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Foodborne pathogens contamination status of weaning foods, drinking water and domestic surfaces in a low-income settlement in Dhaka, Bangladesh

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Abstract

Weaning food contamination can occur through multiple environmental pathways, including contact with dirty hands, food, unsafe water, soil, flies, or domestic animals. This study assessed pathogen contamination in weaning foods, drinking water, and domestic surfaces in an urban informal settlement in Dhaka, Bangladesh to better understand household exposure risks. We conducted a mixed-method cross-sectional study in 32 households with children aged 6–24 months. Samples (n = 197) were collected to detect major foodborne pathogens using real-time qPCR. Structured observations and qualitative interviews (FGD, IDI, SSI) documented food preparation, storage, reheating, utensil cleaning, water use, and household hygiene practices. Overall, 44% of drinking water, 33% of food, and 80% of domestic surface swabs tested positive for at least one targeted pathogen. *Vibrio cholerae*, *Bacillus cereus*, and *Staphylococcus aureus* were the most frequently detected bacterial pathogens. Stored foods (54%) showed higher contamination than freshly cooked foods (19%), while domestic surfaces had the highest contamination prevalence. Rotavirus was detected in 34% of drinking water samples, indicating a possible viral exposure pathway. Qualitative findings suggested unsafe storage, inadequate reheating, untreated water, dirty utensils, and inconsistent handwashing as key drivers, highlighting that interventions should extend beyond hygiene education to include practical food safety packages.

1. Introduction

The first two years of a child's life are critical for health and development, due to underdeveloped immune systems making children more susceptible to infections [1]. Diarrhoea incidence peaks at age 6–11 months and then decreases with age [2] the period when weaning food is first introduced. Solid/semisolid weaning foods, drinking water, and domestic surfaces are important pathways for pathogen transmission in low-resource settings [3]. In the South-East Asia Region, an estimated 60 million children under the age of five fall ill each year due to foodborne diseases [4]. Foodborne illnesses are primarily caused by bacteria such as *Salmonella, Shigella, Escherichia coli* and *V. cholerae*, as well as viruses including norovirus and Hepatitis A virus, and parasites such as Echinococcus, Taenia, Cryptosporidium, and Giardia [5]. In Bangladesh, hospital-based diarrheal disease surveillance of children younger than two years identified *V. cholerae* as one of the leading causes of diarrhoea, alongside rotavirus and enterotoxigenic *E. coli* [6].

Improper food handling, lack of refrigeration, and inadequate caregiver knowledge of food hygiene contribute substantially to contamination of weaning foods [7, 8]. Inadequate water and sanitation infrastructure, such as limited access to safe piped water and poor sewage disposal systems, can contaminate water used for food preparation and household storage [3]. In low-income urban informal settlements, these risks may be amplified due to extreme population density, overcrowding, constrained living conditions, and limited access to basic services. Evidence suggests that, despite various interventions aimed at improving WASH conditions in these settings, reductions in childhood diarrhoea and faecal contamination have been inconsistent [9], suggesting that current intervention does not block all pathogen transmission pathways. Within this context primary caregivers often earn minimal wages

and engage in informal labour, limiting the time available for child food preparation and feeding [10]. As a result, meals are commonly prepared early in the morning and stored at ambient temperatures for later consumption. Storing food at these room temperatures allows microorganisms to multiply rapidly increasing the risk of contamination [11].

Most studies routinely use *E. coli* as an indicator of hygiene and faecal contamination. Because it is relatively inexpensive and easy to detect and is often associated with the presence of enteric pathogens [12]. In Bangladesh, several studies have investigated microbial contamination in child foods, water, and household environments primarily by measuring *E. coli* contamination at different stages of food handling and feeding practices [13–16]. While these studies provide important evidence of faecal contamination in household settings, they offer limited insight into the bacterial and viral pathogens that directly cause foodborne illness. Most WASH and food hygiene studies have relied on *E. coli* or faecal coliforms as indicator organisms rather than measuring specific enteric pathogens [13–15, 17–20]. However, indicator organisms do not consistently reflect the presence, diversity, or concentration of clinically important foodborne pathogens, particularly viruses and several bacterial species [21].

Therefore, comprehensive investigations assessing multiple foodborne pathogens simultaneously across potential exposure sources remain scarce in resource-poor settings [19, 22]. Understanding the prevalence and distribution of these pathogens within households is critical for identifying potential transmission pathways and informing effective interventions. In this study, we aimed to investigate the presence of multiple bacterial and viral pathogens in child weaning foods, drinking water, and domestic surfaces in a low-income urban informal settlement in Dhaka, Bangladesh to better characterize household-level exposure risks. We therefore sought to determine the prevalence of selected pathogens across these exposure sources and identify key caregiver behaviours that may contribute to contamination within child food and feeding environments.

2. Materials and Methods

2.1. Study Setting

This study was conducted in *Korail*, an informal settlement in north-central Dhaka, Bangladesh [23]. Spanning approximately 100 acres, this area is home to around 50,000 residents, many livings below the poverty line. This site was chosen because it represents a typical urban informal setting in Bangladesh, with substantial food hygiene challenges due to limited resource to safe WASH facilities, electricity, and food storage space. The typical living space is a single room where people prepare food, cook, sleep, and use as a living room. The population density is 506,715/km2, with an under-five mortality rate of 34.9 per 1,000 live births [24].

2.2. Study Design

We employed a mixed method study design to assess pathogens contamination and associated risk factors in complementary food, drinking water and household environments. Our target population were

residents of *Korail* that participated in the health and demographic surveillance system (HDSS) in icddrb [24] who had at least one child aged 6–24 months. Based on HDSS records, we identified 79 eligible households. We randomly selected 2 eligible households from each 16 administrative blocks for a total of 32 households. To complement the microbiological findings, we conducted household observations and qualitative interviews with caregivers to better understand behavioural and environmental drivers of contamination. A study schematic flow chart presented in Fig. 1.

2.3. Data Collection

Food, drinking water and domestic surface swab

We collected multiple food samples prepared for children and categorized them according to preparation and handling practices: (a) cooked food, defined as freshly prepared within ≤ 4 hours and not subsequently stored or reheated; (b) stored food, defined as cooked and held for ≥ 4 hours before consumption without reheating; (c) reheated food, defined as cooked, stored for ≥ 4 hours, and then reheated before serving; and (d) snacks, defined as vendor-purchased ready-to-eat items intended for immediate consumption. From each household, approximately 50 g of child food from feeding bowl, 50 mL of drinking water, and domestic surface swab samples were collected from food storage areas following standardized field protocol (Supplementary Information 1). We measured the temperature of each food sample with a TP300 digital food thermometer, designed for water, kitchen, and laboratory use. All collected samples were stored in a cold box and were promptly transported to the Food Microbiology and One Health Laboratory at icddr,b and processed within 4 hours of collection. A detailed description of the collected samples is presented in Table 1.

Table 1
Operational definitions of sample types for assessing pathogen contamination in households at urban low-income settlements, Bangladesh

Sample Type	**Operational Definition**
Cooked food	Food that has been prepared through cooking within the last 4 hours and has not been stored or reheated afterwards.
Stored food	Food that has been cooked and subsequently stored for 4 hours or longer before consumption, without reheating.
Reheated food	Food that has been stored for a minimum of 4 hours and then reheated prior to consumption.
Snacks	Prepared food items purchased from local shops or vendors, intended for immediate consumption. e.g. local fried flat bread, Samosa, local cake.
Drinking water	Water specifically provided to children under 2 years of age for drinking purposes.
Domestic swab	Swabs collected from different surfaces within a household, including areas used for food storage, chopping, cooking, and utensils used by children.

Household observations, interviews, and focus group discussions

To contextualize microbiological findings and identify potential household contamination pathways, household observations (n = 32) and qualitative in-depth interviews (IDIs), Focus Group Discussions (FGDs) were conducted with participating households. Observation conducted for approximately eight hours per household to document routine food preparation, storage, utensil cleaning, environmental hygiene, and handwashing practices. A semi-structured checklists and field notes to record behaviours and contextual factors associated with potential contamination pathways.

Semi-structured in-depth interviews were conducted with caregivers (n = 16) from selected households to further explore food handling practices, perceptions of contamination risk, and barriers to safe food hygiene. Households with higher levels of contamination identified through preliminary laboratory analysis were purposively prioritized for interviews to better understand practices potentially associated with contamination. The interview continued until thematic saturation was reached. In addition, three FGDs (n = 18) were conducted with caregivers recruited from the same community to triangulate and expand findings related to household food hygiene and environmental contamination. All IDIs and FGDs were conducted in Bengali (Bangla) and were audio-recorded, transcribed verbatim, and translated into English.

We also collected data on household demographic composition, food preparation and cooking, water sources, utensil cleaning, food storage behaviours, handwashing practices, and geographic coordinates, which were recorded in Kobo Toolbox software. The data collection and analysis took place from July 2023 to November 2024.

2.4. Laboratory analysis

To assess overall hygienic quality and viable bacterial burden, culture-based enumeration of aerobic plate count (APC) and total coliform count (TCC) was initially performed for food and drinking water samples. Selected foodborne pathogens were subsequently detected in food, drinking water, and domestic surface swab samples using multiplex real-time quantitative PCR (qPCR). The qPCR assay targeted 12 pathogens, including *E. coli O157*, *V. cholerae, B. cereus, S. aureus*, *C. perfringens, Salmonella, Shigella*, rotavirus, and norovirus genogroups I (GI) and II (GII) (Supplementary Information 1). Primer and probe sequences, target genes, final concentrations, and annealing/extension temperatures for each pathogen are provided in table S1.

2.5. Data analysis

2.5.1. Quantitative microbiological analysis

We initially recorded data in Microsoft Excel and subsequently imported into Stata/SE 14.2 for comprehensive analysis. Descriptive statistics were used to summarize household socio-demographic characteristics and sample-level contamination patterns. Box plots were used to display aerobic plate count and total coliform count across food sample categories. Pathogen concentrations in cooked,

stored, reheated, and snack foods, drinking water, domestic surface swabs, and food ingredient samples were summarized using geometric mean values.

2.5.2. Integrated qualitative and hazard analysis

To contextualize microbiological findings, we conducted a triangulation-based mixed-methods analysis. Pathogen detection results from food, drinking water, and domestic surface swab samples were systematically compared with themes from household observations, caregiver interviews, and focus group discussions. An iterative coding and synthesis process were used to identify recurring patterns linking contamination with food handling practices, hygiene behaviours, and environmental conditions. This integrated analysis informed the development of a conceptual hazard pathway framework to identify potential transmission routes and key contamination points within the household environment.

3. Result

Demographic and socio-economic characteristics

The primary caregivers in our study were predominantly mothers (87%); most over 18 years old (94%) and below secondary education (63%). Most household heads work in the informal sector (63%) and earn more than 15,000 BDT (125 USD) monthly (72%). Almost all households (97%) were constructed with cement and bamboo, 91% of households have a smart phone mobile, 75% have a meat safe (cool storage cabinet), and 34% own a refrigerator (Table 2).

Table 2
Socio-demographic characteristics of primary caregivers and children at urban low-income settlements, Bangladesh

Variable	Number of samples (n)	Percentage (%)
Age in months (Child)		
6–12 months	19	59
13–24 month	13	41
Sex		
Male	10	31
Female	22	69
Relationship with child		
Mother	28	87
Female relatives	4	13
Age in years (Caregiver)		
< 18	2	6
> 18	30	94
Mothers Education		
Below Secondary	20	63
Above secondary	12	37
Occupation of household head		
Service	12	37
Others (Day labour, Rickshaw Puller etc.)	20	63
Household income (BDT)		
< 15000/$125	9	28
> 15000/$125	23	72
Household Type		
Cement Bamboo with mud	31	97
Stone with mud	1	30
Child's living room has a cross-ventilation system		
Well ventilation system	15	47

Variable	Number of samples (n)	Percentage (%)
Age in months (Child)		
Poor ventilation system	17	53
Number of Family members		
< 5	17	53
> 5	15	47
Household with smart mobile	29	91
Household with Refrigerator	11	34
Household with meat safe	24	75

Microbial contamination

A total of 193 samples (97 food samples, 32 drinking water samples, and 64 surface samples) were collected from participating households. Sources of food samples were cooked food (47), stored food (24), reheated food (15), and snacks (11). Detailed results on APC and TCC in food and drinking water samples are presented in table S2 and figure S1, with full numerical distributions provided in Supplementary Information 2.

Among food samples, 33% of 97 total were positive for at least one of the tested pathogens. *V. cholerae* and *S. aureus* exhibited the highest prevalence rates in snacks (2/11, 18% each) and stored food (4/24, 17% each). *B. cereus* was predominantly found in stored food (5/24, 21%) and reheated food (3/15, 20%) (Fig. 2). The geometric mean of *B. cereus* was the highest gene copy number at 9.20×10^5 copies/g, followed by *C. perfringens* at 1.45×10^5 copies/g and *V. cholerae* at 7.23×10^4 copies/g. According to food condition, *C. perfringens* was the highest levels, particularly in stored (1.82×10^5 copies/g) food. *B. cereus* remained high in stored food (1.81×10^5 copies/g). *V. cholerae* peaked in snacks (1.06×10^5 copies/g), while *S. aureus* prevalent was equal in stored food and reheated food (3.53×10^4 copies/g) (Table 3).

Table 3
Quantification (geometric mean of gene copy number per gram or mL) of different pathogens in collected food, domestic surfaces, and drinking water samples collected from each household.

Pathogen name	Any food (N = 97)	Cooked (N = 47)	Stored (N = 24)	Reheated (N = 15)	Snacks (N = 11)	Drinking water (N = 32)	Domestic surface (N = 64)
	Gene copies/g					Gene copies/mL	
V. cholerae	7.23×10^4	5.54×10^4	1.00×10^5	--	1.06×10^5	--	1.93×10^4
B. cereus	9.20×10^5	4.31×10^4	1.81×10^5	6.09×10^4	--	--	9.92×10^3
S. aureus	5.27×10^4	--	3.53×10^4	3.53×10^4	1.75×10^5	--	5.70×10^3
C. perfringens	1.45×10^5	1.15×10^5	1.82×10^5	--	--	--	8.68×10^3
V. parahaemolyticus	1.03×10^5	--	--	--	--	--	3.21×10^3
Rotavirus	6.59×10^3	--	--	--	--	3.42×10	3.90×10^3

Note: *(--) pathogen was not detected or detected only in 1 sample or not tested

Among drinking water samples, 14 of 32 (44%) were positive for at least one of the tested pathogens. Viral pathogens were also detected, with rotavirus found in 11 samples (34%) and norovirus in 2 (6%) and 1 (3%) samples for GI and GII, respectively (Fig. 2). The geometric mean of rotavirus in drinking water samples was 3.42 × 10 gene copies/mL (Table 3). Domestic surface swab samples revealed a high positivity rate, with 51 out of 64 (80%) testing positive for at least one pathogen. Bacterial contamination was high, with *V. cholerae* detected in 37 samples (58%), *B. cereus* in 35 (55%), *S. aureus* in 32 (50%), and *C. perfringens* in 18 (28%). Less frequently detected bacteria included *V. parahaemolyticus* (2/64, 3%) and *Shigella* (1/64, 2%). Viral pathogens were also present, with rotavirus in 6 samples (9%) and norovirus GI in 5 samples (8%) (Fig. 2). The geometric mean of *V. cholerae* in domestic surface swabs was 1.93×10^4 gene copies/mL, *B. cereus* was 9.92×10^3 gene copies/mL, and *S. aureus* was 5.70×10^3 gene copies/mL. *C. perfringens* had a geometric mean of 8.68×10^3 gene copies/mL, and rotavirus was 3.90×10^3 gene copies/mL (Table 3).

Household observations, interviews, and focus group discussions findings

Shared kitchen use was observed among 81% of caregivers. Handwashing before food preparation was reported in 35% of caregivers. Most caregivers (82%) fed children by hand, while 36% washed their hands before feeding the child and 73% cleaned utensils with water and soap before feeding. Reheating of food

prior to feeding was observed in 25% of cases. Leftover food was fully covered in only 41% of observations. 38% cleaned utensils with water and soap after feeding. 34% boiled drinking water. Flies present in the cooking areas of 90% of households; only 63% had a waste bin available. (Table 4)

Table 4
Caregiver food handling and hygiene practices (Semi-structured observation) in N = 32 household

Observed event	Number of samples (n)	Percentage (%)
Cooking in shared kitchen	26	81
Handwashing practice		
Before food preparation	9	35
Before feeding the child	10	36
Use hand for feeding the child	23	82
Storage practice of the leftovers		
Fully covered	13	41
Half covered	4	13
Not covered	13	41
Reheating practice	8	25
Drinking water boiling practice	11	34
Utensils with dirt	6	21
Clean utensils with water and soap		
Before feeding	16	50
After feeding	12	38
Waste bin present in the cooking area	20	63
Faeces (child, poultry, animal) present in cooking area	13	41
Flies present in cooking area	25	90

Interviews explored patterns of behaviour that contributed to foodborne contamination and their causes. Caregivers commonly prepared food once daily and repeatedly fed the same food to children throughout the day. Foods were often inadequately reheated, and some caregivers rinsed spicy foods with untreated tap water before feeding children. Fuel shortages, irregular gas supply, overcrowded shared kitchens, and limited cooking space limited caregivers' ability to reheat food properly. Cooked foods were frequently stored at ambient temperature for prolonged periods, often until the following day. Although caregivers reported covering foods, observations showed that foods were commonly uncovered or partially covered and stored on floors, under beds, or inside damaged storage cabinets. Rats,

cockroaches, flies, and animal faeces were frequently observed around cooking and feeding areas. Drinking water was commonly stored in uncovered and visibly dirty containers, while water treatment was uncommon because of fuel and financial constraints.

Utensils were generally cleaned at communal washing areas located near shared toilets, where crowding and inconsistent water supply limited effective cleaning. Some caregivers relied on ash when soap was unavailable, and cleanliness was commonly judged by visible appearance rather than hygienic safety. Feeding bottles and child utensils were not consistently boiled, and wet utensils were often stored without drying.

Household floors and surfaces were commonly cleaned using only water and a single multipurpose dish cloth used for several domestic tasks. Children frequently played on contaminated floors and nearby alleyways accessible to animals. Although caregivers were aware of key handwashing moments, soap use was inconsistent because of limited access and concerns about theft. Most children were fed directly by hand, and water-only rinsing before feeding was common.

Potential contamination points, likely transmission mechanisms, and priority household-level control opportunities were identified across weaning food preparation and feeding practices. Table 5 summarizes the major hazards, contamination pathways, and suggested control measures identified in the household environment. Overall, the hazard identification suggests that the main critical control points occurred after cooking. These included safe storage of cooked food, adequate reheating before feeding, use of treated water, hygienic cleaning and drying of feeding utensils, protection of food from pests, cleaning of feeding surfaces, and handwashing with soap before child feeding.

Table 5
Potential food contamination pathways and identification of Critical Control Points (CCP)

Exposure point	Main hazards identified	Evidence from contamination data	Likely source or mechanism	CCP	Suggested control measure
Cooking / initial preparation	*V. cholerae*, *B. cereus*, *C. perfringens*	Pathogens load was high in cooked food	Contaminated raw ingredients, contaminated utensils, post-cooking handling	CCP 1: Adequate cooking	Ensure food is cooked thoroughly and served soon after preparation
Ambient storage of cooked food	*B. cereus*, *C. perfringens*, *S. aureus*, *V. cholerae*	High prevalence of pathogens was detected for stored food	Growth during prolonged storage, exposure to flies/pests, uncovered food, storage on floor/under bed	CCP 2: Safe storage	Cover food immediately, store in clean elevated space, avoid prolonged room-temperature storage
Reheating before feeding	*B. cereus*, *S. aureus*	Reheated food remained contaminated	Food only warmed, not reheated sufficiently; fuel and kitchen constraints	CCP 3: Effective reheating	Reheat stored food until steaming hot throughout before child feeding
Addition of water / dilution of food	*V. cholerae*, rotavirus, norovirus	Viral contamination was detected in drinking water	Untreated water added to dilute the food or used for rinsing utensils	CCP 4: Safe water use	Use treated/boiled water for child food preparation, dilution, and utensil rinsing
Utensil cleaning and storage	Enteric bacteria, *S. aureus*	Utensils were inadequately cleaned and often kept wet	Washing with water only, communal washing near toilets, wet storage, no air drying	CCP 5: Clean feeding utensils	Wash with soap, rinse safely, air-dry inverted, store separately in clean covered place
Domestic surfaces / feeding area	*V. cholerae*, *B. cereus*, *S. aureus*, *C. perfringens*	Domestic surfaces showed the highest contamination prevalence	Contaminated floors child play areas with flies, animal faeces	CCP 6: Clean feeding environment	Clean feeding surfaces with detergent, reduce animal access,

Exposure point	Main hazards identified	Evidence from contamination data	Likely source or mechanism	CCP	Suggested control measure
Hand feeding / caregiver hands	Faecal pathogens, *S. aureus*, viral pathogens	Food, surface, and water contamination suggest multiple transfer routes	Feeding by hand, inconsistent soap use, multipurpose dish cloths	CCP 7: Hand hygiene before feeding	Wash both caregiver and child hands with soap before food preparation and feeding, separate child napkin and dish cloths

4. Discussion

This study demonstrates that weaning food is the major pathway for delivering pathogens in an urban low-income settlement in Bangladesh. Considerable variation was observed in both pathogen detection and concentration across food types. This follows known patterns of bacterial growth and post-cooking recontamination when food is store for long periods and handled repeatedly. Studies from Bangladesh and similar settings show that stored weaning foods become highly contaminated within a few hours [13, 25]. Our findings show the same pattern across multiple pathogens *V. cholerae, B. cereus*, rotavirus, and norovirus, not just faecal indicator *E. coli* bacteria. Additionally, household surfaces play a different role. They act as reservoirs of contamination, with pathogens detected in 80% of surface samples. Several organisms identified on surfaces were also detected in food samples. This suggests constant transfer between surfaces and food. Similar studies show that contamination moves easily between these pathways inside households [20]. In contrast, drinking water showed a distinct contamination profile, with viral pathogens detected despite the absence of bacterial pathogens. This suggests that viruses survive differently and are not well captured by bacterial indicators. Together, these pathways propose an interconnected system of household contamination. As a result, young children may experience repeated exposure to multiple pathogens across food, water, and the household environment. This may help explain why interventions focused on a single pathway have shown limited impact [26]. Reducing risk will require interrupting the chain of microbial transfer, particularly during food storage, handling, reheating, and child feeding.

The qualitative findings help explain the multi-pathogen contamination pattern observed in this study. It showed that food was commonly cooked once daily, stored for several hours at room temperature, inadequately reheated, and sometimes mixed or rinsed with untreated tap water before feeding. These practices may explain the detection of storage-associated and spore-forming bacteria such as *B. cereus* and *C. perfringens* in stored and reheated foods. Similar contamination pathways have been reported in food hygiene studies from Nepal and Kenya, where unsafe storage, inadequate reheating, and poor feeding hygiene increased microbial risk in complementary foods [25, 27].

The detection of *V. cholerae, S. aureus, B. cereus*, and *C. perfringens* on domestic surfaces also suggests that household surfaces may act as reservoirs for recontamination. This is supported by qualitative observations of foods and utensils being stored on floors, under beds, or in damaged storage spaces, with frequent exposure to flies, cockroaches, rats, dust, and animal faeces. Similar evidence from Bangladesh has shown that hands, food, soil, flies, and surfaces can form interconnected faecal oral transmission pathways in child domestic environments [20]. Poor hand hygiene and utensil handling may have further contributed to contamination. Most children were fed by hand, while caregivers often rinsed hands with water only before feeding. Utensils were commonly washed at shared water points near toilets, stacked dirty during the day, and stored wet without drying. These findings align with previous intervention studies showing that safe food storage, clean utensils, handwashing with soap, and improved household hygiene are important control points for reducing foodborne exposure among young children [28, 29].

Overall, the hazard identification suggests that the main critical control points occurred after cooking. These included safe storage of cooked food, adequate reheating before feeding, use of treated water, hygienic cleaning and drying of feeding utensils, protection of food from pests, cleaning of feeding surfaces, and handwashing with soap before child feeding. Therefore, reducing child exposure in informal settlements will require more than hygiene education. It will require an integrated household food safety package that addresses both caregiver practices and structural constraints, including limited fuel, shared kitchens, poor storage, pest exposure, and inadequate access to soap and safe water.

5. Strengths and Limitations

A key strength of this study is the assessment of multiple bacterial and viral pathogens in complementary foods, drinking water, and domestic surfaces. Most previous studies relied mainly on indicator bacteria such as *E. coli.* Our approach provides a broader picture of pathogen-specific exposure risks in the child feeding environment. Samples were collected during routine household activities and child feeding times, which reduced recall bias and reflected real-life practices. The addition of household observations and qualitative findings also helped explain contamination pathways and identify potential critical control points. This study has some limitations. The cross-sectional design does not allow causal inference. Samples were collected once from each household, so seasonal or day-to-day variation could not be assessed. In addition, qPCR detects pathogen genetic material but does not confirm viability or infectivity. Therefore, positive results indicate potential exposure, not confirmed infectious risk.

6. Conclusion

This study shows that young children in urban informal settlements are exposed to multiple pathogens through food, water, and domestic surfaces. Stored and reheated foods, unsafe water use, contaminated utensils, household surfaces, pests, and poor hand hygiene are key control points for intervention. Reducing exposure will require practical household food safety packages that support safe storage, adequate reheating, treated water use, clean feeding utensils, pest control, surface cleaning, and

handwashing with soap. Future interventions should address both caregiver practices and the structural constraints that make safe food hygiene difficult in low-resource settings.

Declarations

Authorship contribution statement

Study conceptualization- RH, RD, and PJW. Data curation: SN and NA. Data analysis: RH and SA. Formal analysis: RH and SMH. Laboratory investigation and supervision: MZR, JQA, MEH, MBA, and HS. Supervision: MR (1), RD and PJW. Writing – original draft: RH. Writing – review and editing: TS, MBA, MR (6), RD, PJW, HS, and all co-authors. All authors reviewed, revised, and approved the final manuscript before submission. AI was used solely for language editing to improve clarity, and all content was reviewed and verified by the authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethical considerations

The study protocol (#23079) was reviewed and approved by the Research Review Committee (RRC) and Ethical Review Committee (ERC) of the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b). Written informed consent was obtained from the primary caregiver (parents/grant parents/ legal gurdian) each participating child prior to enrolment in the study. Written informed consent was also obtained from participating caregivers before interviews. All methods were performed in accordance with the Declaration of Helsinki and relevant guidelines.

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Author Contribution

Study conceptualization- RH, RD, and PJW. Data curation: SN and NA. Data analysis: RH and SA. Formal analysis: RH and SMH. Laboratory investigation and supervision: MZR, JQA, MEH, MBA, and HS. Supervision: MR (1), RD and PJW. Writing – original draft: RH. Writing – review and editing: TS, MBA, MR (6), RD, PJW, HS, and all co-authors. All authors reviewed, revised, and approved the final manuscript before submission.

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Data Availability

All data supporting the findings of this study are available within the paper and its Supplementary Information. Data will be available from the corresponding author upon request.

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Figures

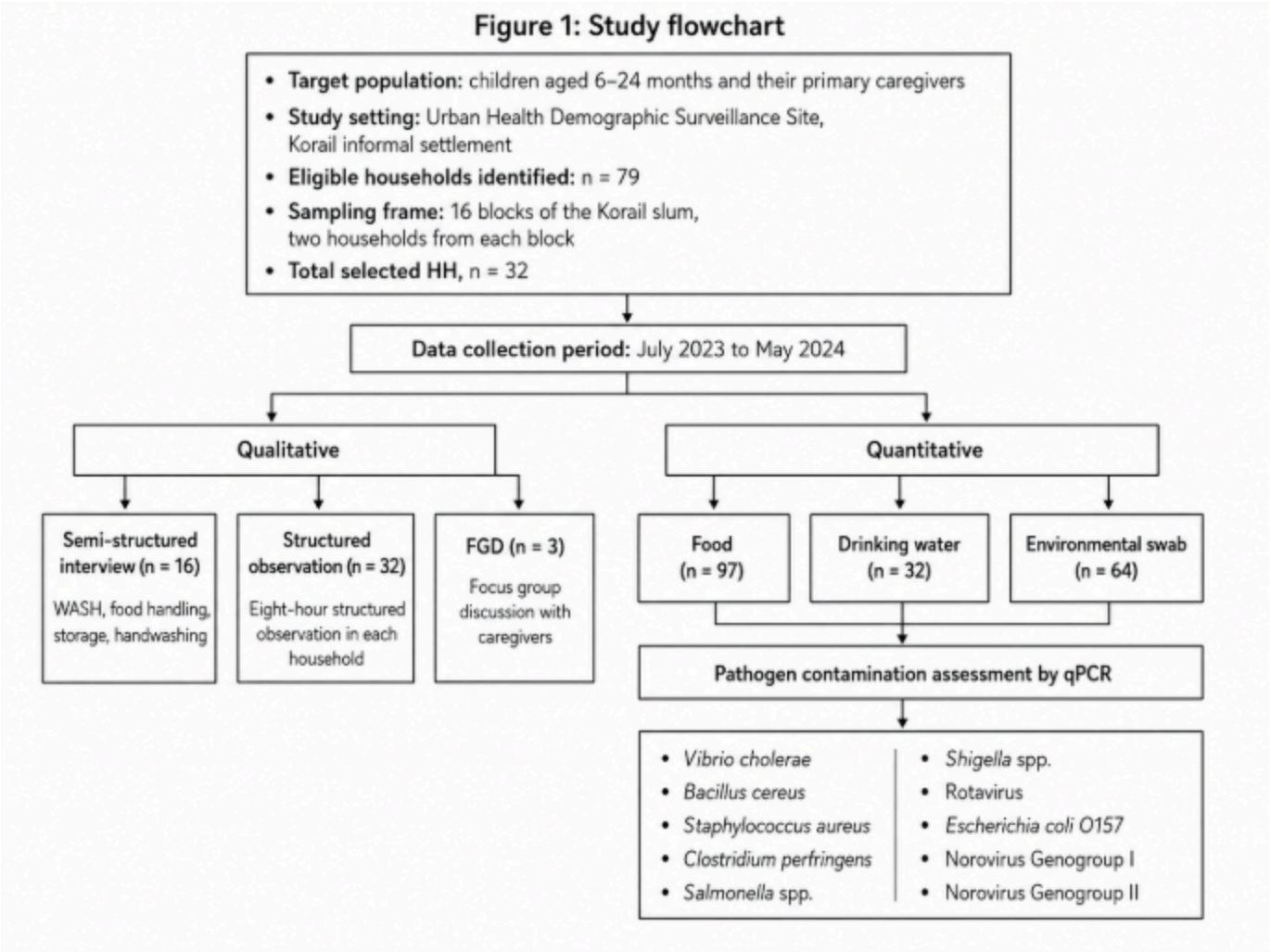


Figure 1

Study flow chart.

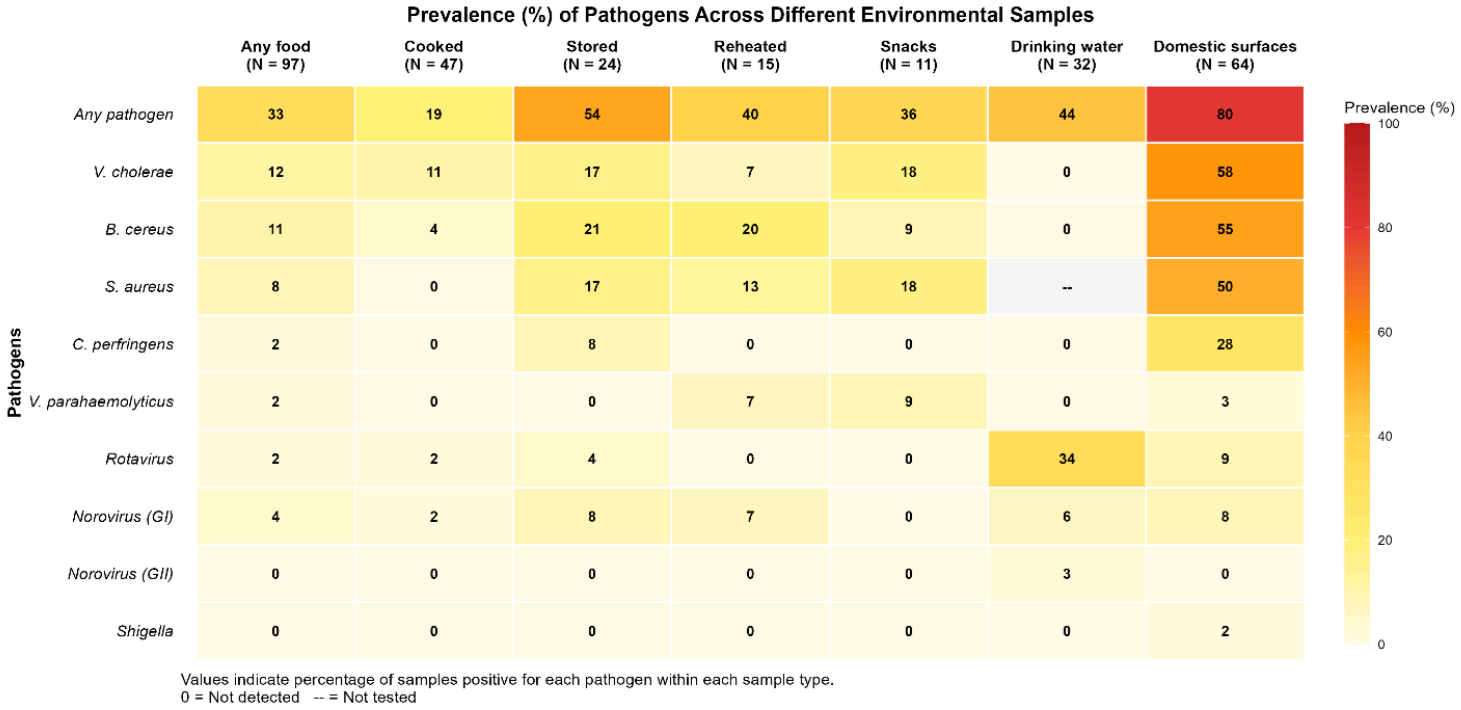


Figure 2

Heatmap showing the prevalence (%) of bacterial and viral pathogens across food, drinking water, and domestic surface samples collected from households in an urban informal settlement in Dhaka, Bangladesh. Darker colours indicate higher prevalence.

Supplementary Files

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- HaqueRSFoodContaminationSuplementaryInformation.docx