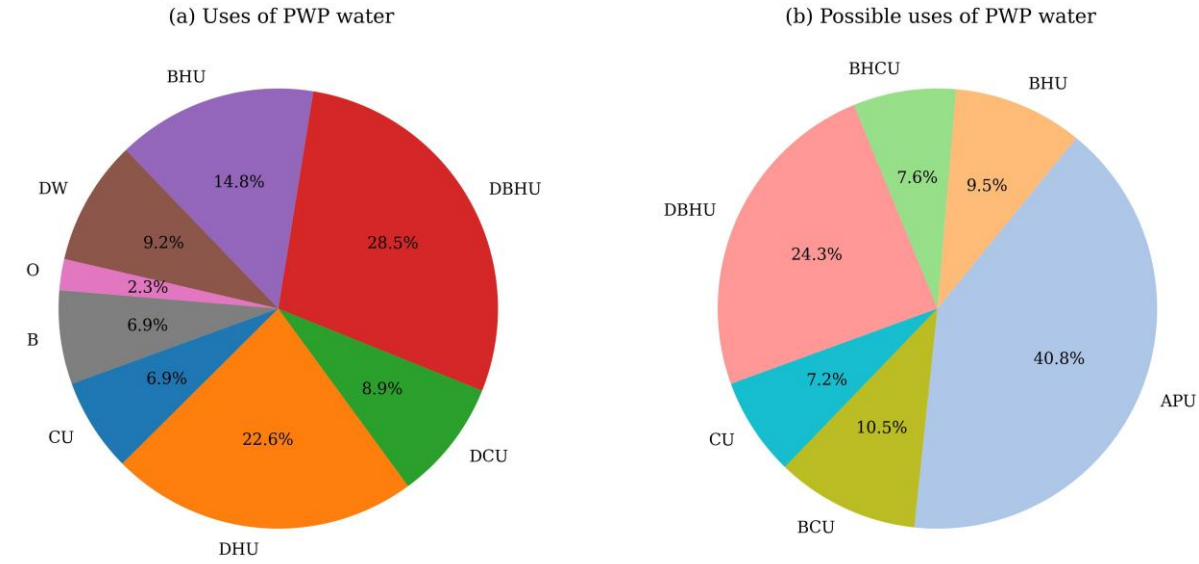

(a) Coliform bacteria counts
CFU/100ml
2000
1500
1000
500
0
Total Coliform
Faecal Coliform
1800
130
600
168
500
268
210
180
45
20
PWP-1
PWP-19
PWP-25
PWP-37
PWP-5
PWP-7
PWP-34
(b) Pseudomonas spp. counts
CFU/100ml
200
150
100
50
0
14
12
6
171
PWP-1
PWP-19
PWP-25
PWP-37
PWP-5
PWP-7
PWP-34
(c) Pathogen detection status
Salmonella spp.
Shigella spp.
Absent
PWP-1
PWP-19
PWP-25
PWP-37
PWP-5
PWP-7
PWP-34
Present
Absent

Fig. 6



Abbreviations:
CU – Commercial Use | DHU – Drinking & Household Use | DCU – Drinking & Commercial Use | DBHU – Drinking, Bathing & Household Use
BHU – Bathing & Household Use | DW – Drinking Water | O – Other | B – Bathing | BC – Bathing & Commercial Use
APU – All Possible Uses | BHCU – Bathing, Household & Commercial Use

Fig. 7

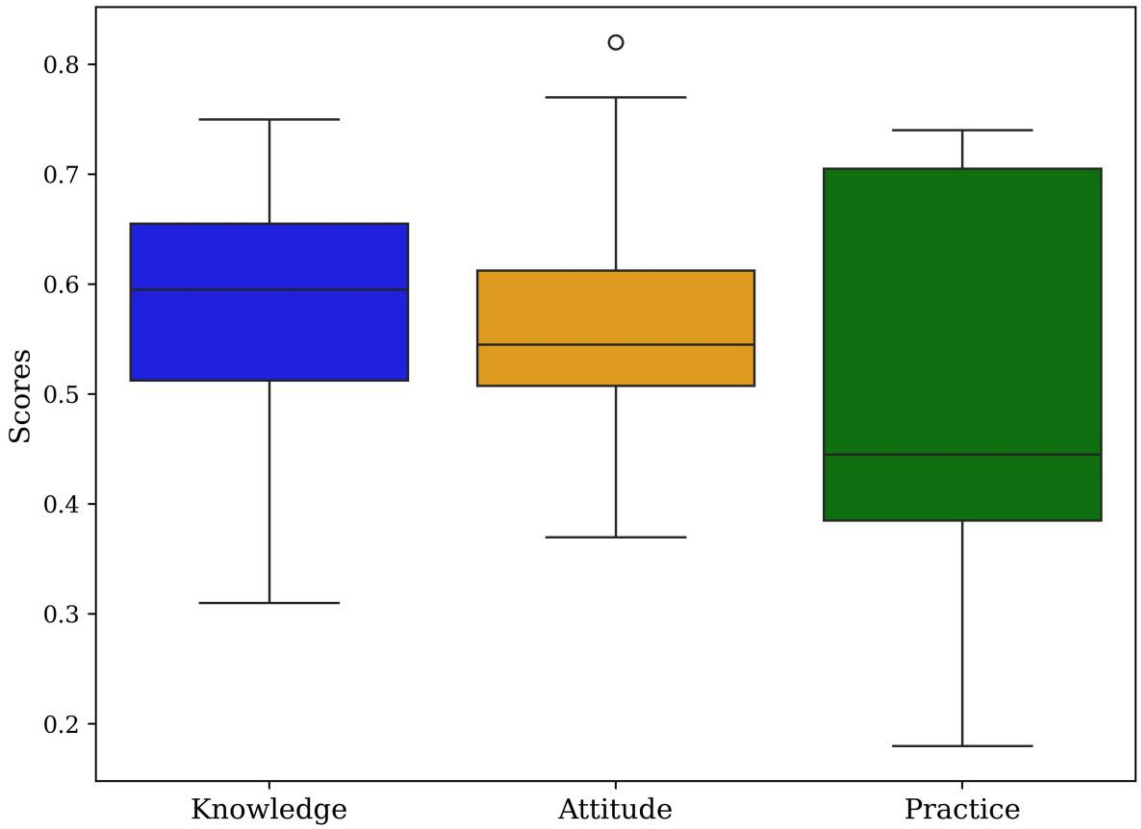


Fig. 8

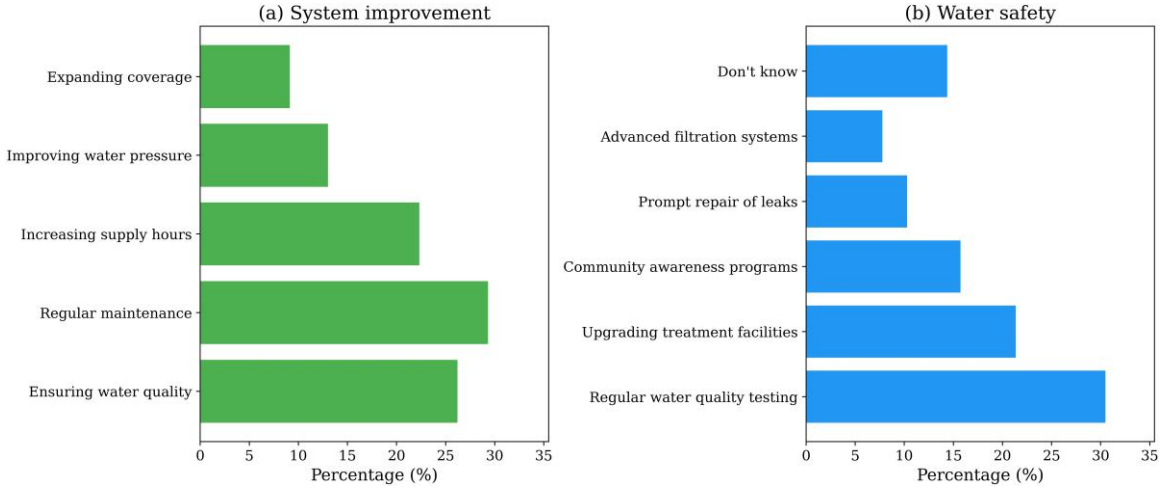

(a) System improvement
Expanding coverage
Improving water pressure
Increasing supply hours
Regular maintenance
Ensuring water quality
0 5 10 15 20 25 30 35
Percentage (%)
(b) Water safety
Don't know
Advanced filtration systems
Prompt repair of leaks
Community awareness programs
Upgrading treatment facilities
Regular water quality testing
0 5 10 15 20 25 30 35
Percentage (%)

Fig. 9

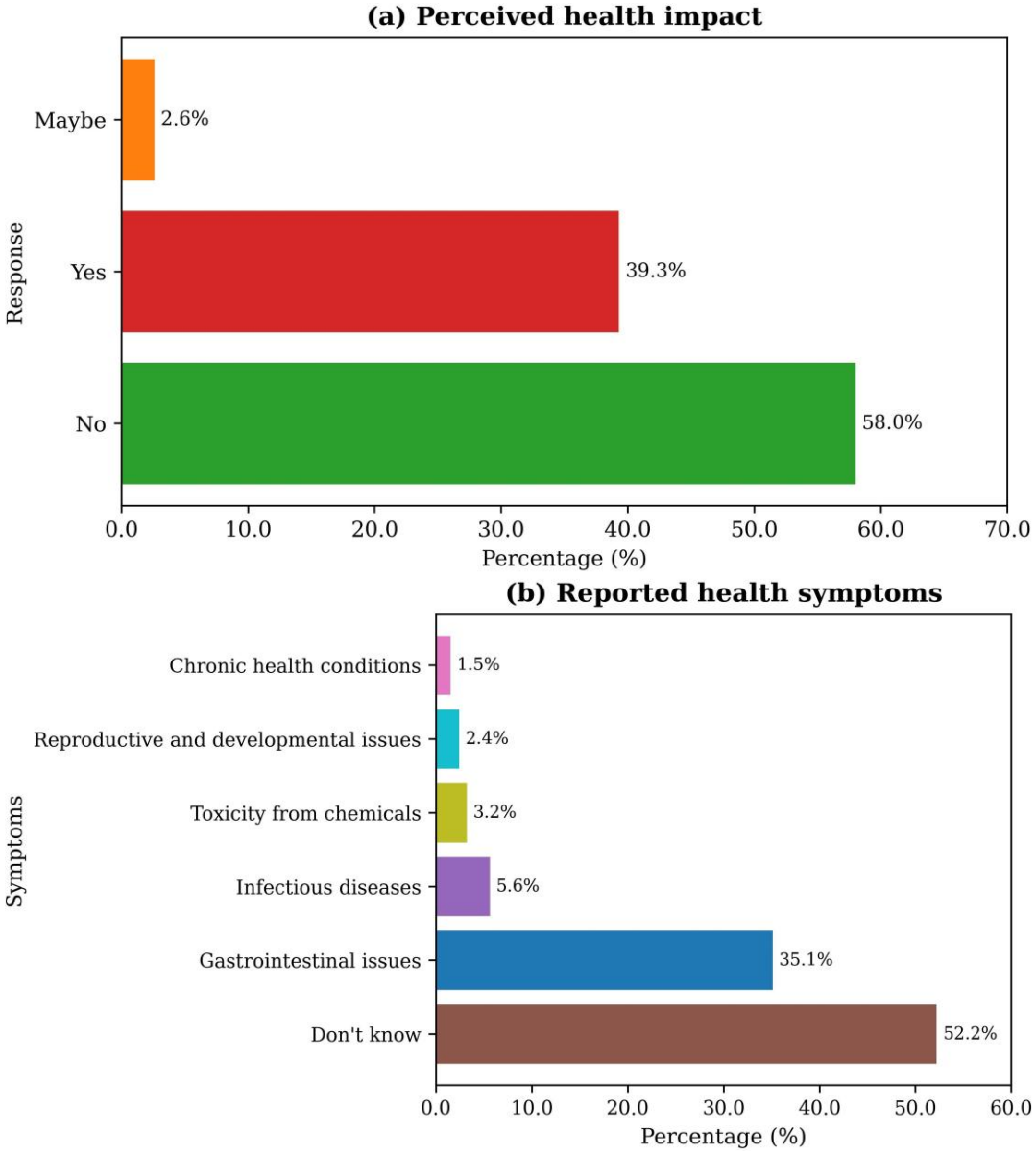

(a) Perceived health impact
Response
Maybe
Yes
No
2.6%
39.3%
58.0%
0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0
Percentage (%)
(b) Reported health symptoms
Symptoms
Chronic health conditions
Reproductive and developmental issues
Toxicity from chemicals
Infectious diseases
Gastrointestinal issues
Don't know
1.5%
2.4%
3.2%
5.6%
35.1%
52.2%
0.0 10.0 20.0 30.0 40.0 50.0 60.0
Percentage (%)

Fig. 10

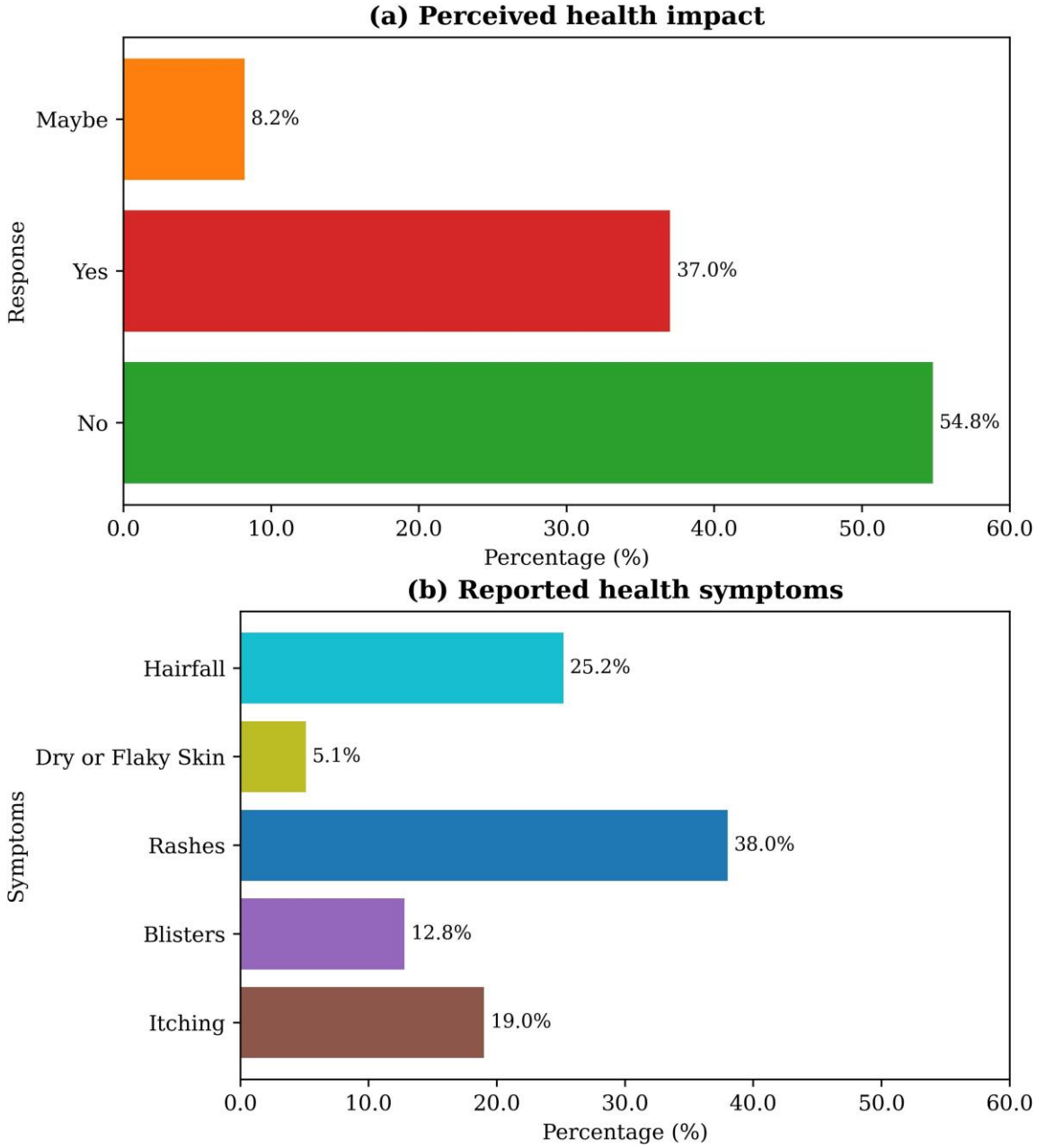
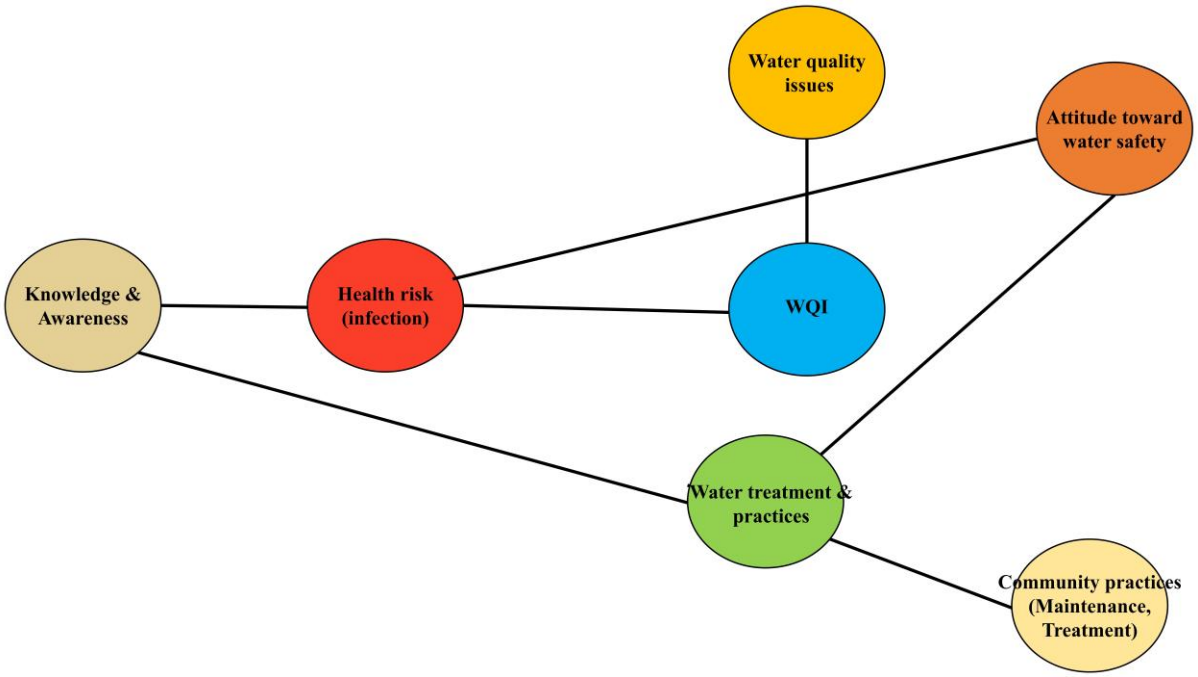

(a) Perceived health impact
Maybe
Yes
No
Response
8.2%
37.0%
54.8%
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Percentage (%)
(b) Reported health symptoms
Hairfall
Dry or Flaky Skin
Rashes
Blisters
Itching
Symptoms
25.2%
5.1%
38.0%
12.8%
19.0%
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Percentage (%)

Fig. 11



Tables

Table 1. Scoring system for Knowledge, Attitude, and Practice based on question type and response options

Table 2. Estimated daily and annual infection risks for adults and children based on microbial dose (CFU/day) from different PWP samples

Table 3. Descriptive tables of demographic variables

Table 4. Respondents' knowledge on pipeline water safety and contamination risks in Kushtia Municipality (N = 305)

Table 5. Respondents' attitude on pipeline water safety and contamination risks in Kushtia Municipality (N = 305)

Table 6. Respondent's practice on pipeline water safety and contamination risks in Kushtia Municipality (N = 305)

Table 7. Selected variables, PC loading, variance, and calculated final weight for overall KAP calculation

Table 8. Predictor-level summary (Including intercept)

Table 9. Model-level summary

982 **Table 1**

Question type	Answer	Score
Yes/No	Yes	1
	No	0
	Maybe	0.5
Likert Scale Questions	Very important	1
	Important	0.75
	Neutral	0.5
	Not important	0
Willingness/Concern/Confidence Questions	Very willing/concerned/confident	1
	Somewhat willing/concerned/confident	0.75
	Neutral	0.5
	Somewhat unwilling/unconcerned/unconfident	0.25
	Not willing/concerned/confident	0
Frequency-Based Questions	Regularly	1
	Frequently	0.75
	Occasionally	0.5
	Rarely	0.25
	Never	0

983

984 **Table 2**

	Dose (CFU/day)		Daily risk		Annual risk	
PWP no.	Adult (2L)	Children (1L)	Adult	Children	Adult	Children
PWP-7	0	0	0.00%	0.00%	0.00%	0.00%
PWP-5	400	200	9.38%	5.04%	100.00%	98.48%
PWP-37	3600	1800	52.98%	35.32%	100.00%	100.00%
PWP-34	0	0	0.00%	0.00%	0.00%	0.00%
PWP-25	5360	2680	62.99%	40.47%	100.00%	100.00%
PWP-1	2600	1300	47.32%	27.65%	100.00%	100.00%
PWP-19	3360	1680	51.15%	30.98%	100.00%	100.00%

985

986 **Table 3**

Individual-level variables	Frequency (N)	Percent (%)	Mean±SD
Age	305	-	43±14
Gender			
Male	206	67.54	
Female	99	32.46	
Education level			
No formal education	111	36.63	
Primary education (Class 1–5)	73	24.09	
Secondary education (Class 6–10, SSC or equivalent)	81	26.73	
Higher secondary education (HSC or equivalent)	25	8.25	
Undergraduate and above (Bachelor's, Master's, or higher degrees)	13	4.29	
Occupation			
Unemployed (students, homemakers)	89	29.57	
Day laborer	50	16.61	
Govt./private employee	11	3.65	

Self-employed/professional	54	17.94	
Retired	2	0.66	
Businessman	71	23.58	
Other	24	7.98	
Secondary sources of water supply			
Tube well	229	75.08	
Bottled water	42	13.77	
Tube well and surface water (Rivers, ponds, etc.)	20	6.56	
Tube well and bottled water	7	2.30	
Surface water	4	1.31	
Tube well, surface water, and bottled water	3	0.98	
Average monthly income (in Tk)	305		13990±15737
Duration of residence (in year)	305		29.44±18.49
Duration of pipeline water usage (in year)	305		10.29±10.93
Number of people directly depend on PWP water	305		7±18
Presence of children and other vulnerable groups dependent on PWP water			
Yes	211	69.18	
No	94	30.82	
Number of dependent children and other vulnerable groups on the PWP water	211		3±14

987

988 **Table 4**

Questions	**N**	**%**	**Mean score**
Do you know how the water is treated before it reaches you?			
Yes	141	46.23	0.54
No	116	38.03	
Maybe	48	15.74	
Do you think microbial contaminants (e.g., bacteria, viruses) might be present in PWP water?			
Yes	84	27.54	0.41
No	139	45.57	
Maybe	82	26.89	
Do you think chemical contaminants (e.g., arsenic, lead, iron) might be present in PWP water?			
Yes	216	70.82	0.75
No	62	20.33	
Maybe	27	8.85	
Do you think physical contaminants (e.g., sediment, rust) might be present in PWP water?			
Yes	174	57.05	0.6
No	115	37.7	
Maybe	16	5.25	
As per your knowledge, how is the quality of your accessed water?			0.53
Is the current supplied water fit for drinking?			
Yes	186	60.98	0.65
No	95	31.15	
Maybe	24	7.87	
Are you aware of any water quality standards set by the government?			
Yes	132	43.28	0.46
No	157	51.48	
Maybe	16	5.25	
Are you aware of any health risks associated with PWP water?			
Yes	156	51.15	0.59

No	102	33.44	
Maybe	47	15.41	
Are you aware of the potential health risks for children and vulnerable people groups from exposure to high levels of iron and arsenic?			
Yes	180	59.02	0.65
No	88	28.85	
Maybe	37	12.13	
Do you think that your knowledge of water safety affects your water usage?			
Yes	197	64.59	0.73
No	53	17.38	
Maybe	55	18.03	
Do you know who is responsible for maintenance, monitoring, and improving water quality in your area?			
Yes	201	65.9	0.67
No	98	32.13	
Maybe	6	1.97	
Have you taken any steps to improve your knowledge about pipeline water safety?			
Yes	88	28.85	0.31
No	204	66.89	
Maybe	13	4.26	

Table 5

Questions	**N**	**%**	**Mean score**
How satisfied are you with the quality of the water in the pipeline?			0.53
Do you believe pipeline water is safe to drink without further treatment?			
Yes	136	44.59	0.5
No	134	43.93	
Maybe	35	11.48	
How important is it to you that the water you drink is free from contaminants?			
Very Important	136	44.59	0.82
Important	117	38.36	
Neutral	52	17.05	
Not important	0	0	
Do you trust the local authorities to provide safe drinking water?			
Yes	143	46.89	0.56
No	105	34.43	
Maybe	57	18.69	
How willing are you to pay for improvements in the water supply system?			0.47
Do you believe that the current water quality poses a health risk to you and your family?			
Yes	164	53.77	0.62
No	90	29.51	
Maybe	51	16.72	
How concerned are you about the quality of your drinking water?			0.59
How confident are you in protecting yourself from waterborne diseases?			0.53
How often do you discuss water safety with family or neighbors?			
Regularly	0	0	0.37
Frequently	0	0	
Occasionally	67	21.97	
Rarely	85	27.87	
Never	80	26.23	
Do you think community awareness programs are effective in improving water safety practices?			

Yes	206	67.54	0.77
No	42	13.77	
Maybe	57	18.69	

991

992 **Table 6**

Questions	**N**	**%**	**Mean score**
Do you use any additional filtration or treatment methods for water?			
Yes	107	35.08	0.35
No	198	64.92	
How often do you clean your water storage tanks?			
Regularly	112	36.72	0.74
Frequently	110	36.07	
Occasionally	54	17.7	
Rarely	15	4.92	
Never	14	4.92	
How do you ensure the cleanliness of the containers you use for storing water?			
Regularly clean with soap and water	140	45.9	0.73
Occasionally rinse with water	73	23.93	
Clean only when visibly dirty	47	15.41	
Rarely clean the containers	13	4.27	
Never clean the containers	32	10.49	
Do you regularly check the color, taste, and smell of the water before using it?			
Yes	225	73.77	0.74
No	80	26.23	
How do you react when your drinking water appears cloudy or has an unusual smell?			
Discard it and find another safe source	87	28.52	0.63
Try to treat it (e.g., filter, boil) before drinking	207	67.87	
Drink it anyway	11	3.61	
How often do you drink water directly from the pipeline without boiling or filtering it?			
Never	46	15.08	0.38
Rarely	34	11.15	
Sometimes	78	25.57	
Often	19	6.23	
Always	128	41.97	
Have you ever reported a water quality issue to the local authorities?			
Yes	121	39.67	0.40
No	184	60.33	
Do you actively educate others about water safety and hygiene practices?			
Yes	47	15.41	0.18
No	243	79.67	
Maybe	15	4.92	
How often do you take action based on your concerns about water quality?			
Always	69	22.62	0.43
Often	16	5.25	
Sometimes	85	27.87	
Rarely	34	11.15	
Never	101	33.11	
Have you ever participated in a community initiative or program designed to improve local water quality?			

Yes	28	9.18	0.46
No	31	10.16	
Not available, but I would join if it happens	246	80.66	

Table 7

Variable	PC1 Loading	PC2 Loading	PC3 Loading	Weight (PC1)	Variance Explained
Knowledge	0.68	-0.29	-0.67	0.437876	0.53 (PC1)
Attitude	0.71	0.06	0.7	0.457566	0.34 (PC2)
Practice	0.16	0.96	-0.25	0.104558	0.13 (PC3)

Table 8

Variable	Predictor variable	Knowledge	Attitude	Practice	Combined KAP
Age		0.0004	-0.0003	-0.0001	0
Average monthly income		0	0.0.	0	0
Duration of residence in Kushtia Municipality		-0.0012.	-0.0009	-0.0021**	-0.0014*
Gender	Male	0.0394	0.044	0.0154	0.0329
	Female	-0.0269	-0.4248*	-0.1615	-0.2044.
Education level	No formal education	-0.0088	-0.0144	-0.0262	-0.0165
	Primary education (Class 1–5)	-0.0422	-0.0104	-0.1094*	-0.054
	Secondary education (Class 6–10, SSC or equivalent)	-0.0036	0.0334	-0.0766.	-0.0156
	Higher secondary education (HSC or equivalent)	0.0047	0.075	-0.0347	0.0136
	Undergraduate and above (Bachelor's, Master's, or higher degrees)	0.0053	0.084	-0.0122	0.0257
Occupation	Unemployed (students, homemakers)	0.0137	0.1484*	0.038	0.0667.
	Day laborer	-0.0075	0.0264	-0.0097	0.003
	Govt./private employee	-0.0119	-0.1236	-0.0499	-0.0618
	Self-employed/professional	0.0659*	0.0995.	-0.0495	0.0386
	Retired	0.0743	0.0816	-0.1409	0.005
	Businessman	0.034	0.0923	-0.3476	0.0023
	Other	-0.0691.	-0.0171	-0.0206	-0.0356
Years using pipeline water		0.0011	0.0021	0.004***	0.0024*
Intercept (const)		0.7736***	1.3309***	0.6529***	0.9191***
*** = p < 0.001; ** = p < 0.01; * = p < 0.05; . = p < 0.1; *(No mark)* = Not significant					

Table 9

Model	Intercept (const)	R^2	Adj. R^2	F-statistic	F p-value
Knowledge	0.7736	0.0911	0.0396	1.7675	0.0352
Attitude	1.3309	0.0987	0.0476	1.9308	0.0178
Practice	0.6529	0.1508	0.1026	3.1290	0.0001
Combined KAP	0.9191	0.1176	0.0675	2.3485	0.0028

Supplementary Files

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- Supplementaryfilesv1.1.docx