

Drinking water quality and human dimensions of cholera patients to inform evidence-based prevention investment in Karonga District, Malawi

Prince Kaponda, Suresh Muthukrishnan, Rory Barber and Rochelle H. Holm

ABSTRACT

Cholera remains a problem in sub-Saharan Africa, especially in Malawi. Our aim was to investigate drinking water source quality compared with water treatment, risk perception and cholera knowledge for patients who had reported to a health center for treatment in the 2017–2018 outbreak in Karonga District, Malawi. The study analyzed 120 drinking water samples linked to 236 cholera patients. Nearly 82% of the samples met the national criteria for thermotolerant coliforms of 50 cfu/100 ml, while 50% met the more stringent World Health Organization criteria of 0 cfu/100 ml. In terms of the human dimensions, 68% of survey respondents reported that they treated their water, while knowledge of prevention, transmission and treatment of cholera was also generally high. However, of the 32 patients whose drinking water sources had thermotolerant coliforms of 200+ cfu/100 ml, seven reported they felt a low or no personal risk for contracting cholera in the future and their community was extremely well prepared for another outbreak. The cost of a reactive response to cholera outbreaks puts a burden on Malawi, providing an opportunity for investment in innovative and localized preventive strategies to control and eliminate the risk of cholera while acknowledging social and cultural norms.

Key words | behavior change, cholera, drinking water, household water treatment, Malawi

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INTRODUCTION

Vibrio cholerae remains a global public health problem linked to fecal–oral disease transmission. There is a high burden of cholera in the low- and middle-income countries of sub-Saharan Africa (Momba & Azab El-Liethy 2017). Montgomery *et al.* (2018) maintain that cholera response using the oral vaccine should only be an interim solution alongside sustainability in maintaining access to safe drinking water, sanitation and hygiene. Villeminot (2018)

additionally notes cholera responses should move away from a dependence on government and free distribution of water and hygiene items from relief agencies and instead include investment in a market-based approach including locally available soap, chlorine water treatment and improved drinking water storage.

Bwire *et al.* (2017) have shown that in Uganda, shoreline communities have a higher burden of cholera compared with the general population due to the use of contaminated lake water and poor sanitation and hygiene practices. Malawi has experienced regular cholera outbreaks since 1973 (UNICEF 2018), occurring mostly during the rainy

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season from September until May. Changes in climate patterns, including El Niño events, are linked to occurrences of cholera. Using climatic forecasts, [Moore *et al.* \(2017\)](#) predict that Malawi will likely have even more cholera outbreaks due to El Niño events, indicating a need to investigate social and water quality linkages to cholera as part of investment recommendations for local communities as well as for the government.

In the 2017–2018 rainy season, 13 out of 28 districts in Malawi reported cholera cases, of which Karonga District in northern Malawi had the highest cholera incidence rate. In this district, Lake Malawi serves as an economic resource for small-scale fisheries ([Karonga District Council 2013](#)). Most cholera research to date in Malawi has been focused on the southern regions ([Swerdlow *et al.* 1997](#); [Msyamboza *et al.* 2014](#)), but Malawi has great geographic variability in ethnic groups ([National Statistical Office & ICF 2017](#)) and in associated cultural norms and beliefs. Existing water quality literature for Karonga District has highlighted health-related issues ([Manda & Wanda 2017](#); [Mapoma *et al.* 2017](#)).

The purpose of our case study was to investigate water quality at the primary drinking water sources used by cholera patients in northern Malawi and to compare these data with people's water treatment practices, risk perception and knowledge of cholera to inform evidence-based prevention investment.

METHODS

Study site

The Karonga District is located in the northern part of Malawi with a population of 365,000 people as of 2018 and an area of 3,400 km². The district is subdivided geographically into five Traditional Authorities ([National Statistical Office 2018](#)). Culturally, Karonga District consists predominantly of people from the Ngonde ethnic group, who represent less than 1% of the national population, as well as people from the Tumbuka ethnic group, representing less than 10% of the national population ([Karonga District Council 2013](#); [National Statistical Office & ICF 2017](#)).

There were 347 suspected cases of cholera for which patients reported to a health center for treatment in the

district between November 2017 and March 2018. Of these, 343 were single cases while four patients were reported to have been admitted to a health facility more than once (Malawi Government Ministry of Health, personal communication, 18 May 2018). During the outbreak, Karonga District had a case fatality rate of 1.2% and no drinking water surveillance was conducted. The oral cholera vaccination, EuvicholTM, was delivered in February and March 2018 to an estimated 108,000 people in the district ([M'bangombe *et al.* 2018](#); [UNICEF 2018](#)).

Data collection methods

Cholera in this paper refers to suspected cholera, as cases were not systematically confirmed. Our study was not a case-control study. Data on suspected cholera cases, including a person's age, gender and survival outcome, were provided by the Malawi Government Ministry of Health. Patient interviews were conducted during August 2018 and attempted to reach each of 343 patients or a relative in the same household. For the case of a deceased patient, a relative who lived in the same household was surveyed. For the case of children, an adult was interviewed on their behalf. In total, 236 of 343 patients were located.

Drinking water sample analysis included thermotolerant coliforms, turbidity, pH and electrical conductivity. Because cholera transmission is via the fecal–oral route and due to the logistics of working in a rural district, thermotolerant coliforms were selected as a reliable indicator of fecal contamination for this study ([World Health Organization \(WHO\) 2017](#)). Analyses of samples were performed in duplicate and the samples were not filtered. For thermotolerant coliforms, the samples were collected in Whirl-Pak[®] bags with sodium thiosulfate (Nasco, Fort Atkinson, WI, USA). Most analyses were performed within 8 hr of collection, although, due to field logistics and long travel times on a rural road network, a few (14) samples were analyzed within 11 hr of collection. Ice was not available for sample storage. For thermotolerant coliforms the Wagtech Potatest[®] Membrane Filtration Unit (Gateshead, UK) used 100 ml samples incubated at 44 °C for 18 hr. Each day, one equipment blank was used to check field laboratory contamination for thermotolerant coliforms using boiled and cooled water, and each showed zero colony-forming

units (cfu)/100 ml. Where more than 200 cfu were observed per plate, the result 'Too Numerous to Count' and >200 cfu/100 ml was reported. No dilutions of the samples were performed. For other analyses, samples were collected into a Whirl-Pak[®] bag without preservative (Nasco, Fort Atkinson, WI, USA). Determination of pH was done using a Wagtech[®] or Palintest[®] pocket pH meter. Electrical conductivity was determined using the Ohaus[®] Starter 3100C bench conductivity meter (Parsippany, USA). Jackson turbidity tubes were used for turbidity measurements.

For each patient, an interview was conducted in the local language (Chitumbuka, Chichewa or Chingonde), water source site observations were made and GPS readings were taken. The interviews were designed to assess patient knowledge of cholera and hygiene practices. This included questions on causes and transmission pathways, methods for cholera treatment, methods of prevention and the patient's perception of his or her own risk. The interview questions were collected on an Android device using Open Data Kit (ODK) software (Open Source, University of Washington, Seattle, WA, USA).

The cost of investment recommendations based on locally available market systems providing water and hygiene items was obtained through the authors' personal communications.

Data analysis

Data analysis investigated social and water quality linkages to cholera patients in a local area in Malawi.

Water quality data were analyzed using the R Project 3.5.1 statistical package (Vienna, Austria). Water quality results were compared with both the national and WHO guidelines (Malawi Bureau of Standards (MBS) 2005; WHO 2017). If the *p* value was less than the significance level of 0.05, we concluded there were significant differences.

For six cases, patients reported use of more than one drinking water source. In these cases, samples from each source were collected and analyzed. The higher-risk samples (based on thermotolerant coliforms and/or electrical conductivity) were subsequently linked to the patient. Additionally, for 116 patients who shared their water source with another person who had contracted cholera, the same water samples were linked to each patient using the water source.

The patient interview data were coded by hand based on an *a priori* framework. Three scores were developed for each patient: (1) safe water treatment practices; (2) knowledge of cholera; and (3) risk perception. For safe water treatment practices, respondents were ranked as 'good' if they reported practicing boiling, using chlorine or using a water filter; ranked as 'moderate' for reporting they let water settle or strained it through a cloth; and 'poor' for performing no treatment. Researchers did not independently verify reported household water treatment practices. For cholera knowledge, given that all respondents had been admitted for cholera or had a family member admitted, they likely had received information regarding symptoms and treatment. Respondents were ranked as having 'good', 'moderate,' or 'poor' knowledge based on their reporting with one or more responses to five survey questions on prevention, transmission and treatment. For the future cholera risk perception assessment, respondents were ranked as 'low', 'moderate,' or 'high' based on two survey questions: 'What level of risk do you think you have in getting cholera?' and 'How confident are you that your village/community/area can control the spread of cholera if there were another outbreak in the future?' The full survey questions can be found in the Supplementary Material section (available with the online version of this paper).

Ethics

Ethical clearance for this study was obtained from the Government of Malawi, National Commission for Science and Technology (Protocol Number P.07/18/291) and the National Health Sciences Research Committee (Protocol Number 18/07/2077). Verbal consent was obtained from respondents.

RESULTS

Source drinking water quality

This study analyzed 120 drinking water source samples linked to 236 cholera patients (69% of patients could be tracked) (Figure 1).

Based on the levels of thermotolerant coliforms, many patients had safe drinking water with 82% (98/120) meeting

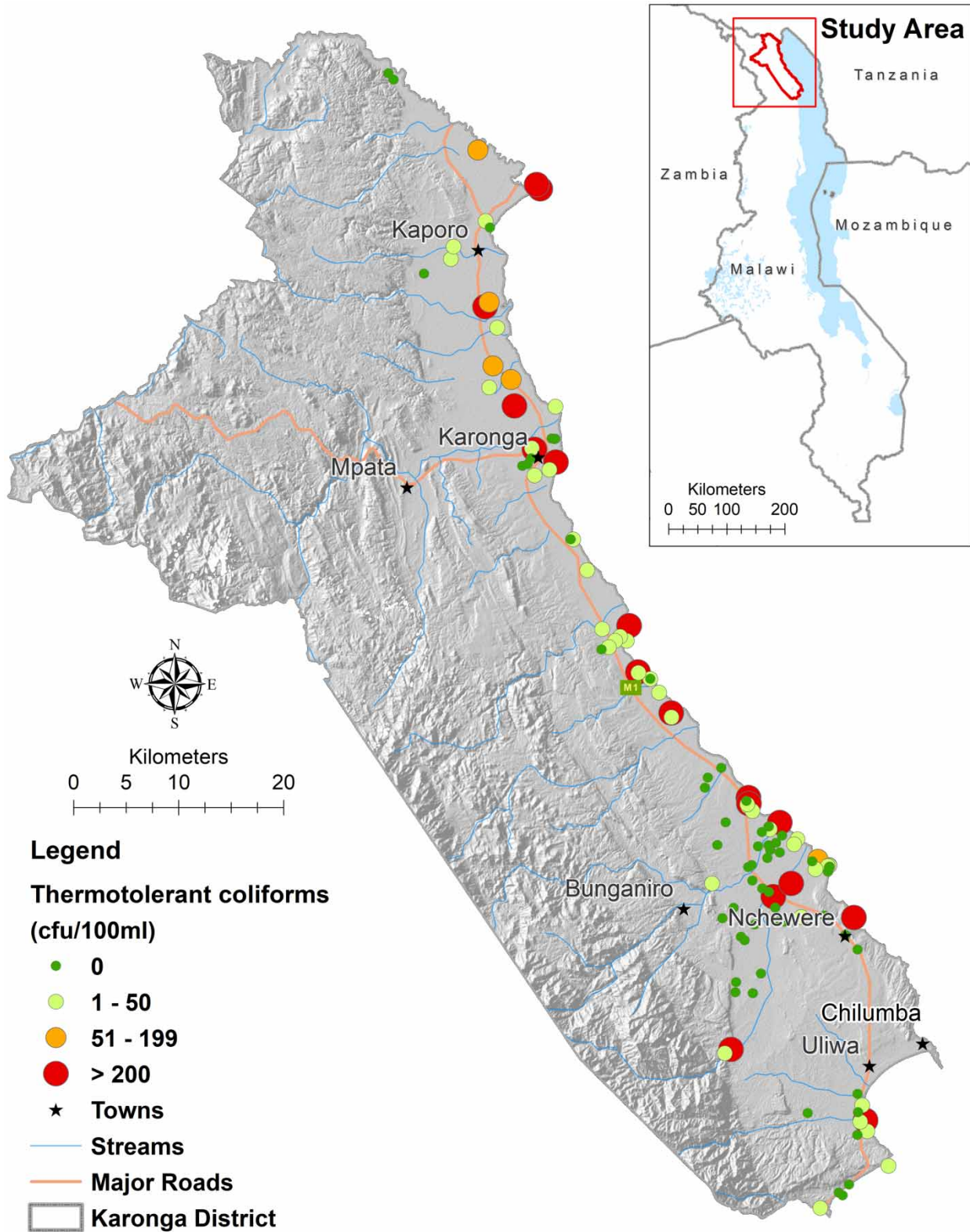


Figure 1 | Thermotolerant coliforms in drinking water sources for cholera patients, Karonga District, Malawi ($n = 120$ water sources covering 236 cholera patients).

the MBS (2005) drinking water criteria of 50 cfu/100 ml, while 50% (60/120) met the more stringent WHO (2017) guideline of 0 cfu/100 ml. Among 120 drinking water sources, 29 (24%) were from Lake Malawi. Of these 29 samples, nine met the WHO guideline and 22 met the MBS guideline for thermotolerant coliforms. While all samples passed the national (MBS 2005) criteria for electrical conductivity, 5% (6/120) had electrical conductivity >1,000 $\mu\text{S}/\text{cm}$. In addition, most samples met the national (MBS 2005) criteria for pH (112/120 were between 6.0 and 9.5; 93%) and for turbidity (107/120 were ≤ 25 JTU; 89%).

A Kruskal–Wallis rank sum test for the thermotolerant coliform counts by Traditional Authority ($n = 120$) indicated there were differences ($p < 0.05$) based on where the patients lived.

Determinants of water quality

Over half (127/236; 54%) of patients reported they collected drinking water from an improved water source (protected shallow well, borehole or piped water). Patients drinking from unimproved sources (Lake Malawi, surface water or unprotected shallow wells) were more often drinking directly from Lake Malawi (67/109; 61%). When looking at water sources classified as improved versus unimproved, a Mann–Whitney U Test for thermotolerant coliforms indicated differences in the median values ($p < 0.05$). As well, improved water sources for patients had a mean of 9 cfu/100 ml ($n = 127$), whereas unimproved water sources had a mean of 66 cfu/100 ml ($n = 109$). A Mann–Whitney test indicated that median patient ages were not different regardless of whether they were drinking from improved or unimproved drinking water sources ($p = 0.36$). Fisher's

exact tests showed no difference in terms of patients drinking from an improved or unimproved source in terms of gender ($p = 0.79$); the water source type also showed no differences in patient survival from cholera ($p = 0.71$), although the survival outcome group was small.

We also found no correlation between age, gender, and survival outcome and thermotolerant coliform counts (Table 1). Linear regression analysis failed to show a significant correlation between thermotolerant coliform counts and patient age ($p = 0.10$; regression coefficient of 0.011). Mann–Whitney tests indicated that median thermotolerant coliform counts were not different in terms of patient gender ($p = 0.18$) or between patients who had died and those who had survived cholera ($p = 0.29$).

Human dimensions

There was no clear association between drinking water source quality and household safe water treatment practices, knowledge of cholera, and risk perceptions (Table 2). Sixty-eight percent (161/236) of respondents reported they had treated their water appropriately before drinking (e.g., boiling, with chlorine or using a water filter). However, 30% (48/161) of those claiming to have treated their water commented they only treated when resources were available, often citing their dependence on the government health team for the supply. Overall, respondents had a good awareness of cholera, with 67% (157/236) of respondents identifying 'Consuming contaminated food and water' as a way of contracting cholera. However, 11% (25/236) of respondents indicated wind or bad air as a cause of cholera. Many (206/236; 87%) respondents were aware of one or more practices to prevent cholera, including the use of a

Table 1 | Gender, age, and survival outcome by source drinking water quality for patients from the 2017–2018 cholera outbreak, Karonga District, Malawi ($n = 236$)

Thermotolerant coliform count	Discharged alive ($n = 229$)								Cholera deaths ($n = 7$)							
	Total	Gender		Age (years)					Total	Gender		Age (years)				
		M	F	<18	18–29	30–45	46–64	65+		M	F	<18	18–29	30–45	46–64	65+
0 cfu/100 ml	105	54	51	34	28	30	12	1	2	2	1				1	
1–50 cfu/100 ml	87	52	35	34	22	18	9	4	3	3	1		2			
51–199 cfu/100 ml	7	4	3	2	1	4										
200+ cfu/100 ml	30	18	12	4	12	11	2	1	2	1	1				2	

Table 2 | Source drinking water quality compared with safe water treatment, knowledge of cholera, and future risk perception for patients from the 2017–2018 cholera outbreak, Karonga District, Malawi ($n = 236$)

	Total	Thermotolerant coliform count			
		0 cfu/ 100 ml	1–50 cfu/ 100 ml	51–199 cfu/ 100 ml	200+ cfu/ 100 ml
Household safe water treatment					
Good practices	160	64	71	3	22
Moderate awareness	3	1	1	1	
Poor understanding	73	42	18	3	10
Cholera knowledge					
Good awareness	180	92	61	3	24
Moderate awareness	52	12	28	4	8
Poor	4	3	1		
Future risk perception					
Low likelihood	96	46	36	2	12
Moderate likelihood	82	35	34	3	10
High likelihood	58	26	20	2	10

pit latrine, treating stored household drinking water, washing hands with soap and food safety. Although each patient in the study had reported to a government health center for treatment, 90% (212/236) indicated this was an immediate step when signs and symptoms of cholera were present. No respondent indicated seeking traditional healers or traditional medicine. With regard to risk perception, of the 32 people who had water source thermotolerant coliform levels of 200+ cfu/100 ml, seven reported feeling there was a low risk or zero risk to themselves of contracting cholera in the future and that their community was extremely well prepared to respond to another outbreak.

DISCUSSION

Many patients had safe drinking water sources in terms of thermotolerant coliform levels. Behavioral practices and other transmission pathways, such as eating contaminated

food, may have been more influential in the spread of cholera in Karonga. Even though 90% of households in the district are reported to have access to an improved drinking water source (National Statistical Office & ICF 2017), our survey shows that only 54% (127/236) of the cholera patients actually had this access. Manda & Wanda (2017) found 56% of samples exceeding the WHO (2017) guideline for *Escherichia coli* in Karonga town, compared with our district-wide results of 50% which met the guideline. Most of our study communities would be considered as small communities with residents living within walking distance of their water source, similar to the conditions of John Snow's original research into cholera outbreaks in Soho, London (Snow 1855). Rural water supplies rarely serve a single individual, yet others either did not contract cholera or did not report to a health facility for cholera treatment. In Kenya, Shapiro et al. (1999) noted the use of drinking water from Lake Victoria as a cholera risk factor, but they further noted that the convenience factor associated with accessing lake water makes the recommendation of alternative drinking water sources in shoreline communities of Lake Victoria impractical. In our study, some respondents from shoreline communities reported the saltiness of groundwater as the reason for opting to drink from Lake Malawi, and our mean electrical conductivity was 320 $\mu\text{S}/\text{cm}$ compared with results from Mapoma et al. (2017) of 413 $\mu\text{S}/\text{cm}$.

Tyner et al. (2018) found in the Central Region of Malawi high *E. coli* levels in Lake Malawi shoreline water (90% of samples were above the WHO drinking water guideline), although our results for the distribution of thermotolerant coliforms are generally lower (69% of shoreline samples were above the WHO guideline). *Vibrio cholerae* can survive in some aquatic environments for months to years (Momba & Azab El-Liethy 2017), therefore further study of local ecological factors influencing its occurrence, persistence and survival along the shores of Lake Malawi is necessary.

Msyamboza et al. (2014) noted the importance of social and cultural norms related to cholera outbreaks, especially witchcraft and religion, among fishing communities in the Southern Region of Malawi. While nearly all fishers working on Lake Malawi are male (Government of Malawi 2017), our study showed that not only men contract cholera. The Karonga District has a deeply rooted patriarchal culture, including the practice of polygamy (Karonga District

Council 2013; M. Mlenga 2016). When families are polygamous, further work is needed to ascertain household water use, and context-specific cholera behavioral change interventions are needed. Although none of our respondents identified traditional healing as a method of treating cholera, it is a widely used practice among the Ngonde ethnic group and could delay treatment after symptoms of cholera are shown. J. Mlenga (2016) writes ‘it is believed among the Ngonde that natural illness is the one that yields to biomedical treatment or traditional treatment, and healing is expected to take place immediately or a few days after treatment’. Historically, Ngonde people believe illnesses may result from angry ancestors or curses and these ancestral spirits are associated with the lake and pools of water within the district. Mackenzie (1925), when describing ancestral spirits in the Karonga District, writes ‘on the lake, during a storm, they are still to be heard, demanding a victim to be thrown to them who they may “eat”’.

Further research is needed to better understand other causal factors for cholera transmission. Such factors may include safe storage of water, health and hygiene practices, eating contaminated food, and taking water from alternative sources while travelling or working, particularly in the case of fishers. The latter could be significant, as communities often shared a water source and cholera cases were not clustered around unsafe water sources.

Although there are benefits to the normal case-control methodology, there are also drawbacks in a rural district in terms of cost and time. This study offered an alternative, novel method to case-control studies to investigate social and water quality linkages to cholera patients in a local area in Malawi. The opportunity to learn from cholera cases using a census shortly after an outbreak may increase the efficiency of national cholera elimination plans to prioritize investment recommendations.

Investment recommendations

The presence of cholera triggered emergency response funds in the study area. In 2016, it was estimated the cost burden of treating cholera within Malawi per patient episode to a household was USD\$65.6, in addition to the cost of treatment at a health center of USD\$59.7 (Ilboudo *et al.* 2017). When compared with the Malawian monthly minimum

wage of USD\$41.7 (Ministry of Labour, Youth, Sports and Manpower Development, personal communication, 7 January 2019) the cost of treatment becomes unaffordable for many people. Prioritizing investment could increase the efficiency of national cholera elimination plans.

Manually drilled boreholes could provide rural water supply to communities lacking access to a well-drilling rig in the district. Manual drilling with an Afridev pump installation in the study area would cost MK1,456,000 (USD\$2,020) per well, while a mechanically drilled well with an Afridev pump would cost from MK3,400,800 (USD\$4,720) to MK3,660,500 (USD\$5,080) (personal communication with I. Mkandawire on 24 September 2018 and with T&T Investment on 25 September 2018, Mzuzu, Malawi). In our study area, installing improved water sources for 22 geographic areas with high-risk drinking water quality (>50 cfu/100 ml) would require an investment of USD\$112,000. Treatment of lake water through small-scale water treatment facilities, focused on reduction of thermotolerant coliforms, managed by communities in the study area, requires further innovation in a local market-based approach.

Household-level water filters are not commonly available in the study area. The local market price of a 1.25% solution of sodium hypochlorite, sold in a 200 ml bottle, an equivalent dosage to treat 1000 L, is MK449 (USD\$0.62; on 26 December 2018). Some respondents reported treating their water when it was provided (at no cost) to them but this treatment was not something prioritized with their own money. Therefore, given the low cost and local availability of this intervention, use of sodium hypochlorite remains a recommended practice, particularly as water contamination during household storage is highly possible.

Locally available handwashing soap is MK120 (USD\$0.17; on 26 December 2018).

Well-targeted behavioral change interventions are required to end cholera outbreaks. In Malawi, for other behavioral change interventions at a community level (specifically Community Led Total Sanitation campaigns), the delivery cost was approximately \$19 per household (personal communication by Mzuzu University). Any behavioral change interventions may need to account for social and cultural norms, such as the presence of more than one

wife or mother in a household within this study area and known Ngonde culture.

Limitations

Although cholera patients self-reported to the health facility for treatment, social and cultural norms may have prevented others from seeking care. More than 100 cases, likely fishers and those unknown to local health workers, could not be traced and are likely the highest-risk population group. Water samples were tested for thermotolerant coliforms as an indicator, but not directly for *V. cholerae*. Water quality in this study may have been better than during the outbreak, as this study was conducted soon after the cholera outbreak in the dry season. In addition, respondents do not necessarily use only one source for drinking water, and it is likely many drank water from other sources while travelling or working. The survey was also conducted after each patient had contracted cholera, therefore their knowledge and awareness of cholera prevention, transmission and treatment is likely to have improved while receiving treatment and hence these respondents were likely to appear better informed than the general population.

Conclusions

Cholera and the human dimensions of water are not an innovative topic. For approximately 100 years we have known the mode of transmission of cholera and have understood Ngonde water customs in Karonga District. This study is, however, the first to link water quality and water-related behaviors among cholera patients in northern Malawi. The results of this study describe 120 drinking water samples linked to 236 cholera patients and show the problems in Karonga District involve more than just drinking water source quality or cholera patient household safe water treatment practices, knowledge of cholera, and risk perceptions. Evidence from our study shows 'improved' drinking water sources did not eliminate the risk of cholera, with 54% of affected patients having used an improved water source. Improved water sources were not necessarily providing safe water. The cost of a reactive response to cholera outbreaks puts a burden on Malawi, but provides an opportunity for investment in innovative and localized

preventive strategies to control and eliminate the risk of cholera while acknowledging known social and cultural norms. These strategies can include promoting household water treatment using chlorine, targeted behavioral change interventions accounting for social and cultural norms, and the proposed addition of new water sources for 22 geographic areas with drinking water of poor quality.

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REFERENCES

- Bwire, G., Munier, A., Ouedraogo, I., Heyerdahl, L., Komakech, H., Kagirita, A., Wood, R., Mhlanga, R., Njanpop-Lafourcade, B., Malimbo, M., Makumbi, I., Wandawa, J., Gessner, B. D., Garimoi Orach, C. G. & Mengel, M. A. 2017 *Epidemiology of cholera outbreaks and socio-economic characteristics of the communities in the fishing villages of Uganda: 2011–2015*. *PLoS Negl. Trop. Dis.* **11** (3), e0005407. DOI:10.1371/journal.pntd.0005407.
- Government of Malawi 2017 *2017 Annual Frame Survey Report of the Small-Scale Fisheries*. Ministry of Agriculture, Irrigation and Water Development, Department of Fisheries, Lilongwe, Malawi.
- Ilboudo, P. G., Huang, X. X., Ngwira, B., Mwanyungwe, A., Mogasale, V., Mengel, M. A., Cavaller, P., Gessner, B. D. & Le Gargasson, J.-B. 2017 *Cost-of-illness of cholera to households and health facilities in rural Malawi*. *PLoS ONE* **12** (9), e0185041. DOI:10.1371/journal.pone.0185041.

- Karonga District Council 2013 *Karonga District Socio Economic Profile 2013–2018*. Karonga, Malawi.
- Mackenzie, D. R. 1925 *The Spirit-Ridden Konde: A Record of the Interesting but Steadily Vanishing Customs & Ideas Gathered During Twenty-Four Years' Residence amongst These Shy Inhabitants of the Lake Nyasa Region, from Witch-Doctors, Diviners, Hunters, Fishers & Every Native Source*. Seeley, Service & Co. Limited, London, UK.
- Malawi Bureau of Standards (MBS) 2005 *Malawi Standard: Borehole and Shallow Well Water Quality Specification, MS 733:2005*. Malawi Standards Board, Blantyre, Malawi.
- Manda, M. & Wanda, E. 2017 [Understanding the nature and scale of risks in Karonga, Malawi](#). *Environment & Urbanization* **29** (1), 15–32. DOI:10.1177/0956247817692200.
- Mapoma, H. W. T., Xie, X., Liu, Y., Zhu, Y., Kawaye, F. P. & Kayira, T. M. 2017 [Hydrochemistry and quality of groundwater in alluvial aquifer of Karonga, Malawi](#). *Environ. Earth Sci.* **76**, 335. DOI: 10.1007/s12665-017-6653-2.
- M'bangombe, M., Pezzoli, L., Reeder, B., Kabuluzi, S., Msyamboza, K., Masuku, H., Ngwira, B., Cavailler, P., Grandesso, F., Palomares, A., Beck, N., Shaffer, A., MacDonald, E., Senbete, M., Lessler, J., Moore, S. M. & Azman, A. S. 2018 [Oral cholera vaccine in cholera prevention and control, Malawi](#). *Bull. World Health Organ.* **96**, 428–435. DOI:10.2471/BLT.17.207175.
- Mlenga, J. 2016 *Dual Religiosity in Northern Malawi, Ngonde Christians and African Traditional Religion*. Mzuni Press, Mzuzu, Malawi.
- Mlenga, M. 2016 *Polygamy in Northern Malawi: A Christian Reassessment*. Mzuni Press, Mzuzu, Malawi.
- Momba, M. & Azab El-Liethy, M. 2017 *Vibrio cholerae* and Cholera biotypes. In: *Global Water Pathogen Project* (J. B. Rose & B. Jiménez-Cisneros, eds), Michigan State University, E. Lansing, MI, USA, and UNESCO <http://www.waterpathogens.org/book/Vibrio> (accessed 23 December 2018).
- Montgomery, M., Wilson-Jones, M., Kabole, I., Johnston, R. & Gordon, B. 2018 [No end to cholera without basic water, sanitation and hygiene](#). *Bull. World Health Organ.* **96**, 371–371A. DOI:10.2471/BLT.18.213678.
- Moore, S. M., Azman, A. S., Zaitchik, B. F., Mintz, E. D., Brunkard, J., Legros, D., Hill, A., McKay, H., Luquero, F. J., Olson, D. & Lessler, J. 2017 [El Niño and the shifting geography of cholera in Africa](#). *Proc. Natl. Acad. Sci. USA* **114** (17), 4436–4441. DOI:10.1073/pnas.1617218114.
- Msymboza, K. P., Kagoli, M., M'bang'ombe, M., Chipeta, S. & Masuku, H. D. 2014 [Cholera outbreaks in Malawi in 1998–2012: social and cultural challenges in prevention and control](#). *J. Infect. Develop. Countr.* **8** (6), 720–726. DOI:10.3855/jidc.3506.
- National Statistical Office (NSO) 2018 *Malawi Population and Housing Census, Preliminary Report*. Zomba, Malawi.
- National Statistical Office (NSO) & ICF 2017 *Malawi Demographic and Health Survey 2015–16*. NSO and ICF, Zomba, Malawi, and Rockville, MD, USA.
- Shapiro, R. L., Otieno, M. R., Adcock, P. M., Phillips-Howard, P. A., Hawley, W. A., Kumar, L., Waiyaki, P., Nahlen, B. L. & Slutsker, L. 1999 [Transmission of epidemic *Vibrio cholerae* O1 in rural western Kenya associated with drinking water from Lake Victoria: an environmental reservoir for cholera?](#) *Am. J. Trop. Med. Hyg.* **60** (2), 271–276.
- Snow, J. 1855 *Mode of Communication of Cholera*, 2nd edn. John Churchill, London, UK.
- Swerdlow, D. L., Malenga, G., Begkoyian, G., Nyangulu, D., Toole, M., Waldman, R. J., Puh, D. N. D. & Tauxe, R. V. 1997 [Epidemic cholera among refugees in Malawi, Africa: treatment and transmission](#). *Epidemiol. Infect.* **118**, 207–214. DOI:10.1017/S0950268896007352.
- Tyner, E. H., Jensen, P., Ngochera, M. & Bootsma, H. A. 2018 [Escherichia coli \(E. coli\) distribution in the Lake Malawi nearshore zone](#). *Journal of Great Lakes Research* **44** (6), 1281–1288. DOI:10.1016/j.jglr.2018.10.011.
- United Nations Children's Fund (UNICEF) 2018 *Oral Cholera Vaccine Report for Karonga/Rumphi Districts*. Lilongwe, Malawi.
- Villemainot, N. 2018 [Strengthening market systems that provide water and hygiene items for cholera mitigation and emergency preparedness in Haiti](#). *Waterlines* **37** (3), 307–318. DOI:10.3362/1756-3488.17-00027.
- World Health Organization (WHO) 2017 *Guidelines for Drinking-Water Quality*, 4th edn. Incorporating the First Addendum. WHO, Geneva, Switzerland. <http://apps.who.int/iris/bitstream/handle/10665/254637/9789241549950-eng.pdf;jsessionid=054D53AD5EE1CCD6C897ED3194E1EB80?sequence=1> (accessed 22 April 2018).

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