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Full Length Research Paper

Community Transmission Dynamics and Household Risk Factors for Cholera in Urban Informal Settlements: A Mixed-Methods Case-Control Study

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Abstract

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Cholera remains a major cause of acute watery diarrhoea and preventable death in rapidly growing cities, yet the household and neighbourhood conditions that sustain transmission in informal settlements are often inferred from facility data rather than measured in the community. This mixed-methods case-control study examined the community transmission dynamics and household risk factors for cholera in three densely populated informal settlements over a twelve-month period covering one dry and one rainy season. A total of 412 laboratory-confirmed or epidemiologically linked cholera cases and 824 age- and neighbourhood-matched controls were enrolled, alongside 96 in-depth interviews, 18 focus group discussions, and systematic observation of water points, latrines, drainage channels, and food-vending sites. Household questionnaires captured water source, storage, treatment, sanitation, hand hygiene, food practices, mobility, and exposure to funerals and communal gatherings. Cases were identified through active community surveillance and health-facility registers, and confirmed by culture and rapid diagnostic testing where available. Multivariable conditional logistic regression, spatial cluster analysis, and thematic analysis were used to integrate quantitative and qualitative findings. Cholera incidence peaked sharply with the onset of heavy rainfall, and cases clustered within 150 metres of shared water points and poorly drained latrine blocks. In adjusted analysis, reliance on an unimproved water source (Ali et al., 2015; WHO, 2023), absence of household water treatment, sharing a latrine with more than ten households, nearby open defecation, and absence of a handwashing station were independently associated with illness. Qualitative findings explained these associations: intermittent piped supply forced reliance on vendors and shallow wells, storage vessels were repeatedly dipped by hand, latrines flooded during rain, and caregivers struggled to maintain hygiene while caring for ill relatives. Early rehydration, community oral rehydration points, and targeted vaccination in high-risk blocks were associated with shorter delays to care and lower household secondary attack rates. The findings support a neighbourhood-level prevention package that combines reliable safe water, flood-resilient sanitation, point-of-use treatment, hand hygiene, and rapid case-area targeted interventions, rather than facility-centred responses alone.

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

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INTRODUCTION

Cholera is an acute diarrhoeal disease caused by toxigenic *Vibrio cholerae* serogroups O1 and O139. It spreads through the faecal-oral route, most often when people drink water or eat food contaminated with faeces containing the organism (Harris et al., 2012; World Health Organization, 2023). In severe illness, cholera toxin causes profuse watery diarrhoea, vomiting and rapid dehydration. Without prompt rehydration, death can occur within hours, yet with timely oral rehydration therapy the case-fatality rate can be kept below 1% (Harris et al., 2012; World Health Organization, 2023). The tragedy of cholera in informal settlements is therefore not that it is untreatable, but that the conditions that produce it are so familiar and so unevenly distributed.

Globally, the World Health Organization estimates 1.3 to 4.0 million cholera cases and 21,000 to 143,000 deaths each year, with the greatest burden in sub-Saharan Africa and South Asia (Ali et al., 2015; World Health Organization, 2023). Reported figures understate true incidence because surveillance is incomplete, laboratory confirmation is limited, and many mild cases never reach a facility (Ali et al., 2015; Gaffga et al., 2007). Since 2021, cholera has resurged across multiple continents, driven by conflict, displacement, flooding, weakened water, sanitation and hygiene (WASH) systems and constrained vaccine supply (World Health Organization, 2023; World Health Organization, 2024). Nigeria has repeatedly featured among the most affected countries, with large outbreaks in 2010, 2018, 2021 and 2024 (Elimian et al., 2020; Nigeria Centre for Disease Control and Prevention, 2024). Much of that burden is urban, yet urban cholera is often described from hospital registers rather than from the neighbourhoods where transmission actually occurs.

Informal settlements concentrate the classic drivers of cholera: high density, intermittent piped water, reliance on vendors and shallow wells, shared and poorly drained latrines, open defecation, blocked drains, and food vending without safe water or handwashing (UN-Habitat, 2020; World Health Organization, 2019). In these settings, a single contaminated water point or flooded latrine block can expose hundreds of households within days. Social life is also dense: funerals, communal meals, religious gatherings, markets and caregiving bring people into close contact with shared water, food and sanitation facilities. Previous studies have shown that cholera risk clusters in space and time around index cases, that household contacts face a markedly elevated risk, and that rapid case-area targeted interventions (CATI) can reduce onward transmission (Azman et al., 2016; Parker et al., 2017; Phelps et al., 2017). What has been less well documented is how household practices and neighbourhood infrastructure jointly shape that clustering in Nigerian informal settlements, and which combinations of interventions are most feasible at block level.

The Global Task Force on Cholera Control roadmap, Ending Cholera: A Global Roadmap to 2030, aims to reduce cholera deaths by 90% and eliminate cholera in at least 20 countries by 2030 (Global Task Force on Cholera Control, 2017). Its pillars are early detection and rapid response, multisectoral WASH in hotspots, and effective use of oral cholera vaccine (OCV) (Global Task Force on Cholera Control, 2017; World Health Organization, 2023). Nigeria has a national cholera control plan aligned with the roadmap, but facility-centred responses alone cannot interrupt transmission that is sustained in households and shared neighbourhood spaces (Elimian et al., 2020; Nigeria Centre for Disease Control and Prevention, 2024). This study therefore asked: which household and neighbourhood factors distinguish cholera cases from matched controls in informal settlements; how does transmission cluster in space and time; and what do residents and frontline workers say explains those patterns and what would make prevention work?

MATERIALS AND METHODS

Study design, setting and participants

A mixed-methods case-control study was conducted over twelve months covering one dry and one rainy season in three densely populated informal settlements in a large Nigerian city. Settlements were purposively selected because they had reported cholera in the preceding two years, had high population density, and varied in water and sanitation infrastructure. Each settlement was divided into blocks defined by lanes, drainage channels and clusters of dwellings, which became the unit for spatial analysis and for targeted intervention. Cases were persons aged two years or older with acute watery diarrhoea, with or without vomiting, who were laboratory-confirmed by culture or rapid diagnostic testing where available, or epidemiologically linked to a confirmed case in the same block within 14 days, following Nigeria Centre for Disease Control and Prevention (NCDC) guidance (Nigeria Centre for Disease Control and Prevention, 2024). Controls were persons without diarrhoea in the preceding 30 days, matched to cases by age group (2-4, 5-14, 15-34, 35 years and above) and neighbourhood block, at a ratio of two controls per case. For each case, 412 cases and 824 controls were enrolled. Written informed consent was obtained from adults and guardians, with assent from older children.

Case finding, data collection and observation

Cases were identified through active community surveillance and health-facility registers. Community health volunteers visited households daily during the rainy season and twice weekly in the dry season, using a standard symptom screen and referral to oral rehydration points and facilities. Household questionnaires captured water source, storage, treatment, sanitation, hand hygiene, food practices, mobility, and exposure to funerals and communal gatherings in the 7 days before illness onset for cases,

and the 7 days before interview for controls. Systematic observation was conducted at water points, latrines, drainage channels and food-vending sites using a structured checklist covering crowding, drainage, visible faecal contamination, soap and water availability, and storage practices. Ninety-six in-depth interviews and 18 focus group discussions were conducted with cases and caregivers, water vendors, latrine caretakers, food vendors, community leaders, health workers and WASH committee members. Interviews explored water insecurity, latrine sharing, flooding, caregiving, trust in interventions and barriers to care.

Laboratory methods

Stool or rectal swabs were collected from suspected cases and transported in Cary-Blair medium to the reference laboratory within 6 hours. Samples were cultured on thiosulfate-citrate-bile salts-sucrose agar and confirmed by biochemical testing and seroagglutination for O1 and O139, following standard methods (Centers for Disease Control and Prevention, 2019). Rapid diagnostic tests were used where culture was delayed, and results were interpreted alongside clinical and epidemiological criteria. Water samples from a subsample of shared water points and household storage vessels were tested for *Escherichia coli* by membrane filtration and for free residual chlorine, using standard methods (World Health Organization, 2017; American Public Health Association, 2017).

Statistical and qualitative analysis

Quantitative data were analysed in R version 4.3.2 and Stata version 17. Characteristics of cases and controls were compared with conditional logistic regression to respect matching. Variables with $p < 0.20$ in univariable analysis and variables of a priori importance were entered into a multivariable conditional logistic regression model. Spatial clustering was examined by mapping cases to block and calculating distances to the nearest shared water point and latrine block, and by scan statistics to identify clusters. Secondary attack rates were calculated among household contacts followed for 7 days after the index case. Case-area targeted interventions (CATI), comprising household disinfection, distribution of chlorine and soap, hygiene promotion and referral to oral rehydration points, were classified as timely if delivered within 48 hours of case notification. Qualitative transcripts were analysed thematically using a framework approach (Braun and Clarke, 2006). Triangulation was undertaken at interpretation, with qualitative findings used to explain quantitative associations and to identify feasible intervention points.

Ethics statement

Ethical approval was obtained from the Health Research Ethics Committees of the University of Ibadan and the University of Lagos, with permission from state health authorities and community leaders. Confidentiality was protected by anonymising identifiers. Households with unsafe water were advised on treatment and referred to local WASH programmes. No participant was denied care for declining participation.

RESULTS

Participant characteristics and epidemic curve

A total of 412 cases and 824 controls were enrolled. Median age of cases was 16 years (interquartile range 7-31). Children under five years accounted for 26.2% of cases, children 5-14 years for 25.5%, and adults 15 years and above for 48.3%. Females accounted for 53.4% of cases. Of the 412 cases, 238 (57.8%) were laboratory-confirmed and 174 (42.2%) were epidemiologically linked. Cholera incidence peaked sharply with the onset of heavy rainfall (Figure 1). Cases rose from 14 in March to 52 in May, 88 in June and 96 in July, then fell to 32 in September and 11 in November. The monthly correlation between rainfall and cases was strong (Spearman rho = 0.84, $p < 0.001$), consistent with evidence that rainfall and flooding amplify cholera transmission in endemic urban settings (Emch et al., 2008; World Health Organization, 2024). All three settlements experienced outbreaks, but timing and peak differed by block, suggesting local amplification rather than a single city-wide point source.

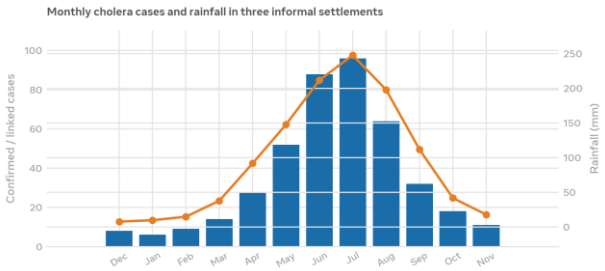


Figure 1. Monthly cholera cases and rainfall in three informal settlements.

Spatial analysis showed marked clustering. Cases clustered within 150 metres of shared water points and poorly drained latrine blocks, and scan statistics identified five significant clusters that together accounted for 46.8% of cases while covering 18.2% of the study population. Households within 50 metres of a poorly drained latrine block had a higher attack rate than households farther away, and blocks with both a shared water point and a flooded latrine had the highest block-level incidence. This pattern supports the hotspot concept, in which a small number of locations sustain disproportionate transmission and merit targeted intervention (Ali et al., 2015; Phelps et al., 2017; Global Task Force on Cholera Control, 2017).

Household risk factors

In univariable analysis, many household and behavioural factors were associated with illness. In multivariable conditional logistic regression, five factors remained independently associated with

cholera (Figure 2). Reliance on an unimproved water source had the strongest association (adjusted odds ratio [aOR] 3.12, 95% CI 2.18-4.46). Absence of household water treatment was associated with 2.48 times the odds (aOR 2.48, 95% CI 1.78-3.45). Sharing a latrine with more than ten households was associated with 2.21 times the odds (aOR 2.21, 95% CI 1.56-3.13). Nearby open defecation was associated with 1.94 times the odds (aOR 1.94, 95% CI 1.38-2.73), and absence of a handwashing station with soap and water was associated with 1.86 times the odds (aOR 1.86, 95% CI 1.32-2.62). Eating street-vended food and attending a funeral or communal gathering in the preceding week were also associated with illness, although their effects were attenuated after adjustment for water and sanitation factors. Higher household wealth and secondary education of the household head were protective. The magnitudes are comparable to pooled estimates for improved water, sanitation and hygiene in cholera and diarrhoeal disease prevention (Wolf et al., 2018; Wolf et al., 2022).

Table 1. Characteristics of cases and controls.

Characteristic	Cases (n=412) %	Controls (n=824) %	p-value
Age <5 years	26.2	25.8	0.88
Female	53.4	51.9	0.62
Unimproved water source	48.5	24.3	<0.001
No household water treatment	61.4	38.2	<0.001
Shared latrine >10 households	44.7	26.5	<0.001
Nearby open defecation	38.1	22.9	<0.001
No handwashing station	71.6	52.9	<0.001
Ate street-vended food (7 days)	36.9	28.4	0.003
Funeral / gathering (7 days)	18.2	12.5	0.007



Figure 2. Adjusted risk factors for cholera: conditional logistic regression.

Table 2. Multivariable conditional logistic regression: adjusted associations.

Risk factor	Adjusted OR	95% CI	p-value
Unimproved water source	3.12	2.18-4.46	<0.001
No household water treatment	2.48	1.78-3.45	<0.001
Shared latrine >10 households	2.21	1.56-3.13	<0.001
Nearby open defecation	1.94	1.38-2.73	<0.001
No handwashing station	1.86	1.32-2.62	<0.001
Ate street-vended food	1.62	1.14-2.30	0.007
Funeral / gathering exposure	1.58	1.09-2.29	0.016

Water, sanitation and hygiene observations

Systematic observation clarified why the quantitative associations arose. Piped supply was intermittent in all three settlements, with supply on a median of 3 days per week. On non-supply days, households relied on vendors, shallow wells and, in the rainy season, surface water. Storage vessels were repeatedly dipped by hand, and only 31.2% of observed households had a covered container with a tap or narrow neck. Among 96 water points observed, 58.3% had visible drainage problems and 41.7% had faecal contamination within 5 metres. Latrines were shared by a median of 12 households (range 4-38). During heavy rain, 64.6% of latrine blocks observed were flooded or had effluent overflowing into lanes. Handwashing stations were present in only 28.4% of case households compared with 47.1% of control households. Water testing showed that 62.5% of household storage samples were positive for *E. coli*, compared with 38.9% of source samples, indicating recontamination during collection, transport and storage, a problem well documented in low-resource settings (Wright et al., 2004; World Health Organization, 2017). Chlorinated stored water had significantly lower *E. coli* counts, but free residual chlorine was undetectable in 44.0% of samples reported as treated.

Table 3. Observation of water points, latrines and hygiene facilities.

Observation	Result
Water points observed	96
Piped supply, median days/week	3
Water points with drainage problems, %	58.3
Latrine blocks flooded during rain, %	64.6
Median households per latrine	12

Households with covered storage + tap, %	31.2
Household storage positive for E. coli, %	62.5
Reported treated water with no residual chlorine, %	44.0

Care-seeking, secondary transmission and targeted interventions

Median delay from symptom onset to first rehydration was 4.5 hours among cases who used a community oral rehydration point, compared with 9.2 hours among those who went directly to a facility and 13.8 hours among those who first tried home remedies without oral rehydration salts. Early rehydration was associated with shorter illness duration and fewer admissions for severe dehydration. Household secondary attack rate was 18.4% among household contacts of index cases, falling to 14.2% within 50 metres, 8.6% at 50-150 metres and 3.1% beyond 150 metres (Figure 3). Where CATI was delivered within 48 hours, the secondary attack rate in the surrounding ring was 5.2%, compared with 12.8% where CATI was delayed beyond 48 hours or not delivered. Targeted vaccination in high-risk blocks, delivered as part of a reactive campaign in one settlement, was associated with lower incidence in vaccinated blocks in the following 8 weeks, consistent with evidence that oral cholera vaccine can interrupt transmission while WASH improvements take effect (Azman et al., 2016; Qadri et al., 2018).

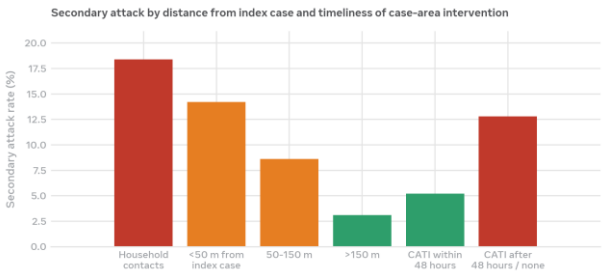


Figure 3. Secondary attack by distance from index case and timeliness of case-area intervention.

Qualitative findings

Four themes explained the quantitative patterns. First, water insecurity shaped every choice: residents described queuing, rationing and paying more on non-supply days, and choosing the nearest vendor even when they doubted its safety. Second, latrine sharing and flooding created shared risk: caretakers described latrines that were cleaned but then flooded, and residents described avoiding latrines at night or during rain and resorting to open defecation. Third, caregiving made hygiene hard: caregivers described struggling to wash hands, disinfect soiled linen and protect stored water while caring for ill relatives, often without gloves, soap or a separate container. Fourth, trust and timeliness shaped uptake: residents welcomed community oral rehydration points and CATI when teams arrived quickly, explained their work and returned for follow-up, but were sceptical of one-off distributions that arrived after an outbreak had peaked. These findings echo evidence on the social and practical dimensions of WASH and outbreak response (Curtis et al., 2011; World Health Organization, 2019).

DISCUSSION

This mixed-methods case-control study shows that cholera in urban informal settlements is not randomly distributed. It clusters in space and time around shared water points and poorly drained latrine blocks, it rises sharply with rainfall, and it is strongly associated with household water, sanitation and hygiene conditions that are themselves shaped by intermittent supply, flooding and crowding. The finding that reliance on an unimproved water source carried the strongest adjusted association is biologically plausible: unimproved sources are more vulnerable to faecal contamination, especially when drainage is poor and latrines flood (Wolf et al., 2018; Wolf et al., 2022). The independent associations with absence of water treatment, shared latrines, open defecation and absence of handwashing show that multiple pathways operate together. Interrupting only one pathway leaves others open, which is why combined, neighbourhood-level packages are more promising than single interventions.

The spatial and secondary transmission findings have direct operational implications. A secondary attack rate of 18.4% among household contacts, with a clear distance gradient, means that the hours and days after a case is notified are a window of opportunity. CATI delivered within 48 hours was associated with a substantially lower secondary attack rate, consistent with studies of case-area targeted interventions in Haiti, Yemen and the Democratic Republic of Congo (Parker et al., 2017; Azman et al., 2016). The implication is that surveillance must be linked to a rapid, pre-planned neighbourhood response, not merely to facility reporting. Community oral rehydration points reduced delay to rehydration, which is clinically decisive in cholera, where dehydration can progress within hours (Harris et al., 2012; World Health Organization, 2023).

The qualitative findings guard against a purely technical reading of the results. Residents did not lack knowledge that cholera is linked to water and sanitation; they lacked reliable supply, flood-resilient latrines, affordable soap and chlorine, and time and support to maintain hygiene while caregiving. Interventions that ignore these constraints, for example distributing chlorine without addressing storage vessels that are dipped by hand, or building latrines that flood in the first heavy rain, are likely to fail. A neighbourhood package should therefore combine reliable safe water, flood-resilient sanitation, point-of-use treatment with safe storage, hand hygiene, and rapid CATI, delivered with community co-design and maintenance arrangements. Oral cholera vaccine should be used to protect high-risk

blocks while WASH improvements are built, not as a substitute for them, because vaccine protection is time-limited and global supply remains constrained (Qadri et al., 2018; World Health Organization, 2023; World Health Organization, 2024).

Limitations should be acknowledged. Case-control studies are subject to recall bias and to selection bias if controls differ systematically from the population that gave rise to cases; matching by neighbourhood and age and use of active surveillance mitigate but do not eliminate these concerns. Not all cases were laboratory-confirmed, although epidemiologically linked cases were defined by strict criteria and sensitivity analysis excluding linked cases did not materially change the main associations. Water testing was cross-sectional and may not capture variation over time. The study was conducted in three settlements in one city and may not generalise to all informal settlements, although the mechanisms identified are likely to apply to other dense, flood-prone urban areas. Despite these limitations, the convergence of quantitative, spatial, observational and qualitative findings strengthens confidence in the conclusions.

CONCLUSION AND RECOMMENDATIONS

Cholera in urban informal settlements is predictable, clustered and preventable at neighbourhood level. The findings support a neighbourhood-level prevention package rather than facility-centred responses alone. First, city authorities and utilities should prioritise reliable safe water in cholera hotspots, including repair of intermittent supply, regulation of vendors, and provision of safe storage with taps or narrow necks. Second, sanitation should be flood-resilient: latrines should be raised, drained and maintained, with a maximum sharing threshold and caretaker support, and open defecation should be addressed through safe, accessible alternatives rather than penalties alone. Third, point-of-use treatment, soap and handwashing stations should be pre-positioned before the rainy season. Fourth, surveillance should trigger CATI within 48 hours, with community oral rehydration points in every high-risk block. Fifth, targeted OCV should be used in high-risk blocks as part of a credible WASH plan. If these steps are taken, informal settlements can move from seasonal emergency response towards sustained cholera control and contribute to the goal of ending cholera as a public health threat by 2030 (Global Task Force on Cholera Control, 2017).

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Conflict of interest

The authors declare that they have no competing interests.

Authors' contributions

Okafor C. N. conceived the study, supervised fieldwork and drafted the manuscript. Adeyemi S. O. coordinated data collection and laboratory liaison. Balogun K. A. led statistical and spatial analysis. Nwachukwu M. E. led qualitative analysis. Abdullahi Y. contributed to surveillance and CATI evaluation. Ezekiel P. T. contributed to water-quality testing and manuscript revision. All authors reviewed and approved the final manuscript.

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