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From Source to Storage: Point-of-Use Drinking-Water Contamination, Household WASH, and Under-5 Morbidity in Sylhet, Bangladesh

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Abstract: Child morbidity among children under five in Bangladesh is closely associated with household water, sanitation, and hygiene (WASH). However, access to an improved water source does not guarantee microbiologically safe drinking water, as faecal contamination may occur after collection during transport, handling, and storage. This study assessed the "source-to-storage" pathway during the transition from monsoon to post-monsoon in urban and rural settings in Sylhet, Bangladesh. We conducted a two-round household panel study from August to November 2025 in Sylhet Sadar, Companiganj, and Beanibazar, enrolling 300 households (100 per upazila) with at least one child aged 0-59 months. Child morbidity was recorded using established case definitions (primary outcome: diarrhoea; secondary outcomes: acute respiratory symptoms and fever) within a standardized recall interval. WASH exposures were assessed using a structured questionnaire and direct observations of sanitation functionality, handwashing readiness (availability of soap and water), and safe water storage practices. Paired drinking-water samples were collected from the primary water source and household point-of-use stored water in each round and analyzed for *Escherichia coli* using membrane filtration with selective media and 24-hour incubation, reporting colony-forming unit (CFU) counts per 100 mL. We delineated spatial contamination patterns, quantified recontamination between source and storage, and estimated adjusted associations between WASH indicators, *E. coli* levels, and morbidity using multilevel regression models accounting for clustering and repeated household measurements. These findings identify where contamination is introduced along the source-to-storage continuum and highlight which household WASH components are most strongly associated with morbidity among children under five in Sylhet.

Keywords: WASH; Source-to-storage; Point-of-use; *Escherichia coli*; Diarrhoea; Bangladesh

1. Introduction

Child morbidity in Bangladesh remains strongly linked to household water, sanitation, and hygiene (WASH), especially among children under five who experience high exposure to enteric pathogens and are at increased risk of dehydration, malnutrition, and secondary infections **(Troeger et al., 2018; Prüss-Ustün et al., 2019; Kuddus et al., 2022)**. Despite progress in expanding access to improved drinking-water sources and sanitation, reductions in child morbidity have not consistently mirrored improvements in service coverage. One reason is that infrastructure-based categories (e.g., "improved" source) are imperfect proxies for actual microbial exposure within households. Multiple exposure routes operate within and around the home, including unsafe water collection and handling, faecal contamination of household environments, and inadequate hygiene conditions such as lack of soap and water at accessible handwashing locations **(Curtis & Cairncross, 2003; Freeman et al., 2014)**.

A core explanation for variable health gains from water services is the "source-to-storage" pathway: water that is comparatively safer at the source can become contaminated during collection, transport, storage, and serving, through contact with hands, utensils, container interiors, and the surrounding household environment. Evidence from diverse low- and middle-income settings shows that microbial quality frequently deteriorates between the source and point of use, suggesting that interventions focused only on source improvements may fail to control exposure at consumption **(Wright et al., 2004)**. Reviews also indicate that household water treatment and safe storage can reduce diarrheal risk, but observed effectiveness depends on correct and sustained use and can be difficult to maintain at scale **(Clasen et al., 2007; Brown & Clasen, 2012)**.

Microbial indicators, particularly *Escherichia coli*, are widely used operational markers of faecal contamination in drinking water and can be used to delineate exposure gradients relevant to child health outcomes **(World Health Organization [WHO], 2017)**. While *E. coli* is not the only cause of diarrhea, its detection signals faecal contamination and potential presence of enteric pathogens. Combining quantitative microbial measures with observed WASH conditions strengthens interpretation by helping differentiate risks originating at the source from those introduced through household handling and storage, and by making "recontamination" measurable rather than assumed **(WHO, 2017; Bauza et al., 2019)**.

Seasonality and climate-sensitive vulnerabilities are especially important in northeastern Bangladesh **(Sunny et al., 2020; Dutta et al., 2026)**. Sylhet experiences heavy rainfall, waterlogging in some areas, and hydrological variation that can influence drinking-water quality, sanitation functionality, and household coping behaviors during the monsoon and post-monsoon periods **(Islam et al., 2025)**. The monsoon-to-post-monsoon transition may shift contamination risks through runoff and faecal loading, disruptions to infrastructure, changes in source selection, and longer storage times when access becomes constrained **(Levy et al., 2016; Yeasmin et al., 2022)**. Yet locally grounded evidence in Sylhet that simultaneously evaluates household WASH conditions, microbial drinking-water quality at both source and point of use, and under-five morbidity across contrasting settings remains limited.

This study therefore examined household WASH conditions, paired source and stored-water *E. coli* contamination, and under-five morbidity in Sylhet during the monsoon-to-post-monsoon transition. By applying a two-round panel design in Sylhet Sadar, Companiganj, and Beanibazar and integrating direct observations with microbiological indicators, the study aimed to identify where contamination is introduced along the drinking-water chain and which exposure-proximal household conditions are most strongly associated with diarrheal morbidity.

2. Methodology

2.1 Study design and period

A two-round household panel design was implemented to assess the "source-to-storage" pathway linking household WASH conditions, microbial drinking-water quality, and under-five morbidity during the monsoon-to-post-monsoon transition in Sylhet, Bangladesh. Data collection was conducted from August to November 2025, with Round 1 during late monsoon and Round 2 during post-monsoon. The panel structure enabled within-household comparison across rounds while maintaining feasibility under a modest sample size. Reporting followed STROBE guidance for observational studies **(von Elm et al., 2007)**.

2.2 A Study area and site selection

The study was conducted in three upazilas of Sylhet district: Sylhet Sadar, Companiganj, and Beanibazar. These sites were purposively selected to represent contrasting urban/peri-urban, hard-to-reach, and rural contexts within the same administrative region, capturing heterogeneity in water access, sanitation environments, hygiene readiness, and household water handling that may influence microbial contamination between the source and point of use **(Wright et al., 2004; Kretchy et al., 2025)**.

2.3 Study population and eligibility

Eligible households had at least one child aged 0-59 months residing in the household at enrollment. The primary caregiver served as the respondent for household and child health modules. Households were excluded if consent was not provided or if relocation outside the study area during follow-up was anticipated. In households with more than one under-five child, a single index child was selected using a consistent rule (e.g., the youngest) to avoid non-independence of outcomes within the household.

2.4 Sample size and sampling strategy

A total of 300 households were enrolled, with 100 households from each upazila. Within upazilas, a multistage cluster sampling approach was used. Clusters were selected from appropriate local administrative units (villages in rural settings; wards/mahallas in urban/peri-urban settings). Household listing within clusters identified households with under-five children, and eligible households were selected using systematic or simple random sampling until targets were achieved. Comparative analyses across upazilas were planned, with clustering and repeated measurements handled analytically **(von Elm et al., 2007; Lu et al., 2016)**.

2.5 WASH exposure measurement

WASH exposures were assessed using a structured caregiver questionnaire and standardized spot-check observations conducted by trained field staff. The questionnaire captured drinking-water source type and access, collection and transport, household water treatment, storage duration, and handling behaviors, alongside sanitation facility type, sharing status, and reported use. Because self-reported hygiene behaviors can be biased by social desirability and recall, spot-checks were used to measure exposure-proximal conditions, including whether a designated handwashing place existed and whether both soap and water were present at the time of visit **(Freeman et al., 2014)**. Water and sanitation service categories were classified using internationally recognized improved/unimproved typologies while acknowledging that service category does not guarantee microbiological safety at consumption **(WHO, 2017; WHO & UNICEF, 2021)**.

2.6 Child morbidity outcome measurement

Child morbidity was measured by caregiver report using standard case definitions applied consistently across rounds. The primary outcome was diarrhoea, defined as three or more loose or watery stools in a 24-hour period during the recall window **(WHO, 2017; Khan et al., 2025)**. Secondary outcomes included fever and an acute respiratory symptom complex (e.g., cough accompanied by difficult or rapid breathing) recorded during the same recall window, recognizing that symptom-based definitions are imperfect but widely used in field epidemiology.

2.7 Drinking-water sampling and microbiological analysis

To quantify faecal contamination along the source-to-storage pathway, paired water samples were collected in each round from (i) the household's primary drinking-water source and (ii) stored point-of-use water (the container from which water was actually consumed). Samples were collected using sterile containers and aseptic technique, transported under cooled conditions where feasible, and processed within accepted holding times for indicator testing. *E. coli* was enumerated and reported as CFU per 100 mL using membrane filtration with selective or differential media and approximately 24-hour incubation at 35-37°C **(International Organization for Standardization [ISO], 2014; APHA et al., 2017)**. Interpretation followed WHO guidance regarding *E. coli* as an indicator of faecal contamination and drinking-water health risk **(WHO, 2017)**.

2.8 Data quality assurance

Field quality assurance included enumerator training, tool piloting, standard operating procedures, and supervision. Microbiological QA/QC included routine blanks and periodic duplicates, incubator temperature monitoring, and documentation of media and batch information consistent with standard indicator testing practice **(ISO, 2014; APHA et al., 2017)**. Data were captured using structured forms and subjected to range/logic checks.

2.9 Statistical analysis

Analyses summarized household characteristics, WASH indicators, observed handwashing readiness, and *E. coli* contamination at both source and point of use by upazila. Recontamination was quantified by comparing paired source and stored-water measurements within household-visits. Multilevel regression models were used to estimate adjusted associations between WASH indicators, *E. coli* levels, and diarrhoea while accounting for clustering and repeated measurements. Models included a priori confounders (child age, caregiver education, household wealth, crowding, and flooding/waterlogging) and terms for upazila and seasonal round. Seasonal effect modification was explored to assess whether associations differed between late monsoon and post-monsoon, consistent with evidence that hydrometeorological dynamics can shift contamination pathways **(Levy et al., 2016; Sentamu et al., 2023)**.

2.10 Ethical considerations

Ethical approval was obtained from an appropriate institutional review committee prior to implementation. Written informed consent was obtained from caregivers. Personal identifiers were separated from analytic datasets to protect confidentiality. A risk communication protocol provided practical guidance on safe handling and storage where contamination was detected, consistent with public health risk management principles **(WHO, 2017; Islam et al., 2023)**.

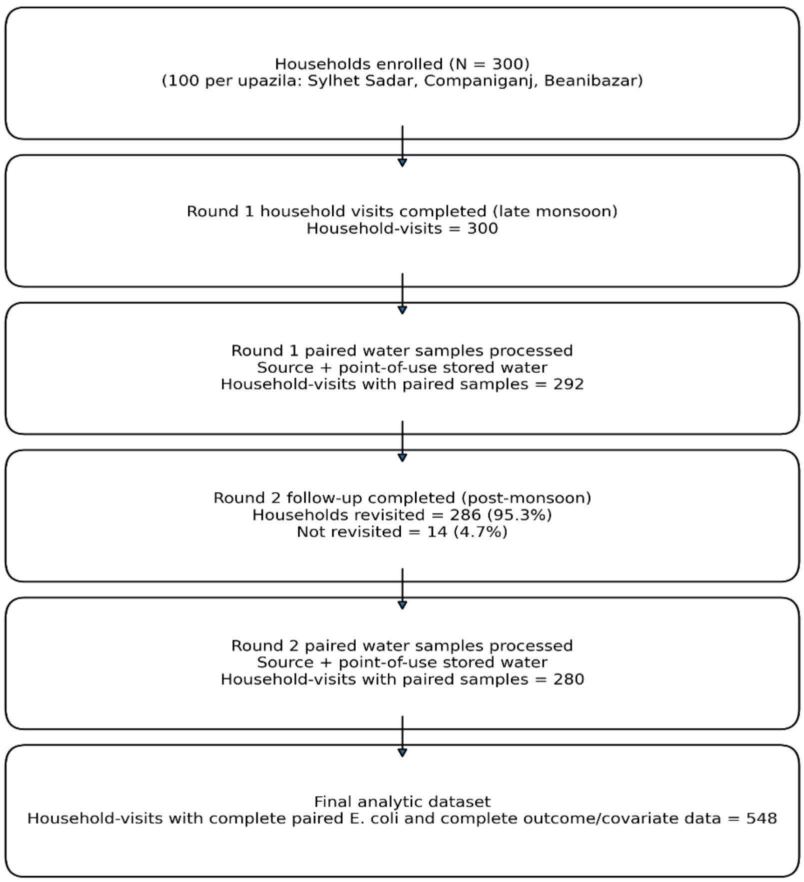

Figure 1. Study flow diagram and completeness of paired water sampling and morbidity outcomes.

3. Results and Discussion

3.1 Participant flow and analytic sample

A total of 300 households were enrolled across Sylhet Sadar, Companiganj, and Beanibazar (100 households per upazila). Round-2 follow-up was completed for 286 households (95.3%), while 14 households (4.7%) were not revisited due to temporary unavailability or migration. Paired microbiological samples were processed for 292 household-visits in Round 1 and 280 household-visits in Round 2. The final analytic dataset used for adjusted models included 548 household-visits with complete paired *E. coli* results and complete morbidity and covariate data required for multivariable analyses.

3.2 Household and child characteristics

Household and child characteristics were broadly comparable across upazilas (Table 1). Index children had a mean age of 27.8 months (SD 16.1), and 48.7% were female. Caregiver education was highest in Sylhet Sadar and lower in Companiganj and Beanibazar. Crowding was highest in Companiganj. Flooding or waterlogging in the prior 30 days was reported by 31.7% overall and was more common in Companiganj than Sylhet Sadar, supporting its inclusion in adjusted models as an exposure-relevant contextual variable.

Table 1. Household WASH conditions, microbial drinking-water quality, and under-five morbidity by upazila

Variable	Sylhet Sadar (n=100)	Companiganj (n=100)	Beanibazar (n=100)	Total (n=300)
Index child age (months), mean (SD)	28.1 (16.3)	27.4 (15.9)	27.8 (16.1)	27.8 (16.1)
Female child, n (%)	49 (49.0)	47 (47.0)	50 (50.0)	146 (48.7)
Caregiver education (years), mean (SD)	7.8 (3.6)	6.4 (3.9)	6.9 (3.7)	7.0 (3.8)
Crowding (persons/room), mean (SD)	3.1 (1.2)	3.4 (1.3)	3.2 (1.2)	3.2 (1.2)
Flooding/waterlogging (last 30 days), n (%)	28 (28.0)	36 (36.0)	31 (31.0)	95 (31.7)
Improved drinking-water source, n (%)	85 (85.0)	78 (78.0)	82 (82.0)	245 (81.7)
Improved sanitation functional (observed), n (%)	73 (73.0)	64 (64.0)	68 (68.0)	205 (68.3)
Handwashing readiness observed (soap + water), n (%)	61 (61.0)	48 (48.0)	55 (55.0)	164 (54.7)
Safe storage observed (covered container), n (%)	69 (69.0)	56 (56.0)	61 (61.0)	186 (62.0)
Source water *E. coli* (CFU/100 mL), median (IQR)	5 (1–18)	12 (3–38)	8 (2–27)	8 (2–27)
Stored water *E. coli* (CFU/100 mL), median (IQR)	25 (6–90)	55 (12–180)	35 (8–120)	38 (9–140)
Stored *E. coli* > source *E. coli*, n (%)	62 (62.0)	71 (71.0)	66 (66.0)	199 (66.3)
Diarrhoea (recall period), n (%)	14 (14.0)	18 (18.0)	16 (16.0)	48 (16.0)
Fever (recall period), n (%)	22 (22.0)	26 (26.0)	24 (24.0)	72 (24.0)
Acute respiratory symptoms (recall period),	12 (12.0)	14 (14.0)	13 (13.0)	39 (13.0)

Variable	Sylhet (n=100)	Sadar Companiganj (n=100)	Beanibazar (n=100)	Total (n=300)
n (%)				

Notes: Handwashing readiness defined as observation of both soap and water at a designated handwashing location. Safe storage defined as observation of a covered drinking-water storage container. CFU = colony-forming units; IQR = interquartile range.

3.3 WASH conditions and exposure-proximal practices

Improved drinking-water source access was common (81.7% overall), but exposure-proximal indicators assessed through observation showed more variability (Table 1). Functional improved sanitation was observed in 68.3% overall, with higher prevalence in Sylhet Sadar than in Companiganj. Handwashing readiness defined as observed availability of both soap and water was present in 54.7% overall and was lowest in Companiganj. Safe storage (covered containers) was observed in 62.0% of households overall. These observed conditions were treated as stronger proxies for exposure control than self-reported behavior alone and were emphasized in inferential analyses.

3.4 Microbial water quality at source and point of use

E. coli contamination differed markedly between source water and stored point-of-use water (Table 1; Figure 2). Median source-water contamination was lowest in Sylhet Sadar (5 CFU/100 mL; IQR 1-18) and highest in Companiganj (12; IQR 3-38). In contrast, median stored-water contamination exceeded source contamination in all upazilas, with the highest stored-water median in Companiganj (55; IQR 12-180). Overall, stored-water contamination exceeded source-water contamination in 66.3% of observations, indicating frequent post-collection recontamination.

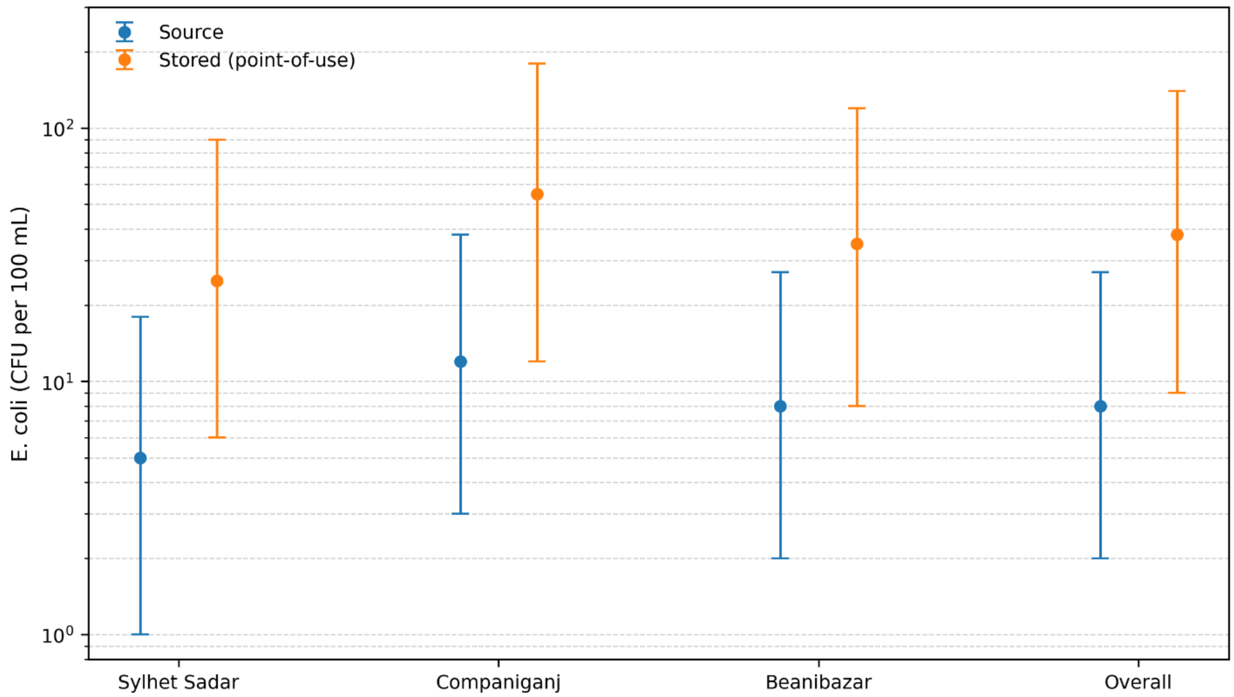

Figure 2. *E. coli* contamination at source and point-of-use stored water by upazila (median and IQR; log scale).

3.5 Recontamination frequency across settings

Recontamination defined as stored point-of-use *E. coli* exceeding the paired source value occurred in 66.3% overall and was most common in Companiganj (71%) (Table 1; Figure 3). This pattern indicates that household-level handling and storage processes likely contributed substantially to microbial exposure at consumption, even where improved sources were common.

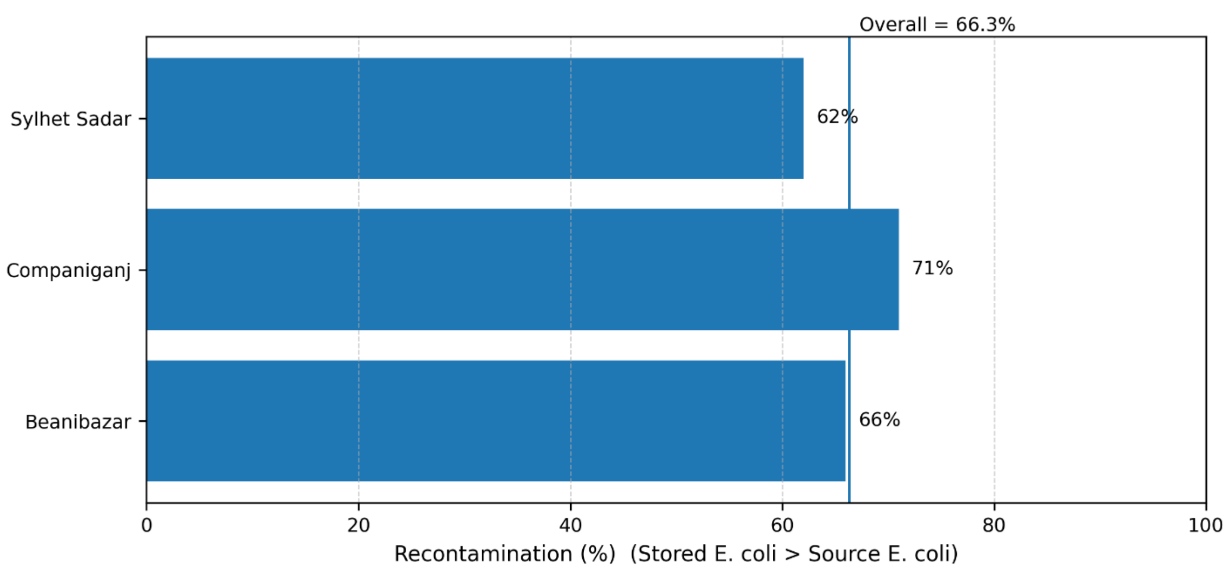

Figure 3. Proportion of household-visits with recontamination (stored point-of-use *E. coli* > source *E. coli*).

3.6 Under-five morbidity patterns

Diarrhea prevalence during the recall period was 16.0% overall, ranging from 14% in Sylhet Sadar to 18% in Companiganj (Table 1). Fever occurred in 24.0% and acute respiratory symptoms in 13.0%. Secondary outcomes were interpreted cautiously given their lower specificity to faecal–oral transmission pathways compared with diarrhea.

3.7 Adjusted associations with under-five diarrhoea

In multilevel regression models accounting for clustering and repeated household measurements, higher stored point-of-use *E. coli* contamination was associated with higher odds of diarrhoea (aOR 1.55 per log10 increase in CFU/100 mL; 95% CI 1.22-1.97; p<0.001) (Table 2). Source-water *E. coli* showed a weaker and non-significant association with diarrhoea (aOR 1.10; 95% CI 0.88-1.36; p=0.39). Observed handwashing readiness was associated with lower odds of diarrhoea (aOR 0.68; 95% CI 0.49–0.94; p=0.02), as was covered storage (aOR 0.72; 95% CI 0.53-0.99; p=0.04). Functional improved sanitation was protective in direction but not statistically significant (aOR 0.84; 95% CI 0.61-1.17; p=0.30). Seasonal round was near null (aOR 0.91; 95% CI 0.69-1.21; p=0.52).

Table 2. Multilevel adjusted associations with under-five diarrhoea

Predictor	Adjusted OR	95% CI	p-value
Stored water *E. coli* (per log10 increase CFU/100 mL)	1.55	1.22–1.97	<0.001
Source water *E. coli* (per log10 increase CFU/100 mL)	1.10	0.88–1.36	0.39
Handwashing readiness observed (soap + water: yes, vs no)	0.68	0.49–0.94	0.02
Safe storage observed (covered container: yes, vs no)	0.72	0.53–0.99	0.04
Improved sanitation functional (yes vs no)	0.84	0.61–1.17	0.30
Post-monsoon vs late monsoon (Round 2 vs Round 1)	0.91	0.69–1.21	0.52
Upazila: Companiganj vs Sylhet Sadar	1.18	0.86–1.63	0.31
Upazila: Beanibazar vs Sylhet Sadar	1.05	0.77–1.44	0.75
Child age (per 12-month increase)	0.92	0.82–1.03	0.14
Caregiver education (per year)	0.97	0.93–1.01	0.11
Wealth index (per quintile increase)	0.95	0.84–1.07	0.41
Crowding (persons/room)	1.08	0.98–1.20	0.12
Flooding/waterlogging (yes vs no)	1.20	0.89–1.61	0.23

Notes: OR = odds ratio; CI = confidence interval; CFU = colony-forming units. Models accounted for clustering and repeated household measurements and adjusted for listed covariates.

4. Discussion

This study assessed a key exposure pathway often under-captured by standard WASH coverage indicators: contamination introduced between water source and consumption. Paired measurements showed that stored point-of-use water was substantially more contaminated than source water across upazilas, with two-thirds of paired observations exhibiting recontamination (stored *E. coli* > source *E. coli*). Importantly, diarrhoea risk tracked more closely with point-of-use microbial quality than with source contamination; stored-water *E. coli* was significantly associated with diarrhoea (aOR 1.55 per log10 increase), while source-water *E. coli* was not. This pattern supports the practical implication that "improved source" coverage alone is an incomplete proxy for the microbial safety of what children actually drink and aligns with evidence that water quality frequently deteriorates after collection due to household handling and storage **(Wright et al., 2004; WHO, 2017).**

Observed handwashing readiness and covered storage were independently associated with lower odds of diarrhoea, reinforcing that feasible enabling conditions at the household level can reduce exposure. Observation-based indicators are particularly valuable because self-reported hygiene behaviors can be inflated by social desirability, whereas spot-checks capture whether soap and water are actually available at the time of visit **(Freeman et al., 2014).** The protective associations for handwashing readiness and safe storage are also biologically coherent with the recontamination signal: contamination introduced during storage and dispensing is plausibly reduced when storage is covered and when hand hygiene is feasible. Functional improved sanitation showed a protective direction but was not statistically significant, consistent with the reality that sanitation benefits may partly operate through community-level externalities and environmental pathways not fully captured by household-only indicators or short follow-up windows **(Luby et al., 2018; Humphrey et al., 2019).**

Seasonal round was near null after adjustment, suggesting that persistent household-level recontamination mechanisms and cross-context differences contributed more strongly to diarrhoea risk than short-term seasonal shifts during this study period. From a program standpoint, these findings argue for strengthening the "last meter" of water safety through protected storage and dispensing, container hygiene routines, and sustained soap-and-water availability, while maintaining attention to sanitation functionality and flooding/waterlogging conditions that can intensify reliance on storage **(WHO, 2017; WHO & UNICEF, 2021).** Limitations include caregiver-reported morbidity and *E. coli* as an indicator rather than pathogen-specific assays, potential residual confounding, and the restricted seasonal window; therefore, results should be interpreted as adjusted associations rather than causal estimates **(Islam et al., 2020; Huda et al., 2021; Izah & Ogwu, 2025).**

4. Conclusions

Drinking-water safety in Sylhet was strongly shaped by post-collection processes: stored point-of-use water was frequently more contaminated than source water, and under-five diarrhoea was more strongly associated with point-of-use *E. coli*, observed handwashing readiness, and covered storage than with source contamination alone. These findings support WASH strategies that complement source improvements with practical household-level controls to reduce recontamination protected storage and dispensing, container hygiene, and reliable soap-and-water availability alongside sanitation functionality and targeted risk management during periods of flooding or access disruption. Future studies incorporating pathogen-specific assays and broader seasonal coverage would strengthen inference and guide intervention timing and targeting.

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Author Contribution
The authors were involved in the creation of the study design, data analysis, and execution stages. Every writer gave their consent after seeing the final work.

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A statement of conflicting interests
The authors declare that none of the work reported in this study could have been impacted by any known competing financial interests or personal relationships.

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