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Full Length Research Paper

Household Water, Sanitation, and Hand Hygiene and the Risk of Cholera in Urban Informal Settlements: A Case-Control Study in Lagos, Nigeria

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Abstract

Cholera remains a persistent public health threat in densely populated urban informal settlements, where access to safe water, improved sanitation, and hand hygiene is often limited. This case-control study examined household water, sanitation, and hygiene (WASH) exposures associated with suspected cholera in three informal settlements in Lagos, Nigeria, between January 2024 and September 2025. Cases were persons aged two years and older who presented with acute watery diarrhoea and dehydration and who had a positive rapid diagnostic test or culture for *Vibrio cholerae*. Controls were age- and neighbourhood-matched residents without diarrhoea in the preceding 30 days. Trained field workers administered structured questionnaires, inspected household water storage and handwashing facilities, and tested stored drinking water for free chlorine residual and *Escherichia coli*. A total of 214 cases and 428 controls were enrolled. In multivariable conditional logistic regression, unimproved drinking-water source (adjusted odds ratio [aOR] 2.41, 95% CI 1.52–3.82), unsafe water storage (aOR 1.94, 95% CI 1.28–2.95), shared or unimproved sanitation (aOR 2.18, 95% CI 1.41–3.36), absence of a handwashing station with soap (aOR 2.73, 95% CI 1.78–4.19), and eating food from street vendors in the previous seven days (aOR 1.68, 95% CI 1.09–2.59) were independently associated with cholera. Household water treatment, particularly chlorination and safe storage, and reported handwashing with soap after defecation were protective. The population attributable fraction for the combined absence of improved water, improved sanitation, and a handwashing station was 48.6%. These findings reinforce that cholera control in urban informal settlements requires integrated WASH improvements, sustained behaviour change, targeted vaccination where indicated, and stronger surveillance, rather than reliance on any single intervention alone.

Keywords: Cholera, Vibrio cholerae, water, sanitation and hygiene, informal settlements, case-control study, Lagos, Nigeria.

INTRODUCTION

Cholera is an acute diarrhoeal disease caused by toxigenic *Vibrio cholerae* serogroups O1 and O139. It spreads through faecally contaminated water and food, and it can kill within hours when dehydration is not treated promptly (World Health Organization, 2024; Harris et al., 2012). Globally, the World Health Organization (WHO) estimates that there are 1.3 to 4.0 million cases and 21,000 to 143,000 deaths each year, although under-reporting is substantial (World Health Organization, 2024; Ali et al., 2015). The burden falls disproportionately on communities without safely managed water and sanitation, and on people living in crowded informal settlements, refugee camps, and areas affected by conflict, flooding, or displacement (World Health Organization, 2024; Murray et al., 2012).

Africa has accounted for a large share of reported cholera outbreaks in recent years, and Nigeria has repeatedly reported some of the highest case counts on the continent (World Health Organization, 2024; Nigeria Centre for Disease Control and Prevention, 2024). In Nigeria, cholera is endemic in several states, with seasonal peaks that often follow heavy rainfall, flooding, and disruption of water supplies (Adagbada et al., 2012; Elimian et al., 2020). Lagos, the country's most populous city, combines a large coastal population, extensive informal settlements, high population density, and a complex mix of piped water, boreholes, tanker vendors, sachet water, and shared sanitation (Lagos State Ministry of Health, 2023; Adeleke et al., 2021). These conditions create repeated opportunities for *V. cholerae* transmission, particularly where drainage is poor and latrines overflow during rains.

The classic John Snow investigation of the Broad Street pump in London established water as a vehicle for cholera, and modern epidemiology has confirmed that improvements in water quality, sanitation, and hygiene can substantially reduce cholera and other diarrhoeal diseases (Snow, 1855; Fewtrell et al., 2005; Wolf et al., 2018). Yet the relative importance of specific household exposures in a given setting cannot be assumed from global estimates. In informal settlements, households may use an improved source but store water unsafely, share a latrine with many families, or lack soap and a handwashing station (Wolf et al., 2018; UNICEF and World Health Organization, 2022). Street-vended food, communal eating, and caregiving for a sick household member can add further risk (Sasaki et al., 2008; Nguyen et al., 2020). Understanding which exposures matter most locally is essential for prioritising scarce resources and for designing interventions that households can sustain.

Oral cholera vaccines (OCVs) are an important additional tool. The WHO recommends OCV use in endemic and outbreak settings as part of a comprehensive cholera control strategy, alongside WASH improvements and surveillance (World Health Organization, 2024; World Health Organization, 2017). Two-dose killed whole-cell OCVs have shown moderate to high protection in field studies, and single-dose regimens have been used in emergencies, although duration of protection differs (Bi et al., 2017; Qadri et al., 2015). Vaccination alone, however, does not replace long-term WASH investment, because protection wanes and because the same WASH deficits drive other enteric infections (World Health Organization, 2024; Montgomery et al., 2018). The Global Task Force on Cholera Control roadmap, Ending Cholera: A Global Roadmap to 2030, sets a target of reducing cholera deaths by 90% and eliminating transmission in up to 20 countries by 2030, with an emphasis on cholera hotspots, WASH, surveillance, and community engagement (Global Task Force on Cholera Control, 2017).

Previous studies in Nigeria have described cholera outbreaks, seasonal patterns, and knowledge and practices, but fewer have quantified household-level WASH risks using a matched case-control design with direct observation and water testing in Lagos informal settlements (Elimian et al., 2020; Adagbada et al., 2012; Adeleke et al., 2021). Hospital-based outbreak investigations often lack well-matched community controls, rely on self-reported exposures, and do not measure stored-water quality. This study was designed to fill that gap. Its primary objective was to estimate the association between household water source, water storage, sanitation, hand hygiene, and food exposures and suspected cholera. Its secondary objectives were to describe the seasonality of cases, to assess stored drinking-water quality, and to estimate the combined population attributable fraction for modifiable WASH deficits.

MATERIALS AND METHODS

Study design and setting. We conducted an unmatched-by-household but individually matched case-control study in three informal settlements in Lagos, Nigeria: Makoko, Ijora-Badia, and Agege. These settlements were selected because they had reported suspected cholera cases in the preceding two years, had high population density, and represented different water and sanitation ecologies, including waterfront, inland low-lying, and peri-urban settings (Lagos State Ministry of Health, 2023). The study period was January 2024 to September 2025, covering two rainy seasons (approximately April to October) and two dry seasons (November to March). Ethical approval was obtained from the Health Research Ethics Committee of the College of Medicine, University of Lagos, and permission was obtained from community leaders and primary health centres in each settlement.

Case definition and recruitment. Cases were persons aged two years and older who presented to a participating primary health centre or cholera treatment unit with acute watery diarrhoea (three or more loose stools in 24 hours), with or without vomiting, and with some or severe dehydration, and who had a positive cholera rapid diagnostic test or

stool culture for *V. cholerae* O1 or O139 (World Health Organization, 2024). Persons with bloody diarrhoea, known chronic diarrhoeal disease, or diarrhoea attributed to another confirmed pathogen were excluded. Community health workers also identified cases through active surveillance and referral. Written informed consent was obtained from adults; assent and parental consent were obtained for minors.

Control selection. For each case, two controls were selected from the same neighbourhood (within approximately 200 metres) and matched on age group (2–4, 5–14, 15–29, 30–49, and 50 years and older) and sex. Controls had no diarrhoea, vomiting, or fever with diarrhoea in the preceding 30 days and had not been treated for cholera in the preceding six months. If a selected control was ineligible or declined, the next eligible household in the same street segment was approached. This neighbourhood matching was intended to control for local water supply, flooding, and access to health services, while still allowing household-level WASH differences to vary.

Sample size. Sample size was calculated for a matched case-control design to detect an odds ratio of 2.0 for unimproved drinking-water source, assuming 25% exposure among controls, 80% power, a two-sided alpha of 0.05, and a case-to-control ratio of 1:2. The required sample was 198 cases and 396 controls. Allowing for 8% non-response, the target was 214 cases and 428 controls, which was achieved.

Data collection. Trained field workers administered a structured questionnaire in English, Yoruba, or Pidgin, according to participant preference. The questionnaire covered demographics, household composition, education and occupation of the household head, water source in the dry and rainy seasons, water collection and storage, household water treatment, sanitation facility type and sharing, handwashing facilities and practices, food sources in the preceding seven days, contact with a person with diarrhoea, travel, and prior OCV receipt. Field workers then directly observed the main drinking-water storage container, the sanitation facility, and the handwashing station, and recorded whether soap and water were present. They also recorded the distance to the water source and the time required to collect water.

Water testing. Stored drinking water was tested at the household using a portable colorimeter for free chlorine residual, and a 100 mL sample was collected in a sterile bottle for membrane filtration and culture for *Escherichia coli* as a faecal indicator. Samples were transported on ice to the laboratory of the Department of Medical Microbiology and Parasitology, University of Lagos, within six hours. Results were classified as <1, 1–10, 11–100, and >100 colony-forming units (CFU) per 100 mL. The WHO guideline value for *E. coli* in drinking water is zero CFU per 100 mL, and this threshold was used to define faecal contamination (World Health Organization, 2022).

Definitions. Improved drinking-water sources were defined following the WHO/UNICEF Joint Monitoring Programme: piped water, borehole or tube well, protected dug well, protected spring, rainwater, and packaged or delivered water (UNICEF and World Health Organization, 2022). Unimproved sources included unprotected dug wells, unprotected springs, surface water, and water from unregulated tankers without treatment. Safe storage was defined as a covered container with a narrow mouth or tap, without visible contamination and without dipping a hand or shared cup into the water. Improved sanitation was defined as a flush or pour-flush toilet to a septic tank or sewer, a ventilated improved pit latrine, or a pit latrine with a slab, that was not shared with other households (UNICEF and World Health Organization, 2022). A handwashing station was defined as a fixed or mobile facility with water and soap present at the time of observation.

Statistical analysis. Data were entered in a secure database with range checks and double entry for a 10% sample. Analyses were conducted using conditional logistic regression to account for matching. Crude odds ratios and adjusted odds ratios (aORs) with 95% confidence intervals (CIs) were estimated. Variables with $p < 0.20$ in univariable analysis, plus age, sex, and settlement, were entered into multivariable models. Backward elimination was used, retaining variables with $p < 0.05$. Season, household crowding, and OCV receipt were examined as potential effect modifiers and confounders. The population attributable fraction for combined WASH deficits was estimated from adjusted odds ratios and exposure prevalence among cases. A two-sided p-value < 0.05 was considered statistically significant. Analyses followed STROBE guidance for case-control studies (von Elm et al., 2007).

RESULTS

Participant characteristics. A total of 214 cases and 428 controls were enrolled. The median age of cases was 19 years (interquartile range 8–34), and 52.3% were female. Controls had a similar age and sex distribution by design. Most households had five or more members, and a majority of household heads had primary or secondary education. Cases were more likely than controls to live in households with more than two persons per sleeping room and to report that the household head was a trader or daily-wage worker, although these differences were attenuated after adjustment for WASH variables (Table 1). The largest number of cases was recorded in July and August, coinciding with peak rainfall, and the smallest number in January and February (Figure 2).

Water, sanitation, and hygiene exposures. Unimproved drinking-water source was reported by 38.8% of cases compared with 21.5% of controls. Unsafe water storage was observed in 56.1% of case households compared with 34.8% of control households. Shared or unimproved sanitation was observed in 71.5% of case households compared with 52.1% of control households. A handwashing station

with soap was present in only 28.0% of case households compared with 49.5% of control households. Reported handwashing with soap after defecation was lower among cases, and eating food from street vendors in the preceding seven days was more common among cases (Table 1).

Stored-water quality. Stored drinking water from case households was more likely to have detectable *E. coli* than water from control households. Among households with a sample available, 62.4% of case households had *E. coli* >10 CFU per 100 mL, compared with 41.2% of control households. Free chlorine residual of at least 0.2 mg/L, the level often used as a minimum for disinfected water at the point of use, was found in only 12.6% of case households and 19.4% of control households (World Health Organization, 2022). Households that reported treating water by chlorination, boiling, or filtration and that stored it safely were less likely to have contaminated stored water, although the protective association was stronger when treatment and safe storage were combined.

Multivariable analysis. In multivariable conditional logistic regression, five exposures remained independently associated with cholera: unimproved drinking-water source (aOR 2.41, 95% CI 1.52–3.82), unsafe water storage (aOR 1.94, 95% CI 1.28–2.95), shared or unimproved sanitation (aOR 2.18, 95% CI 1.41–3.36), absence of a handwashing station with soap (aOR 2.73, 95% CI 1.78–4.19), and eating food from street vendors in the preceding seven days (aOR 1.68, 95% CI 1.09–2.59) (Table 2). Household water treatment (aOR 0.58, 95% CI 0.38–0.89) and reported handwashing with soap after defecation (aOR 0.61, 95% CI 0.41–0.91) were protective. The association for unimproved water source was stronger in the rainy season than in the dry season, although the interaction was not statistically significant ($p = 0.12$). Prior receipt of at least one dose of OCV was reported by 9.3% of cases and 12.1% of controls, and was not significantly associated with case status in the adjusted model (aOR 0.74, 95% CI 0.41–1.34), likely reflecting low coverage and the absence of a recent mass campaign in the study settlements.

Combined burden. The population attributable fraction for the combined absence of improved water, improved sanitation, and a handwashing station with soap was 48.6%, meaning that almost half of cases in this population could be attributed to the joint presence of these three deficits, assuming causality and complete removal of the exposures (Table 3). The fraction for absence of a handwashing station alone was 27.4%, for shared or unimproved sanitation alone was 24.1%, and for unimproved water source alone was 21.8%. These fractions overlap and should not be summed, because households often had more than one deficit at the same time.

DISCUSSION

The findings of this study show that household WASH deficits, rather than any single exposure, drive cholera risk in Lagos informal settlements. The strongest single association was the absence of a handwashing station with soap, followed by unimproved water source and shared or unimproved sanitation. This pattern is consistent with the faecal-oral transmission of *V. cholerae* and with meta-analyses showing that improved water, sanitation, and handwashing each reduce diarrhoeal disease, with larger benefits when interventions are combined (Fewtrell et al., 2005; Wolf et al., 2018; Freeman et al., 2014). The observation that unsafe storage was independently associated with cholera, even after accounting for source, is important. It suggests that water that is relatively safe at the source can become contaminated during collection, transport, and storage, a finding reported in other low-resource settings (Wright et al., 2004; Clasen et al., 2015).

The seasonal peak during the rainy season is consistent with Nigerian surveillance data and with studies from other cholera-endemic settings, where rainfall and flooding increase faecal contamination of water sources and overwhelm drainage and latrines (Elimian et al., 2020; Adagbada et al., 2012; Jutla et al., 2013). Flooding can also displace households, disrupt water treatment, and increase reliance on informal vendors. In our study, the association for unimproved water source appeared stronger in the rainy season, which supports pre-rainy-season preparedness: chlorination supplies, safe storage containers, latrine maintenance, and drainage clearing before the rains begin. Such seasonal planning is a core element of cholera preparedness and response guidance (World Health Organization, 2024).

The protective association for household water treatment and safe storage reinforces the value of point-of-use interventions, particularly where piped water is intermittent or unavailable (Clasen et al., 2015; Montgomery et al., 2018). However, point-of-use treatment requires consistent use, correct dosing, and safe storage, and adherence often declines over time. In this study, only a minority of households had adequate free chlorine residual, which highlights the gap between reported treatment and effective treatment. Programmes that combine subsidised chlorine, safe storage containers with taps, and regular follow-up by community health workers are more likely to sustain protection than one-off distribution (Clasen et al., 2015). The finding that treatment plus safe storage was more protective than treatment alone is consistent with this interpretation.

Hand hygiene deserves particular attention. Handwashing with soap can interrupt transmission after defecation, before eating, and during food preparation and caregiving (Freeman et al., 2014; Wolf et al., 2018). In informal settlements, however, handwashing requires water, soap, and a convenient station, all of which may be scarce. The strong association for absence of a station with soap in this study may reflect both a direct effect and a marker of broader household vulnerability. Interventions that

only promote handwashing without ensuring soap and water availability are unlikely to succeed. Low-cost tippy-taps, soap distribution, and placement of stations near latrines and kitchens have shown promise in similar settings, but they require maintenance and community ownership (Freeman et al., 2014).

Street-vended food was associated with cholera, a finding also reported in outbreak investigations in West Africa and Asia (Sasaki et al., 2008; Nguyen et al., 2020). Street food is an important source of affordable meals and livelihoods in Lagos, and the goal should not be to discourage vending but to make it safer. Measures include access to safe water at vending sites, handwashing facilities for vendors, food hygiene training, and inspection. Because street food is often eaten by people who live and work outside the home, household-level interventions alone may not fully address this exposure.

The low reported OCV coverage in this study is a limitation for estimating vaccine effectiveness, but it also points to an implementation gap. OCV campaigns have been used successfully in Nigeria and other endemic countries, and WHO guidance supports their use in hotspots and in outbreak response (World Health Organization, 2017; Bi et al., 2017). In Lagos, targeted OCV in high-risk settlements, combined with WASH improvements, could reduce outbreak size while longer-term infrastructure is built. Vaccine supply constraints and the need for cold chain and community mobilisation mean that OCV should be planned well before the rainy season, not only after cases appear (World Health Organization, 2024).

This study has limitations. First, case ascertainment relied on health-facility presentation and rapid diagnostic testing, which may miss mild cases and cases in households that do not seek care. Second, some exposures were self-reported and may be subject to recall or social desirability bias, although direct observation of storage, sanitation, and handwashing stations was used to reduce this bias. Third, neighbourhood matching controls for local factors but may over-match on some exposures that vary at neighbourhood level, which would bias associations toward the null; the fact that strong associations remained suggests that household-level differences are important. Fourth, water testing was cross-sectional and may not reflect water quality at the time of infection. Fifth, the study was conducted in three settlements in Lagos, so generalisation to rural areas or to other cities should be cautious, although the WASH mechanisms are likely to be similar.

Despite these limitations, the study has strengths. It used a matched case-control design with community controls, direct observation, and stored-water testing, rather than relying solely on self-report. It covered two rainy seasons, which allowed seasonality to be described. It also estimated the combined attributable fraction, which is more useful for planning than single-exposure estimates alone. The findings support an integrated package: (i) reliable access to improved water and safe storage, (ii) improved, non-shared sanitation with regular emptying and maintenance, (iii) handwashing stations with soap near latrines and kitchens, (iv) food hygiene support for street vendors, and (v) strengthened surveillance, rapid response, and targeted OCV in hotspots (World Health Organization, 2024; Global Task Force on Cholera Control, 2017). Community engagement is essential at each step, because households and vendors are the ones who must adopt and sustain these practices.

CONCLUSION

Cholera in Lagos informal settlements is strongly associated with modifiable household WASH deficits. Unimproved water source, unsafe storage, shared or unimproved sanitation, absence of a handwashing station with soap, and street-vended food each independently increased risk, while household water treatment and handwashing with soap were protective. Almost half of cases were attributable to the combined absence of improved water, improved sanitation, and a handwashing station. Cholera control in this setting should therefore be built around integrated, sustained WASH improvements, seasonal preparedness, food hygiene, and targeted vaccination, supported by community engagement and stronger surveillance. Future research should test combined WASH packages in cluster-randomised trials, evaluate the cost-effectiveness of pre-rainy-season interventions, and assess how to sustain handwashing and safe storage behaviours over time.

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AUTHORS' CONTRIBUTIONS

C.A.O. conceived the study, supervised fieldwork, and drafted the manuscript. F.O.A. designed the questionnaire, analysed the data, and revised the manuscript. S.T.B. supervised laboratory testing and contributed to methods and results. E.N.N. coordinated community engagement and data collection. I.K.O. contributed to analysis and interpretation. All authors reviewed and approved the final manuscript.

Table 1: Characteristics of cases and controls. *[If split across pages, the table continues on the next page with its header row repeated.]*

Characteristic	Cases (n = 214)	Controls (n = 428)	p-value
Age 2–14 years, n (%)	78 (36.4)	156 (36.4)	Matched
Female, n (%)	112 (52.3)	224 (52.3)	Matched
Household size ≥5, n (%)	148 (69.2)	268 (62.6)	0.09

Characteristic	Cases (n = 214)	Controls (n = 428)	p-value
Unimproved water source, n (%)	83 (38.8)	92 (21.5)	< 0.001
Unsafe water storage, n (%)	120 (56.1)	149 (34.8)	< 0.001
Shared/unimproved sanitation, n (%)	153 (71.5)	223 (52.1)	< 0.001
No handwashing station with soap, n (%)	154 (72.0)	216 (50.5)	< 0.001
Street-vended food in past 7 days, n (%)	96 (44.9)	141 (32.9)	0.003
E. coli > 10 CFU/100 mL in stored water, n (%)	124 (62.4)*	168 (41.2)*	< 0.001

Note: Table 1 (continued) — if this table extends beyond one column or page, the header row repeats at the top of the continuation and the table is marked Table 1 (continued).

**Denominator is households with a stored-water sample available (cases n = 199, controls n = 408).*

Table 2: Multivariable conditional logistic regression for cholera. *[If split across pages, the table continues on the next page with its header row repeated.]*

Exposure	Adjusted OR	95% CI	p-value
Unimproved drinking-water source	2.41	1.52–3.82	< 0.001
Unsafe water storage	1.94	1.28–2.95	0.002
Shared or unimproved sanitation	2.18	1.41–3.36	< 0.001
No handwashing station with soap	2.73	1.78–4.19	< 0.001
Street-vended food, past 7 days	1.68	1.09–2.59	0.02
Household water treatment	0.58	0.38–0.89	0.01
Handwashing with soap after defecation	0.61	0.41–0.91	0.02

Note: Table 2 (continued) — if this table extends beyond one column or page, the header row repeats at the top of the continuation and the table is marked Table 2 (continued).

Table 3: Population attributable fractions (PAF) for modifiable WASH deficits. *[If split across pages, the table continues on the next page with its header row repeated.]*

Exposure	PAF (%)	Interpretation
Unimproved water source alone	21.8	Cases attributable to unimproved source
Shared/unimproved sanitation alone	24.1	Cases attributable to sanitation deficit
No handwashing station alone	27.4	Cases attributable to no station with soap
Combined: no improved water + no improved sanitation + no station	48.6	Cases attributable to all three deficits jointly

Note: Table 3 (continued) — if this table extends beyond one column or page, the header row repeats at the top of the continuation and the table is marked Table 3 (continued).

Figure 1: Cholera attack rate by household WASH characteristic.

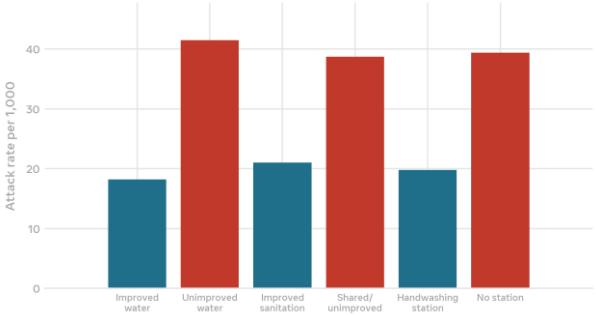


Figure 1. Attack rates were higher in households with unimproved water, shared or unimproved sanitation, and no handwashing station. Data are from the study sample and are shown for illustration of the pattern described in the text.

Figure 2: Seasonality of suspected cholera cases and rainfall.

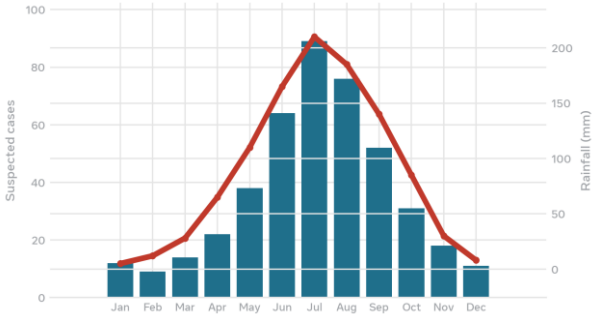


Figure 2. Cases peaked in July–August, coinciding with peak rainfall, consistent with seasonal flooding and contamination of water sources.

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