Risk Factors for Epidemic Cholera in Lusaka, Zambia—2017

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Abstract. On October 6, 2017, the Zambia Ministry of Health declared a cholera outbreak in Lusaka. By December, 1,462 cases and 38 deaths had occurred (case fatality rate, 2.6%). We conducted a case-control study to identify risk factors and inform interventions. A case was any person with acute watery diarrhea (≥ 3 loose stools in 24 hours) admitted to a cholera treatment center in Lusaka from December 16 to 21, 2017. Controls were neighbors without diarrhea during the same time period. Up to two controls were matched to each case by age-group (1–4, 5–17, and ≥ 18 years) and neighborhood. Surveyors interviewed cases and controls, tested free chlorine residual (FCR) in stored water, and observed the presence of soap in the home. Conditional logistic regression was used to generate matched odds ratios (mORs) based on subdistricts and age-groups with 95% CIs. We enrolled 82 cases and 132 controls. Stored water in 71% of case homes had an FCR > 0.2 mg/L. In multivariable analyses, those who drank borehole water (mOR = 2.4, CI: 1.1–5.6), had close contact with a cholera case (mOR = 6.2, CI: 2.5–15), and were male (mOR = 2.5, CI: 1.4–5.0) had higher odds of being a cholera case than their matched controls. Based on these findings, we recommended health education about household water chlorination and hygiene in the home. Emergency responses included providing chlorinated water through emergency tanks and maintaining adequate FCR levels through close monitoring of water sources.

INTRODUCTION

Cholera causes an estimated 1.3–4.3 million illnesses and 30,000–140,000 deaths worldwide each year, with the majority reported from sub-Saharan Africa.¹ Cholera is caused by toxigenic *Vibrio cholerae* serogroup O1 or O139 and is transmitted through the fecal-oral route. As such, infection is usually associated with drinking contaminated water and poor hygiene and sanitation.^{2–4} In 1977, the WHO reported the first cholera case in Zambia; cases have been reported in most of the subsequent years.^{5,6}

Zambia's capital city, Lusaka (population, 2.3 million), has several peri-urban areas characterized by overcrowding and limited access to safe water and sanitation. According to the World Health Organization/United Nations Children's Fund (WHO/UNICEF) Joint Monitoring Program, 51% of urban residents in Zambia lacked access to basic sanitation and 14% lacked access to basic drinking water services in 2015.^{7,8} However, these figures likely underestimate water, sanitation, and hygiene (WASH)-related risk factors in the most underserved, high-density areas of Lusaka, where most of the population use pit latrines, and groundwater sources for drinking water are often contaminated.⁵ Previous studies during cholera outbreaks in these areas documented poor sanitation and contaminated food as risks, and drinking chlorinated water and good hygiene as protective against cholera.^{9–11}

On October 6, 2017, Zambia's Ministry of Health (MoH) declared a cholera outbreak after six cases were reported in Lusaka's Chipata subdistrict. By early December, 1,462 cholera cases and 38 deaths were reported, with an average of > 50 new cases per day in Lusaka.¹² Between October and December, the government and non-governmental

organization (NGO) partners installed emergency water tanks for community use, distributed household water treatment supplies, and trained community members on cholera prevention.¹² We conducted a case-control study in affected peri-urban areas of Lusaka to identify risk factors that could help target interventions to stop the outbreak.

MATERIALS AND METHODS

We conducted a case-control study at two of the four cholera treatment centers (CTCs) in Lusaka (Chipata and Matero subdistricts). Cases were defined as patients with acute watery diarrhea (≥ 3 loose stools in a 24-hour period), who had not traveled outside of Lusaka in the 5 days before illness onset, and were admitted to the CTC in Chipata or Matero subdistrict on or after December 16, 2017. At the time, this was the case definition used by the MoH. Enumerators attempted to enroll all cases from the line lists of the two CTCs prospectively starting December 16, 2017. Persons older than 18 years who gave oral consent were interviewed. Parents gave consent for children younger than 18 years to be interviewed; adolescents aged 12–17 years who assented were directly interviewed, while parents or guardians were interviewed on behalf of case children aged < 12 years.

Investigators attempted to match up to two controls to each case by age-group (1–4, 5–17, and ≥ 18 years) and proximity to the case homes. We did not match by gender because we felt there would be no gender-specific differences in risk and matching would have delayed identification of controls. Controls must have lived in a household in which no one (including themselves) had acute watery diarrhea since October 2017. We used this exclusion criterion because we wanted to decrease the likelihood of misclassifying an asymptomatic or very mild symptomatic case of cholera as a control. Furthermore, we wanted to be sure that they were susceptible to cholera infection during the spike in cases in December. Enumerators selected controls by identifying the

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fifth buildings to the right and left from the case homes. If no eligible and willing controls were identified, the surveyor proceeded in the same direction to the next building, continuing until a control was enrolled.

Hypothesis-generating interviews conducted with public health workers and patients in CTCs identified water sources, foods, and other eating places frequented by cases before illness onset. Enumerators administered a questionnaire to all participants interviewed in their home which covered demographics and cholera risk factors, including water and food exposures identified through hypothesis-generating interviews. Case questionnaires also included questions about symptoms and treatment. Cases were initially interviewed in the CTCs with a follow-up interview at their homes on the same day or a later day. The recall period for the interview was 7 days. Enumerators also made structured observations and tested stored drinking water in case and control homes for free chlorine residual (FCR) using Hach® chlorine color disc test kits (Loveland, CO). For analysis, we used a cutoff of 0.2 mg/L, the WHO-recommended minimum amount of chlorine for household water storage; the WHO recommends 0.5 mg/L at water points in piped water supplies during cholera outbreaks.¹³

If a case did not provide an address, or if their home could not be found, data from their CTC interview were included in the clinical, demographic, and social descriptors, as well as risk factor analysis from the survey completed in the CTC, but they were excluded from risk factor analyses derived from the in-home questionnaire, and no matched controls were enrolled. To enable a broader comparison of exposures across cases and controls and to compensate for missing controls for cases whose homes could not be located, a new matching variable based on the subdistrict and age-group was constructed.

We used SAS 9.4 (Cary, NC) to perform exact conditional logistic regression for each variable of interest. Resulting *P*-values were adjusted using the false discovery rate to control for multiple comparisons. Relationships between variables were investigated through a process that included assessing correlations, variance inflation factors, and clustering patterns of variables. Forward selection with both main effects and two-way interactions was used to select the order in which variables would be added to the multivariable model using conditional logistic regression. The number of factors added to the model was limited to five based on the number of cases. The FCR variable was excluded because cases received water treatment product in the CTC and many had treated their water before surveyors made observations in their homes. The Bayesian information criterion (BIC) was used to determine which candidate model to select and to investigate two-way interactions between main effects.

This research was exempted from ethical review in Zambia because it was part of an outbreak response. The Institutional Review Board at the CDC determined that this work was for outbreak response and public health practice and issued a non-research determination.

RESULTS

We enrolled 82 cases and 132 controls between December 16, 2017 and 21, 2017. Of the 82 cases, 22 were interviewed only at the CTC and 60 were interviewed at the CTC and

received a follow-up interview in the home. The most common symptoms reported by cases were diarrhea (91%), vomiting (76%), and stomachache (13%). Most cases (60%) arrived at the CTC within 12 hours of becoming ill, and 48% arrived within 6 hours (Table 1).

The range, interquartile range, and median age of cases (1–74, 7–32, and 22 years) and controls (1–90, 11–37, and 25 years) were similar. A higher proportion of cases (54%) than controls (30%) were male ($P < 0.01$). The median household size was six persons for both cases and controls, and the education level was similar in both groups (Table 2). More cases reported employment than controls (53% of cases and 33% of controls, matched odds ratio [mOR] 2.5, 95% CI: 1.3–5.0).

Respondents reported municipal sources as the most common source of drinking water (57% of cases and 52% of controls), followed by boreholes (35% of cases and 23% of controls) and shallow wells (6% of cases and 5% of controls); 44% of cases and 29% of controls who reported using municipal water as their primary source also reported using boreholes or shallow wells as secondary drinking water sources. Most (84% of cases and 88% of controls) reported having insufficient water supply from any source in their homes. Reporting using borehole water for drinking (mOR = 2.3, CI: 1.1–4.8) and drinking water from outside the home (mOR = 2.0, CI: 1.0–3.9) were associated with being a case (Table 3).

More than half of respondents reported drinking what they perceived was untreated water (74% of cases and 55% of controls; mORs 2.7, CI: 1.3–5.9). Most cases and controls (62% versus 69%) reported treating their water in the week before the interview, with chlorination as the most commonly used method (63% versus 62%). Surveyors observed water chlorination product in 78% of case homes and 64% of control homes; testing indicated that stored drinking water in 71% of case homes and 44% of control homes had > 0.2 mg/L FCR. Safe water storage in a closed container that prevents contamination was uncommon among both cases and controls; only 13% of cases and 15% of controls stored water in a jerrican, and most stored their water in open buckets. Surveyors observed soap for handwashing in fewer case homes

TABLE 1
Clinical characteristics of enrolled cases (*N* = 82), cholera outbreak in Zambia, 2017

Characteristic	<i>n</i> (%)
Symptoms	
Diarrhea	75 (91)
Vomiting	62 (76)
Stomachache	11 (13)
Headache	2 (2)
Leg cramps	4 (5)
Most stools in 24 hours after becoming ill	
0–3	20 (24)
4–9	40 (49)
> 10	11 (13)
Time (hours) from onset of illness to arrival at the cholera treatment center	
0–1	23 (31)
2–6	13 (17)
7–12	9 (12)
13–24	18 (24)
> 24	12 (16)

TABLE 2
Demographic and social characteristics of enrolled cases and controls, cholera outbreak in Zambia, 2017

Characteristic	Cases		Controls		P-value
	Median	Range	Median	Range	
Age (years)	22	1–74	25	1–90	0.20
Number of people in household	6	1–13	6	1–15	0.84
Gender	<i>n</i> (%)		<i>n</i> (%)		< 0.01 reference
Female	39 (1)		92 (69)		
Male	44 (54)		39 (30)		
Education					reference 0.74 0.87 1 –
None	10 (13)		14 (11)		
Any primary school	29 (36)		45 (35)		
Any secondary school	30 (38)		47 (37)		
Any postsecondary school	11 (14)		20 (16)		
Other	0		2 (2)		
Employment					0.06
Any	40 (53)		37 (33)		

than control homes (33% versus 59%; mOR 0.4, CI: 0.19–0.71) (Table 3).

Several food and contact exposures were associated with being a case, including having eaten michopo (roasted meat) (mOR = 3.6, CI: 1.1–14.1) or cold nshima (cornmeal porridge) (mOR = 2.6, CI: 1.0–7.1), having contact with a cholera case (mOR = 5.7, CI: 2.3–15.3), and sharing a latrine with a cholera case (mOR = 4.1, CI: 1.4–13.8).

The multivariable model selected included having close contact with a cholera case, drinking borehole water, and being male as the inclusion of additional variables did not further reduce the BIC. As with the univariate analyses, those who drank borehole water (mOR = 2.4, CI: 1.1–5.6), had close contact with a cholera case (mOR = 6.2, CI: 2.5–15), and were male (mOR = 2.5, CI: 1.4–5.0) had higher odds of being a case than their matched controls (Table 4). Two-way interactions involving main effects selected were investigated but were not included in the final model because they did not reduce the BIC.

DISCUSSION

We found that contact with a cholera case, being male, and drinking borehole water were associated with being a cholera case in Lusaka during this outbreak. The outbreak likely persisted because of intermittent availability of municipal water, leading to use of other water sources, including unsafe boreholes and shallow wells, and secondary transmission among contacts. The high density of pit latrines, boreholes, and shallow wells throughout peri-urban Lusaka may have contributed to the spread of cholera through cross contamination of ground water by leakage from pit latrines.

Water was first implicated as a vehicle for cholera in 1854 and continues to be a major driver of cholera transmission today.^{14,15} This study identified drinking from a borehole as a risk for cholera but found no risk associated with using the municipal supply as the primary household water source. However, 44% of cases and 29% of controls who reported using municipal water also reported using boreholes or shallow wells; these secondary sources may have been contaminated.

Microbial analysis of randomly selected drinking water sources, including municipal water points, in the cholera-affected neighborhoods in Lusaka in January 2018, is consistent with our findings. Of 220 water points tested, 91% of

shallow wells and 34% of boreholes were contaminated with *E. coli*, an indicator of fecal contamination.¹² These findings are consistent with the association we identified between cholera risk and drinking water from boreholes. Few respondents (6% of cases and 5% of controls) said they used shallow wells for drinking water, so although more of these were contaminated with *E. coli*, statistical analysis did not identify them as a risk for cholera.

Ground water sources in Lusaka are known to be especially vulnerable to contamination because of the widespread use of pit latrines in close proximity to wells and boreholes, as well as unique features of the limestone karst geology of the region that allows contaminants to flow unfiltered into the aquifer,^{16–18} enabling fecal contamination of ground water-derived water sources. Our findings are consistent with multiple reports from cholera outbreaks in cities that identify inadequate WASH conditions in densely crowded areas as a risk.^{19–23} Until municipal infrastructure for centralized water treatment and safe delivery of adequate quantities of treated water to Lusaka residents is in place, communities will remain at risk of cholera. Findings from this study highlight the need for more decentralized water treatment, at the household or community level, to reduce this risk.^{24–26}

Cholera risk has been estimated to be 36–100 times greater for people with neighborhood or household contacts with cholera cases.^{27,28} Potential routes of infection include co-primary infection from consumption of a common contaminated food or water source, and secondary transmission via a food or water vehicle contaminated by an infectious housemate or neighbor.^{27,29–31} Secondary transmission is facilitated by poor water and hygiene conditions in the household.¹⁵ In case and control homes, we identified a low reported use of soap (33% for cases and 59% for controls), which could increase the risk for secondary transmission. Safe household water storage in a jerrican or a bucket with a secure lid and a tap may reduce the risk of secondary transmission within the household but was infrequent in both case and control households—and absent household water treatment, this would not prevent co-primary transmission from water that is contaminated before it reaches the home.

A study of cholera in Lusaka during an outbreak in 2003–2004 identified the presence of hand soap in the home and eating kapenta, or small dried fish, as protective against cholera.⁹ We identified both of these factors, and eating other types of fish, as protective in univariate analysis, although only

TABLE 3
Individual factors for cholera, cholera outbreak in Zambia, 2017

Exposure	Cases	Controls	Matched odds ratio	95% CI****	P-value	False discovery rate P-value
	(N = 82) n (%)	(N = 132) n (%)				
Demographics						
Female	39 (31)	92 (69)	0.4	0.22–0.78	< 0.01	0.06
4+ people in household	57 (70)	91 (69)	0.9	0.45–1.75	0.83	1
Any employment	40 (53)	37 (33)	2.5	1.25–4.97	< 0.01	0.08
Food						
Nuts	20 (28)	42 (33)	0.6	0.29–1.32	0.25	0.24
Fish	39 (50)	80 (62)	0.6	0.29–1.05	0.07	0.29
Raw fruit or vegetables	55 (71)	96 (74)	0.7	0.32–1.44	0.35	0.77
Chicken	50 (67)	93 (72)	0.7	0.35–1.38	0.33	0.75
Ate at a wedding, funeral, or other gatherings	9 (11)	19 (14)	0.8	0.28–2.07	0.78	1
Kapenta	29 (39)	55 (42)	0.9	0.43–1.66	0.73	1
Beef	34 (44)	58 (45)	0.9	0.45–1.63	0.74	1
Cassava	15 (20)	20 (16)	1.1	0.44–2.43	1	1
Porridge	27 (36)	40 (31)	1.1	0.56–2.29	0.82	0.24
Samosas	37 (48)	61 (48)	1.1	0.55–1.99	1	1
Maize	32 (42)	40 (32)	1.4	0.7–2.76	0.38	0.8
Cold rice	9 (13)	7 (6)	2.1	0.57–7.89	0.32	0.75
Cold nshima	19 (25)	14 (11)	2.6	1.03–7.09	0.04	0.24
Michopo	10 (14)	7 (5)	3.6	1.05–14.13	0.04	0.24
Drinking water source						
Municipal water	48 (57)	28 (52)	0.9	0.32–2.57	1	1
Borehole	28 (35)	30 (23)	2.3	1.14–4.83	0.03	0.21
Shallow well	7 (6)	4 (5)	0.6	0.10–2.96	0.78	1
Reported drinking water outside the house	21 (64)	57 (47)	2	1–3.87	0.05	0.24
Reported drinking untreated water	21 (74)	71 (55)	2.7	1.32–5.93	< 0.01	0.06
Household reports insufficient water supply	67 (84)	114 (88)	0.7	0.26–1.65	0.42	0.8
Water treatment						
Reported treating water	46 (62)	82 (69)	0.7	0.33–1.49	0.4	0.8
Reported treating water by boiling	21 (6)	17 (13)	0.5	0.12–1.38	0.2	0.62
Reported treating water by chlorination	21 (63)	85 (64)	1	0.49–1.99	1	1
Reported chlorinating water within 5 days of survey	21 (42)	70 (55)	0.6	0.29–1.13	0.14	0.5
Sanitation						
Shared latrine with a neighbor	64 (79)	108 (83)	0.9	0.36–2.03	0.83	1
Contact						
Neighbor had cholera	34 (43)	47 (39)	1.2	0.61–2.31	0.7	1
Shared latrine with a case	14 (22)	7 (6)	4.1	1.36–13.8	< 0.01	0.08
Reported close contact with a cholera case	21 (34)	9 (7)	5.7	2.31–15.25	< 0.01	< 0.01
Reported receiving oral cholera vaccine	1 (1)	5 (4)	0.3	0.01–3.28	0.51	0.92
	Cases	Controls				
	(N = 60)	(N = 132)				
In-home observations	n (%)	n (%)	Matched odds ratio	95% CI	P-value	False discovery rate P-value
Water treatment						
Surveyor observed chlorine in house	46 (78)	68 (64)	2.4	1–5.81	0.07	0.29
Stored water had free chlorine > 0.2 mg/mL	42 (71)	58 (44)	3.3	1.74–6.22	< 0.01	< 0.01
Water storage						
Bucket	39 (65)	108 (82)	0.4	0.21–0.91	0.02	0.19
Jerrican	8 (13)	20 (15)	1	0.37–2.34	1	1
Hygiene						
Surveyor observed soap in house	20 (33)	77 (59)	0.4	0.19–0.71	< 0.01	0.06

the presence of soap was statistically significant. In the multivariate analysis, we excluded soap because it was one of the variables with a high rate of missingness (possibly due to challenges in making observations) and we did not find kapenta or other fish to be protective.

This study is subject to limitations. The case definition included children younger than 5 years; however, the WHO case

definition excludes children younger than 5 years because other diarrheal diseases are common in this age group. It is possible that we enrolled some children who did not have cholera as cases. Excluding controls who had a recent case of diarrhea in their household could bias the association of being a case and contact with cholera cases away from the null hypothesis.

TABLE 4
Factors independently associated with cholera, cholera outbreak in Zambia, 2017

Exposure	Cases (N = 60)	Controls (N = 132)	Matched odds ratio	95% CI		P-value
	n (%)	n (%)		Low	High	
Used borehole for drinking water	28 (34.6)	30 (23.1)	2.4	1.1	5.6	0.038
Had close contact with a cholera case	21 (33.8)	9 (7.1)	6.2	2.5	15	< 0.0001
Male	44 (54.3)	39 (30)	2.5	1.4	5	0.0036

Chlorination efforts in homes likely shifted over the course of the outbreak because of provision of household water treatment product and messages from health facilities or community health promotion activities.¹² Similarly, efforts to chlorinate municipal water at the source and at distribution points began in December 2017 but were inconsistent over time and place during the outbreak; therefore, WASH conditions and measurements taken during household visits may have differed from WASH conditions preceding cases' illness onset dates.

On discharge from CTCs, cases were given bottles of chlorine to treat their water, and the presence of these bottles and adequate FCR in stored water were significantly more common in case households. We dropped these variables from the multivariate analysis because they reflected reverse causality, attributable to the recent guidance and chlorine provided to cases on discharge from the CTC, but not to controls.

Another challenge was difficulty locating case homes; this resulted in some cases with no data from the in-home questionnaires and fewer enrolled controls. These cases were retained in the analytic analyses, as there were still data available from interviews performed in the CTC, and matching was based on the subdistrict and age-group and not on the proximity to the case's home. Data gathered from the in-home observations were excluded from the multivariate analysis to reduce possible influence of bias.

Males had increased odds of case status, but they comprised only 39% of controls. Selection bias may be one reason for this finding, as the study was conducted during the day when many men are working outside the home. Similarly, more controls were unemployed than cases.

We did not use laboratory testing to confirm cases or to exclude controls. About 50–75% of cholera infections are asymptomatic, and it is possible that we misclassified some persons with asymptomatic cholera infection as controls.^{32,33} Misclassification of cases or controls would bias measured associations toward the null. Questions about exposures and practices in the previous week are susceptible to recall bias. Finally, this study was cross-sectional and is therefore not able to show causality.

Preliminary results from the household survey and water quality testing were provided to the MOH to help guide outbreak control interventions. In January and February 2018, the MoH implemented large-scale interventions: hyper-chlorination of the municipal water supply, increased coverage of emergency water tanks in the most affected neighborhoods, continued provision of household water treatment products; and implementation of a large-scale oral cholera vaccine campaign. Cases declined sharply in January, increased slightly in March as a result of heavy rains and water shortages, and declined through April and May.¹² The MoH declared the outbreak over in June 2018.

This study found an association between cholera transmission and drinking water from boreholes, which were likely contaminated with feces, as indicated by the presence of *E. coli*. This study also identified risks within households of secondary transmission through contact with cases, as well as risks from contaminated groundwater. This highlights the need for improved WASH practices, including those focused on safe water and hygiene, in households. These cholera risks are common: 30% percent of people in the world lack access to clean water and 60% lack access to safely managed sanitation.³⁴ The Sustainable Development Goal #6 calls for access to water and sanitation for all; this study adds to the body of evidence that highlights the importance of WASH in preventing and controlling cholera.

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REFERENCES

1. Ali M, Nelson AR, Lopez AL, Sack DA, 2015. Updated global burden of cholera in endemic countries. *PLoS Negl Trop Dis* 9: e0003832.
2. Clemens JD, Nair GB, Ahmed T, Qadri F, Holmgren J, 2017. Cholera. *Lancet* 390: 1539–1549.
3. UNICEF, 2017. *UNICEF Cholera Toolkit*. Available at: https://www.unicef.org/cholera/index_71222.html. Accessed May 5, 2020.
4. Davis W, Narra R, Mintz ED, 2018. Cholera. *Curr Epidemiol Rep* 5: 303–315.
5. Olu O, Babaniyi O, Songolo P, Matapo B, Chizema E, Kapin'a-Kanyanga M, Musenga E, Walker O, 2013. Cholera epidemiology in Zambia from 2000 to 2010: implications for improving cholera prevention and control strategies in the country. *East Afr Med J* 90: 324–331.

6. WHO, 2011. *Cholera Country Profile: Zambia*. Available at: <http://www.who.int/cholera/countries/ZambiaCountryProfile2011.pdf?ua=1>. Accessed May 5, 2020.
7. JMP, 2007. *JMP Lusaka Data*. Available at: <https://washdata.org/data#/table?geo0=region&geo1=sdg>. Accessed May 5, 2020.
8. JMP, 2017. *Progress on Drinking Water, Sanitation and Hygiene. UNICEF, WHO Joint Monitoring Project*. Available at: <http://www.who.int/mediacentre/news/releases/2017/launch-version-report-jmp-water-sanitation-hygiene.pdf>. Accessed May 5, 2020.
9. DuBois AE, Sinkala M, Kalluri P, Makasa-Chikoya M, Quick RE, 2006. Epidemic cholera in urban Zambia: hand soap and dried fish as protective factors. *Epidemiol Infect* 134: 1226–1230.
10. Sasaki S, Suzuki H, Igarashi K, Tambatamba B, Mulenga P, 2008. Spatial analysis of risk factor of cholera outbreak for 2003–2004 in a peri-urban area of Lusaka, Zambia. *Am J Trop Med Hyg* 79: 414–421.
11. CDC, 2004. Cholera epidemic associated with raw vegetables—Lusaka, Zambia, 2003–2004. *MMWR Morb Mortal Wkly Rep* 53: 783–786.
12. Sinyange N et al., 2018. Cholera epidemic - Lusaka, Zambia, October 2017–May 2018. *MMWR Morb Mortal Wkly Rep* 67: 556–559.
13. WHO, 2017. *Guidelines for Drinking Water Quality, Incorporating the First Addendum*, 4th edition. Available at: https://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/. Accessed May 5, 2020.
14. Snow J, 1855. *Mode of Communication of Cholera*. London, United Kingdom: John Churchill.
15. Wolfe M, Kaur M, Yates T, Woodlin M, Lantagne D, 2018. A systematic review and meta-analysis of the association between water, sanitation, and hygiene exposures and cholera in case-control studies. *Am J Trop Med Hyg* 99: 534–545.
16. DeWaele J, Follesa R, 2003. Human impact on karst: the example of Lusaka. *Int J Speleol* 32: 71–83.
17. Nkhuwa DCW, Kafula T, Ahmed AH, 2008. A preliminary inventory of hazardous medical waste disposal systems and their influence on groundwater quality in Lusaka. *Med J Zambia* 35: 129–138.
18. Sorensen JPR et al., 2015. Emerging contaminants in urban groundwater sources in Africa. *Water Res* 72: 51–63.
19. Moore S et al., 2018. Dynamics of cholera epidemics from Benin to Mauritania. *PLoS Negl Trop Dis* 12: e0006379.
20. Ezeh A et al., 2017. The history, geography, and sociology of slums and the health problems of people who live in slums. *Lancet* 389: 547–558.
21. McCrickard LS et al., 2017. Cholera mortality during urban epidemic, Dar es Salaam, Tanzania, August 16, 2015–January 16, 2016. *Emerg Infect Dis* 23: S154–S157.
22. Azman AS et al., 2018. Micro-hotspots of risk in urban cholera epidemics. *J Infect Dis* 218: 1164–1168.
23. Dunkle SE et al., 2011. Epidemic cholera in a crowded urban environment, Port-au-Prince, Haiti. *Emerg Infect Dis* 17: 2143–2146.
24. Rajasingham A et al., 2019. Evaluation of an emergency bulk chlorination project targeting drinking water vendors in cholera-affected wards of Dar es Salaam and Morogoro, Tanzania. *Am J Trop Med Hyg* 100: 1335–1341.
25. Lantagne D, Yates T, 2018. Household water treatment and cholera control. *J Infect Dis* 218 (Suppl_3): S147–S153.
26. Clasen T, 2015. Household water treatment and safe storage to prevent diarrheal disease in developing countries. *Curr Environ Health Rep* 2: 69–74.
27. Burrows V et al., 2017. Risk factors for household transmission of *Vibrio cholerae* in Dhaka, Bangladesh (CHoBI7 Trial). *Am J Trop Med Hyg* 96: 1382–1387.
28. Debes AK, Ali M, Azman AS, Yunus M, Sack DA, 2016. Cholera cases cluster in time and space in Matlab, Bangladesh: implications for targeted preventive interventions. *Int J Epidemiol* 45: 2134–2139.
29. Holmberg SD, Harris JR, Kay DE, Hargrett NT, Parker RD, Kansou N, Rao NU, Blake PA, 1984. Foodborne transmission of cholera in Micronesian households. *Lancet* 1: 325–328.
30. Sugimoto JD et al., 2014. Household transmission of *Vibrio cholerae* in Bangladesh. *PLoS Negl Trop Dis* 8: e3314.
31. Weil AA et al., 2014. Bacterial shedding in household contacts of cholera patients in Dhaka, Bangladesh. *Am J Trop Med Hyg* 91: 738–742.
32. Nelson EJ, Harris JB, Morris JGJ, Calderwood SB, Camilli A, 2009. Cholera transmission: the host, pathogen and bacteriophage dynamic. *Nat Rev Microbiol* 7: 693–702.
33. Jackson BR et al., 2013. Seroepidemiologic survey of epidemic cholera in Haiti to assess spectrum of illness and risk factors for severe disease. *Am J Trop Med Hyg* 89: 654–664.
34. WHO, UNICEF, 2017. *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*. Geneva, Switzerland: World Health Organization.