Abstract
Many healthcare facilities (HCFs) in rural areas of low- and middle-income countries (LMICs) lack safe, sufficient water supplies. We sought to understand which factors affect water quality in rural HCF in LMICs. In Ethiopia, Ghana, Honduras, India, Kenya, Malawi, Mali, Mozambique, Niger, Rwanda, Tanzania, Uganda, Zambia, and Zimbabwe, doctors and nurses were interviewed at over 2,000 outpatient HCFs about their water source, staff training, and management practices. Water samples were also tested for contamination with *E. coli*. We generated descriptive analyses and logistic regressions. Overall, 52% of surveyed HCFs used at least a basic water service, 23% used a limited water service, and 25% had no water service as defined by the WHO/UNICEF Joint Monitoring Programme. Use of an improved water source type (OR ≈ 1.4-1.7), treatment of water (OR = 1.26), management by a person with medical training (OR ≈ 3.4-8.9), and presence of a protocol for operations and management (OR = 1.29) were associated with safer water. These results suggest that in addition to addressing water source, storage, and treatment, stakeholders can also target organizational factors in order to improve water quality in HCFs.

Highlights

- 52% of healthcare facilities used a basic water service as defined by JMP
- 63% of facilities had water under WHO guideline value for *E. coli* (<1 per 100 mL)
- 31% of facilities used a basic water service free of *E. coli*
- Improved water source, water treatment associated with better water quality
- Manager with medical training, O&M protocol associated with better water quality

Keywords
environmental health; infection prevention and control (IPC); management; water, sanitation, and hygiene (WaSH); water quality; sub-Saharan Africa

1. Introduction

Safe and sufficient water services are vital for protecting and maintaining health. Consumption of contaminated water and having insufficient water for personal hygiene are linked to diseases such as cholera, typhoid fever, helminth infections, and trachoma (Prüss-Ustün et al. 2014). In 2015, the need for basic water services was reiterated in Goal 6 of the United Nations' Sustainable Development Goals (SDGs), where target 6.1 calls for universal access to "safe and affordable drinking-water for all" (UN 2017). However, achieving and maintaining adequate water service can be difficult in low- and middle-income countries (LMICs), and in rural areas (Bain et al. 2014).

The WHO/UNICEF Joint Monitoring Programme (JMP) in its SDG monitoring considers "universal access" to drinking-water to include settings such as schools and healthcare facilities (HCFs) (JMP 2019). Sufficient, safe water is particularly important within HCFs in order to maintain a clean environment and prevent the spread of healthcare-associated infections such as urinary tract, surgical-site, lower respiratory tract, and blood infections (Adams et al. 2008; Mathai et al. 2010). In HCFs, water is consumed by patients and staff, and is used for hand hygiene, food preparation, bathing patients, washing linens, sterilizing medical equipment, and cleaning surfaces (Adams et al. 2008). When an HCF's water supply is of insufficient quantity or unsafe quality, its ability to provide safe medical services is compromised. In a study of healthcare workers in ten rural Indonesian clinics, observed hand hygiene compliance was only 20%, in part due to water scarcity: one worker commented, “We don’t even have water to drink or cook; how could you expect us to bathe regularly, let alone wash our hands?” (Marjadi and McLaws 2010). An inadequate water supply can also lead to negative perceptions of the HCF by patients (Bhattacharyya et al. 2015; Karkee et al. 2014; Steinmann et al. 2015) and decrease motivation of healthcare workers at the facility (Alhassan et al. 2013; Melberg et al. 2016).

An assessment of monitoring data on water supplies in HCFs from 78 LMICs estimated that 50% of HCFs do not have a piped water source on-premises (Cronk and Bartram 2018), which may limit the quantity and quality of water available. Data on microbial water quality in LMIC HCFs are sparse: the authors are aware of five studies which document water quality in LMIC HCFs, most in atypical conditions. One study documents water contamination after a natural disaster (Mosley et al. 2004), while others test advanced water treatment methods such as ozonation and ultrafiltration (Echeverry Ibarra et al. 2008; Huttinger et al. 2015). Other than these studies, one non-random assessment of 17 HCFs in Rwanda found that 1 of 16 water samples contained *E. coli* (Huttinger et al. 2017), and a cross-sectional study found that 15% of water samples from HCFs in rural Uganda (n=144) and 30% of water samples from rural Mozambique (n=172) contained *E. coli* (Guo et al. 2017).

No studies model the relationships between water quality in rural HCF in LMIC and factors such as HCF management characteristics, characteristics of water source, water storage and treatment practices. Information on these relationships would be useful in identifying interventions and management solutions. We conducted surveys and water quality sampling at HCFs which provided outpatient care only within 14 LMICs. Through descriptive statistics and logistic regressions, we sought to determine:

1. What is the status of water service and water quality within rural HCFs in LMIC?
2. What factors (general HCF characteristics, training, water source characteristics, etc.) have the greatest impact on water quality within rural HCFs in LMIC?

2. Methods

2.1 Study population and design

This study examines healthcare facilities (HCFs) in rural areas of 14 countries: Ethiopia, Ghana, Honduras, India, Kenya, Malawi, Mali, Mozambique, Niger, Rwanda, Tanzania, Uganda, Zambia, and Zimbabwe. It is part of a larger evaluation of water, sanitation, and hygiene (WaSH) for an international non-governmental organization World Vision, which also examines WaSH in households, communities, and schools. The HCF sample frame was nested within a cluster-randomized household survey design, in which rural clusters were identified across each country and classified as areas where World Vision has active WaSH programs or areas where World Vision does not work. Within each stratum, 56 clusters were identified, where households were mapped and surveyed.

A full list of healthcare facilities was compiled within the woredas (Ethiopia), cells (Rwanda), sub-counties (Kenya, Uganda), districts (Tanzania, Zambia), wards (Zimbabwe), Traditional Authorities (Malawi), communes (Mali, Niger), villages (India), and aldeas (Honduras) where households had been surveyed. Facilities where inpatient care was provided, such as hospitals, were excluded from this list. Simple random samples were taken from this list, so that in each country, 100 HCFs were selected for surveys from World Vision programming areas and 100 HCFs from areas where World Vision did not have programming. HCFs were selected in Mozambique and Ghana using a similar process, but the initial list of all HCFs near selected household clusters was obtained from a prior evaluation of WaSH in HCFs by World Vision (Kayser et al. 2014).

The locations of surveyed healthcare facilities are displayed in Figure 1.

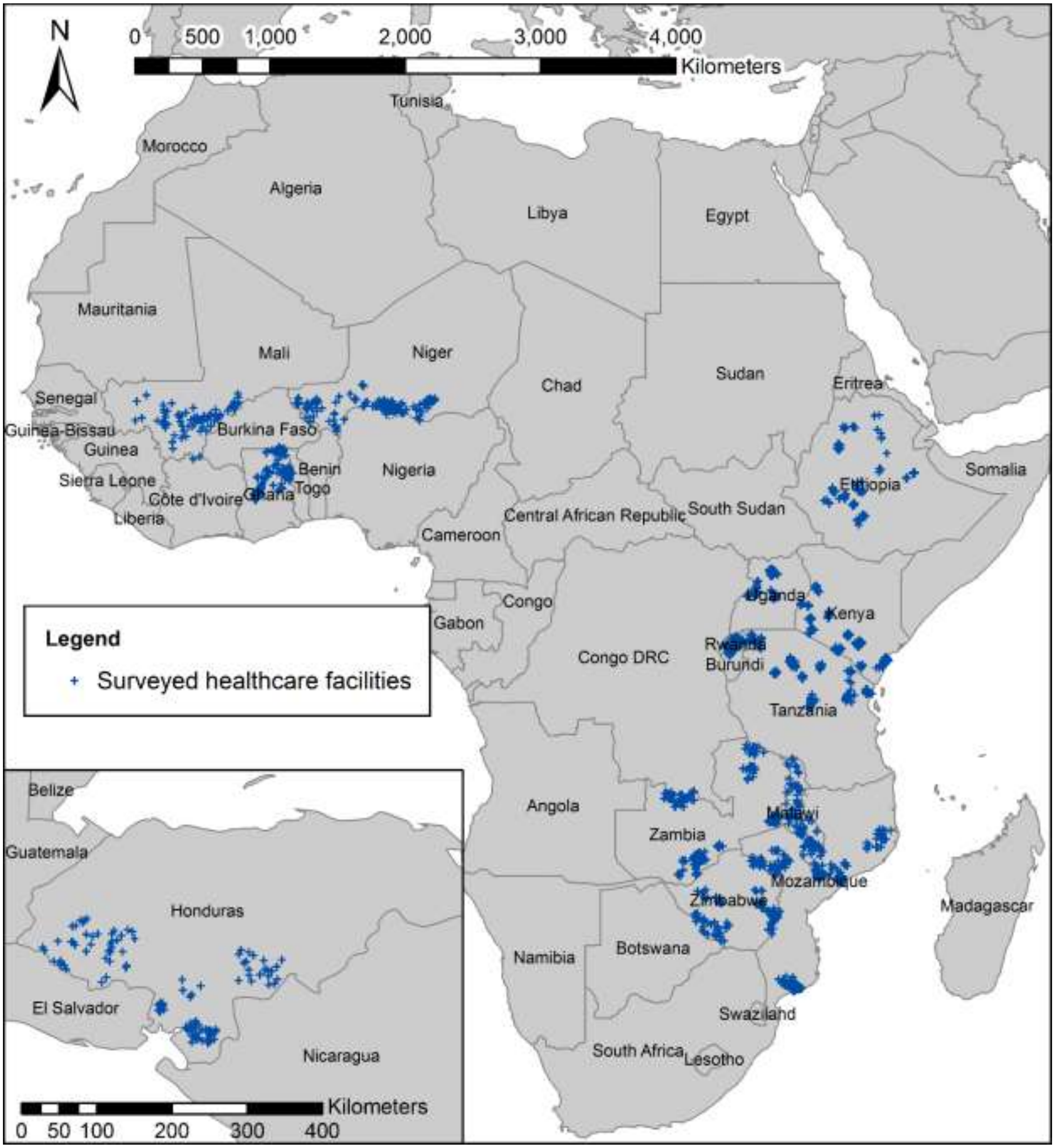

Figure 1. Location of healthcare facilities visited in each country. *This map shows the distribution of surveyed HCFs in 13 countries. GPS data were not collected in India by requirement of local institutional review board.*

2.2 Survey instrument

The survey instrument for this study was adapted from a baseline evaluation of WaSH for World Vision (Kayser et al. 2014). It included verbal questions and observations of healthcare facility characteristics; water (source type, distance to source, availability, water storage, treatment), sanitation (type, functionality, condition, and use); hygiene (hand hygiene, sharps and infectious waste segregation and treatment and disposal); and administration and training (policies, budget, trainings on WaSH and infection prevention and control). These surveys were translated into local languages for each country and verified by research supervisors or World Vision staff in each country. Survey responses were recorded using the mobile survey tool mWater (New York, NY, USA).

2.3 Training and piloting

Research supervisors and enumerators were hired in each country to conduct the surveys. Research supervisors typically sought enumerators with the equivalent of a high-school education, with preference given to women and to candidates with past surveying experience, knowledge of WaSH, and/or expertise using mobile phones.

Staff from The Water Institute at UNC conducted five regional training workshops (East Africa, Southern Africa, West Africa, Honduras, and India) in-person to familiarize research supervisors with the survey, surveying techniques, use of the mWater mobile platform, protocol for taking water samples, and quality checks for data. One training workshop was conducted via video call for the supervisors in Honduras. Supervisors in each country held training workshops for their enumerators just before data collection commenced.

After each regional training workshop, Water Institute staff worked with World Vision staff, supervisors, and enumerators for a three-day piloting period. During this, enumerators visited several villages and practiced all procedures for entering communities and completing surveys, such as mapping of healthcare facilities and water sources in each area, process for taking and reading water quality results, practice filling out and submitting surveys using the mWater platform, and discussion of the verification and quality assurance and quality control processes that should be performed on enumerators' surveys. Enumerators and supervisors were also provided with manuals and contact information for in-field support via video calls, email, text message, and messaging applications.

2.4 Data collection

Data were collected over two to three months in each country, with the earliest country finishing data collection in July 2017 and the last country finishing data collection in December 2017. During the data collection period, teams of enumerators went to each selected facility and attempted to interview the head doctor. If the head doctor was unavailable, they attempted to interview the head nurse. If neither were unavailable, a nurse who had worked at the health center for more than two years was interviewed. The respondent was allowed to decline to respond to any question, and to stop the survey at any time.

In all visited HCFs, interviewees were asked to serve water in the manner someone would usually take it for drinking. A 100 mL volume of this water was processed using the

Compartment Bag Test (CBT) (Aquagenx, Chapel Hill, NC, USA), a low-cost field test for measuring *Escherichia coli*. (a a commonly used indicator of fecal contamination in water samples, which is relatively simple to measure using the CBT. In comparison, measurement of other indicators such as viruses would require laboratory/technical capacity not feasible in the field.) Guidelines for aseptic sampling were followed (Madsen and Guo 2017). Blank samples were collected at 10% of HCFs by processing 100 mL of locally obtained bottled water, and duplicate water samples were processed at another 10% of HCFs.

Water samples were processed immediately after each survey: these were incubated in a CBT for 48 h at ambient temperature between 25 and 30°C, or 24 h at ambient temperature above 30°C. Where the ambient temperature was below 25°C, water samples were stored in a cooler with ice until the end of the day in the field, then were placed in a 35 to 37°C incubator for 24 h.

2.5 Quality assurance and control

Quality checks were in place for multiple stages of data collection, including built-in checks from the mWater platform for survey completeness, a list of checks for supervisors to complete each week while reviewing new data (common-sense checks on number of surveys completed, duration of surveys, number of water samples collected, location of GPS points in country, verification of certain responses based on photos, review of blanks and duplicates), and a final check of all data at the end of the data collection period.

2.6 Data entry, processing, and analysis

Datasets were exported from mWater into Stata/SE 14.2 (College Station, TX, USA) for cleaning and analysis, including individual binary logistic regression models within each country, as well as a mixed effects logistic regression model using the aggregated data from all 14 countries. Water quality was recorded as a binary outcome based on *E. coli* presence in a 100 mL water sample: "safe" (no *E. coli* present) or "unsafe" (*E. coli* present). For continuous variables, outlier values were removed.

From the survey, 22 variables were selected *a priori* for testing based on evidence of factors that influence water quality or plausible relationship (Supplementary Material S1).

Univariable logistic regressions were performed to identify which variables predicted water quality within each country. All variables tested were run as univariate logistic models; we identified variables that had a statistically significant Wald chi-squared value (associated $p < 0.05$) and report these.

For the multivariable mixed-effects logistic model, we clustered results based on country and again ran univariate mixed-effects logistic models on the 22 variables in order to identify variables with statistically significant relationships with the outcome variable (safe water). All variables identified as significantly associated with the outcome ($p < 0.05$) were included in the multivariable model. We verified that none of these variables were highly correlated using Pearson's correlation coefficient and the variance inflation factor.

The odds ratios in the resulting model correspond to the increase in likelihood of having "safe" water with a 1-unit increase in the variable (continuous variables) or the increased likelihood of having "safe" water for a specific group compared to a reference group (categorical variables); a p-value under 0.05 indicates a statistically significant effect for that group, at the 95% confidence level.

2.7 Compliance with Ethical Standards

This study was approved by the UNC-Chapel Hill Institutional Review Board (IRB #17-0663). Free and informed consent was obtained from all participants in their own language before beginning the survey.

Ethical approval was also obtained by agencies within each of the countries. These were the National Regional Government of Oromia Planning and Economic Development Commission in Ethiopia (reference WVE/ORO/0393/2017), the Ministry of Water Resources in Ghana (TJMSW), the Secretary of Energy and Natural Resources in Honduras (DMA-0220-2017), the SRM University School of Public Health in India (SRMSPH/IEC001/2017/24/07/2017), the Ministry of Water and Irrigation in Kenya (MWI/PARAS/10/62/(31)), the Director of Irrigation and Water Development in Malawi (IWD/CONF/1/1), the University of Bamako Medical School in Mali (2017/105/CE/FMPOS), the National Institute of Statistics in Mozambique (2/DICRE/INE/900/2017), the Ministry of Water Resources in Niger (000008/MH/A/DGH), the Ministry of Infrastructure in Rwanda (ND/JOBD/WASH/IPD/20/03/17), the National Institute for Medical Research in Tanzania (NIMR/HQ/R.8a/Vol. IX/2386), the Makarere University School of Biomedical Sciences ethics committee in Uganda (SBS-HDREC-437), the Ministry of Local Government and Housing in Zambia (MLGH/101/18/102), and the Medical Research Council in Zimbabwe (MRCZ/A/2223).

3. Results

3.1 Final Sample

A total of 2,035 healthcare facilities (HCFs) were visited for surveys, as compared to a target of 2,800 (200 surveys per country); respondents at 2,002 HCFs consented to survey. At these 2,002 HCFs, water samples were taken at HCFs where water was available on the day of the survey. While some data were lost because of errors in recording the barcode numbers used to identify each water sample, water sample results were successfully linked to 1,679 of the HCFs (Supplementary Material S2).

Across all 14 countries, the most commonly surveyed type of HCF was the health center. However, health posts were the most common type surveyed in Ethiopia and Tanzania; the community/block health center was most common in Rwanda and Mali; the primary health center was most common in Zimbabwe; and the sub-center was most common in India. The most frequently indicated “Other” healthcare facilities were dispensaries (Kenya, Tanzania), Community Health-based Planning and Services compounds (Ghana), and Case de Santé or ‘health huts’ (Niger).

3.2 Descriptive Analysis

Across all countries, HCFs were most commonly managed by nurses. The most frequently indicated “Other” levels of medical training for HCF managers were clinical/medical assistants (Malawi), medical technicians (Mozambique, Mali), physician assistants (Ghana), health officers (Mozambique, Niger), auxiliary nurse midwives/ANMs (India), accredited social health activist/ASHA workers (India), and nursing assistants (Honduras) (Table 1).

Across all surveyed HCFs, 86% of interviewees reported that the main water source used by people at the facility was of an improved water source type as defined by the WHO/UNICEF Joint Monitoring Programme (JMP), such as a piped connection or a borehole with handpump (JMP 2017). At 87% of HCFs, water was available from the main water source at the time of the survey. At 36% of HCFs, interviewees reported that their HCF's main water source was off-premises (Table 2). Overall, 52% of the surveyed HCFs used at least basic water service, 23% used a limited water service, and 25% had no service as defined by the JMP. 31% of surveyed HCFs used a basic water service that tested free of *E. coli.*

For healthcare facilities where water was stored in containers (n = 1,292), 96% reported that they used a container covered with a lid; 60% reported that water was extracted from the container using a safe method such as dispensing from a spigot, pouring, or scooping with a long-handled ladle; and 34% treated their water to make it safer (Table 2).

The prevalence of an infection prevention and control (IPC) policy in HCFs ranged from 27% in Niger to 96% in Zimbabwe. Similar ranges existed for operation and management protocols (11 to 85%), water, sanitation, and hygiene (WaSH) committees (12 to 79%), community-composed oversight committees (17 to 88%), and designation of an IPC/WaSH focal person (15 to 85%) (Table 3).

At least half of the facilities in each country had held at least one IPC training event in the preceding year, with the exceptions of healthcare facilities in Malawi and Niger; these had usually been attended by nurses rather than doctors or other workers in the facility.

About a fifth of facilities overall and in most countries reported having sufficient budget for IPC/WaSH supplies, ranging from 1% of HCFs in Niger to 41% of HCFs in India.

In 63% of all HCFs where water samples were collected, the sample was in conformity with the World Health Organization (WHO) drinking-water quality guideline value for *Escherichia coli* (<1 *E. coli* per 100 mL water) (Figure 2).

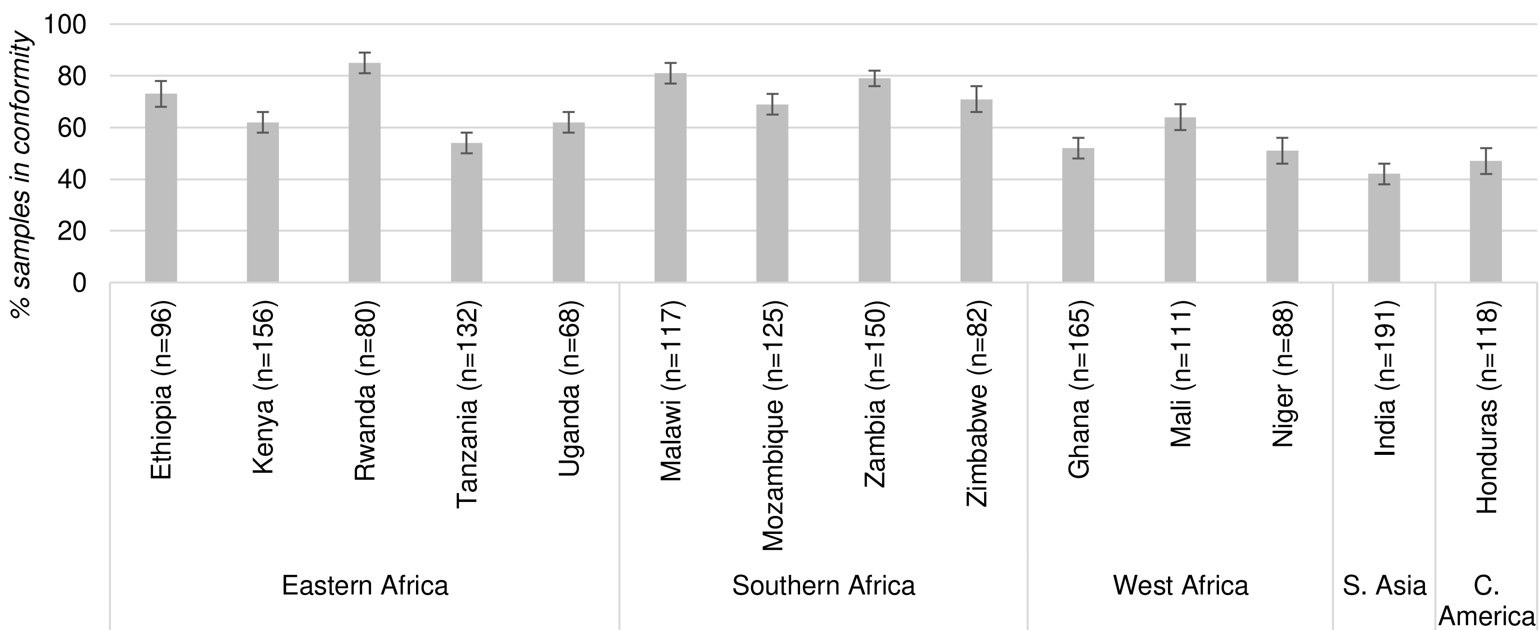

Figure 2. Proportion of healthcare facilities where water was in conformity with the WHO drinking-water quality guideline value for E. coli** (<1 E. coli per 100 mL)* ***at the time of survey, by country.

3.3 Logistic Regressions

Univariable logistic regression within each country demonstrate that treatment of water was associated with safer water quality in four countries: Kenya (OR = 2.02), Rwanda (OR = 4.14), India (OR = 1.82), and Honduras (OR = 2.51). In one country (Ghana), treatment of water was associated with worse water quality; this finding is likely due to collinearity with primary water source type. In Ghana, HCFs with an improved primary water source type were more likely to have safe water than HCFs with an unimproved type source of water (OR = 2.43, $p = 0.071$). However, 24% of HCFs with an unimproved primary water source type treated their water, as opposed to 4% of HCFs with an improved primary water source type; this difference was statistically significant ($p < 0.001$). This suggests that, of the 6% of Ghanaian HCFs where water is treated, the treatment methods are insufficient to disinfect the water.

Storage of water was also associated with safer water quality in three countries (Rwanda, Tanzania, Honduras). However, this is likely due to collinearity with treatment rather than the effect of storage: HCFs where water was stored in a container were more likely to report treatment of their water than respondents at HCFs where water was not stored ($p < 0.001$ in Rwanda and Tanzania, $p = 0.015$ in Honduras).

Within the univariable logistic regressions, WaSH training for healthcare professionals (Ghana), use of an improved water source type (Mozambique), and existence of an IPC policy (India) also had a statistically significant association ($p < 0.05$) with safer water quality. Treatment, storage, and WaSH training were generally associated with better water quality, but treatment of water in Ghana and the existence of an official IPC policy in India were associated with worse water quality (Supplementary Material S3).

In the multivariable mixed-effects logistic regression with the full 14-country dataset (clustered by country) the interclass correlation (ICC) was 0.088 (95% CI: 0.039, 0.184), meaning that about 9% of the variance in water quality was attributable to differences between countries instead of HCF-level characteristics.

Use of an improved water source type was associated with safer water quality in the multivariable mixed-effects logistic regression. The odds of having uncontaminated water for a HCF with an improved main water source type were approximately 1.4 times those of an HCF using an unimproved source type, with boreholes performing particularly well compared to unimproved source types (OR = 1.742). Water treatment also appeared to be associated with safer water quality (OR = 1.26), although this was borderline significant at the 95% confidence level within the multivariable model ($p = 0.074$).

Water quality in HCFs was also influenced by organizational management and training. Within the multivariable model, HCFs managed by a person with some medical training (doctor, nurse, health extension worker, etc.) were three to four times as likely to have safe water than HCFs managed by a person with no medical training. There were no statistically significant differences between the different types of medical training, but the safe-to-unsafe odds ratios for HCFs managed by community health workers/health extension workers (OR = 5.79) and midwives (OR = 8.98) were particularly high. Finally, HCFs with a protocol for operation and management of the facility (including procurement of WaSH supplies) were 1.29 times as likely to have safe water compared to HCFs with no operation and management protocol ($p = 0.052$) (Table 4).

4. Discussion

4.1 Summary and Implications

In this study, we explored water service and water quality in outpatient-focused healthcare facilities (HCFs) in rural areas of 14 low- and middle-income countries (LMICs) by analyzing over 2,000 surveys and over 1,600 water samples, using univariable logistic regressions and a multivariable mixed-effects logistic regression.

We found that 86% of interviewed HCFs had an improved-type main water source. This is consistent with studies in rural HCFs within the same countries, which found 74% of HCFs in Ethiopia to 97% of HCFs in Rwanda and Uganda had an improved-type main water source (Guo et al. 2017). This is also mostly consistent with estimates of water coverage in HCFs in 2016 from the WHO/UNICEF Joint Monitoring Programme (JMP); for 8 of the 11 countries in this study for which JMP reported rural water estimates within HCFs, estimates of improved-type water sources in HCFs from this study were within 7 percentage points of the JMP estimate (JMP 2019).

We also found that water samples from 63% of HCFs contained less than 1 *E. coli per* 100 mL; and that certain water source and handling characteristics were associated with safer water quality. These associations are logical extensions of current knowledge on water quality. Improved water source types are, by definition constructed in a way less likely to have fecal contamination, and piped supplies and boreholes tend to outperform other improved-type sources (Bain et al. 2014; Shields et al. 2015). Treatment by boiling, adding chlorine, filtering, etc. kills or removes bacteria and other microbes. This aligns with our findings, where water from boreholes and piped sources and treated water were most likely to be *E. coli*-free.

Organization-level characteristics, including existence of a protocol for operations and management of the HCF and management of HCFs by a person with medical training, were also associated with better water quality. To our knowledge, this is the first time such a relationship has been documented, and this has policy and practice implications.

Overall, we found 31% of HCFs had a basic water service with *E. coli*-free water (roughly equivalent to "safely managed" water service in households); 21% used a basic water service but water was not *E. coli*-free; 23% used a limited water service; and 25% had no water service. This is an urgent concern: while safe and sufficient water is necessary for HCFs to provide adequate care to their patients, these statistics suggest that many HCFs still have insufficient water to maintain a hygienic environment, and the water available could cause illness if consumed. Water sources for HCFs should be improved types and should also be on-premises, as this allows for easier access to water, supports increased use of water for hygiene and environmental cleaning, and can increase water quality (fewer opportunities for contamination during collection and storage). Based on these results, implementers including government agencies, public and private utilities, and non-governmental organizations should continue working to increase access to improved water source types, preferably by piping water directly into the facility, or providing a tap or borehole on the premises at minimum.

Water treatment should also be promoted in HCFs to ensure the best possible quality. This should be prioritized in areas where water quality is already known to be poor, but should eventually be practiced in all facilities. (While 63% of HCFs had *E. coli*-free water, this single test is an optimistic measure of water quality and does not account for other robust pathogens, such as *Giardia* and *Cryptosporidium* spp., or the potential for spikes in contamination due to environmental fluctuations. These risks must be counteracted by treatment in order to protect immunocompromised patients.) Water treatment activities could be integrated into programming by health authorities/governments, supplemented by activity from non-governmental organizations, and would likely require coordination with the private sector (ex. manufacturers of chlorine tablets). These efforts would require additional attention in areas where treatment occurs but is inadequate, such as the HCFs with unimproved-type sources surveyed in Ghana. Promoting safe water in these HCFs requires a better understanding of current treatment practices (frequency of treatment, dosing, upkeep of filters, etc.) and factors contributing to successful water treatment over time. This may require interviews or additional research.

The relationship between water quality and manager background suggests that skills in WaSH and medicine are needed at the managerial level in order to maintain a safe, hygienic environment in HCFs. HCF administrators should look into the best means to ensure that these skills are represented, and supervise activities in the HCF to see that action is being taken to improve WaSH and IPC. This might be achieved by assigning specific WaSH and IPC responsibilities or providing additional training to existing HCF staff. Alternatively, HCF administrators might consider hiring additional staff to consult on plans for training and programming within the HCF; provide feedback on operations and management policies and whether they provide adequate WaSH and IPC supplies for the facility; help set internal performance goals for safe water handling and treatment; etc.

Finally, these recommendations for water and HCF management should also be reflected in national policies, plans and standards. Health sector plans for improving service delivery should include specific, measurable, attainable, realistic, and time-bound (SMART) goals for WaSH; designate actions for specific people or groups; monitor progress over time; and allocate additional funding to achieve these goals if necessary. These goals will require support from actors outside the health sector, including partners in water resources, environment, statistics, rural development, and finance, and their involvement should be reflected in their respective strategic plans as well. As an example, the Malawi Health Sector Strategic Plan for 2011 to 2016 stated that the Ministry of Health would work with the Ministry of Agriculture, Irrigation and Water Development to provide potable water sources in all healthcare facilities and staff houses. This included annual measurement of the percentage of health centers with water, electricity, and communications working at time of visit as a core performance indicator (Government of Malawi Ministry of Health 2011). By 2016, 100% of hospitals and 99% of other healthcare facilities were using an improved water source type in Malawi (JMP 2019). In addition to service delivery, Ministries of Health should also establish oversight over HCFs in order to ensure that all providers are maintaining adequate conditions, provide guidance for improvement, and if necessary, close unsafe facilities and provide alternative options for care. Within each Ministry, units responsible for inspecting and enforcing environmental requirements should be separate from units responsible providing services, so as to ensure more impartial oversight.

4.2 Strengths and Limitations

The cross-sectional design of the study means that we were not able to establish causality (although we were able to demonstrate a correlation between these factors and differences in water quality) and we were unable to gauge effects such as seasonality. These data were also subject to social desirability bias. We minimized bias and variability by using a standardized format to ask the questions and training all enumerators on impartial interview technique. Because water samples were only taken at HCFs where water was available at the time of the survey, the water quality results may underrepresent HCFs with intermittent or unreliable water service, which are more likely to have contaminated water.

In this study, water quality was measured with a single water sample tested for *E. coli*. This is a moderate indicator of water safety, because it omits some aspects of safety, such as chemical contaminants and other microbial contaminants; will over-estimate safety because of variability in quality over time, and does not account for safe management practices. While we have presented statistically significant (or borderline significant) relationships, the pseudo-R^2 value for all of the univariate regressions were low, with the largest R^2 value only 0.1125. This indicates that most of the variability in water quality is unexplained by the variables tested. Some of this variability might result from noise in the data, as measurements of *E. coli* can vary widely by season, day and time of day even when taken from the same source. Future researchers investigating water quality in HCFs might consider changing aspects of our existing study design – for instance, increasing the number of samples taken from each HCF, measuring for other types of contaminants such as viruses and protozoa, or using a longitudinal design rather than a cross-sectional design – in order to reduce variability and noise in the data.

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Table 1. Characteristics of surveyed healthcare facilities and medical training of facility managers in each country.

	Eastern Africa					Southern Africa				West Africa			Southern Asia	Central America
	Ethiopia (n=172)	Kenya (n=162)	Rwanda (n=81)	Tanzania (n=149)	Uganda (n=77)	Malawi (n=136)	Mozambique (n=133)	Zambia (n=163)	Zimbabwe (n=119)	Ghana (n=175)	Mali (n=118)	Niger (n=172)	India (n=209)	Honduras (n=136)
Type of HCF (%)														
Health post	66	5	12	57	1	2	2	15	<1	10	0	16	3	<1
Health center	30	49	0	17	94	86	96	75	19	34	35	26	18	87
Private clinic	1	3	0	1	5	5	0	2	5	6	0	23	0	<1
Sub center	<1	1	0	0	0	<1	0	0	<1	2	0	5	48	<1
Primary health center	1	2	1	7	0	2	0	1	71	6	4	2	27	2
Community/block health center	<1	6	86	9	0	<1	0	7	3	16	55	15	3	<1
Other	<1	35	0	9	0	4	2	<1	<1	26	6	15	<1	8
Level of medical training for HCF manager (%)														
Doctor	1	10	0	50	16	10	10	2	2	7	52	2	24	40
Nurse	55	71	98	36	53	19	61	77	93	61	24	59	50	54
Community health worker/health extension worker	28	0	0	0	0	0	0	6	0	2	0	28	<1	0
Midwife	0	0	0	0	5	0	0	4	3	13	0	0	0	0
Other	10	18	2	14	26	71	29	10	2	17	25	11	21	0
None	5	<1	0	<1	0	<1	<1	0	0	0	0	0	5	6
Median number of patients served each day	10	50	75	30	50	150	80	45	45	20	16.5	17	11	20

Table 2. Proportion of healthcare facilities with an improved main water source type and safe storage and treatment practices.
(Point estimates are shown ± standard error.)

	Eastern Africa					Southern Africa				West Africa			Southern Asia	Central America
	Ethiopia (n=172)	Kenya (n=162)	Rwanda (n=81)	Tanzania (n=149)	Uganda (n=77)	Malawi (n=136)	Mozambique (n=133)	Zambia (n=163)	Zimbabwe (n=119)	Ghana (n=175)	Mali (n=118)	Niger (n=172)	India (n=209)	Honduras (n=136)
The main water source used by people at the facility is an improved source type. (%)	84 ± 3	94 ± 2	96 ± 2	73 ± 4	94 ± 2	100	92 ± 2	97 ± 1	97 ± 1	87 ± 3	99 ± 0.9	70 ± 4	94 ± 2	89 ± 3
The main water source is available on premises. (%)	24 ± 3	68 ± 4	84 ± 4	54 ± 4	69 ± 4	84 ± 3	60 ± 4	78 ± 3	69 ± 4	51 ± 4	93 ± 2	35 ± 4	54 ± 3	63 ± 4
Water was available from the main water source at the time of survey. (%)	61 ± 4	94 ± 2	94 ± 3	82 ± 3	94 ± 2	93 ± 2	71 ± 4	78 ± 3	89 ± 3	92 ± 6	94 ± 2	68 ± 4	86 ± 2	66 ± 4
(Of facilities who store water) Water is stored in a safely covered container. (%)	86 ± 4	98 ± 1	100	97 ± 1	98 ± 1	99 ± 1	96 ± 2	100	95 ± 3	98 ± 1	97 ± 2	96 ± 2	95 ± 2	89 ± 4
People at the facility use some method to treat their water before drinking it. (%)	30 ± 4	57 ± 4	80 ± 4	48 ± 4	57 ± 4	21 ± 4	39 ± 4	37 ± 3	10 ± 3	6 ± 2	26 ± 4	26 ± 3	31 ± 3	46 ± 4
The main water source has continuous service (water available from the source 24 hours a day). (%)	49 ± 4	73 ± 4	85 ± 4	78 ± 3	73 ± 4	89 ± 3	89 ± 3	80 ± 3	88 ± 3	92 ± 2	89 ± 3	73 ± 3	79 ± 3	61 ± 4

Table 3. Proportion of healthcare facilities where IPC and WaSH-related training or management programs were reported. *(Point estimates are shown ± standard error.)*

	Eastern Africa					Southern Africa				West Africa			Southern Asia	Central America
	Ethiopia (n=172)	Kenya (n=162)	Rwanda (n=81)	Tanzania (n=149)	Uganda (n=77)	Malawi (n=136)	Mozambique (n=133)	Zambia (n=163)	Zimbabwe (n=119)	Ghana (n=175)	Mali (n=118)	Niger (n=172)	India (n=209)	Honduras (n=136)
Infection prevention and control (IPC) policy exists for the facility. (%)	58 ± 4	73 ± 3	90 ± 3	92 ± 2	73 ± 3	56 ± 4	53 ± 4	80 ± 3	96 ± 2	71 ± 3	52 ± 5	27 ± 3	62 ± 3	86 ± 3
Protocol for operation and management of the facility, including procurement of IPC/WaSH supplies, exists and is followed. (%)	16 ± 3	60 ± 4	85 ± 4	68 ± 4	60 ± 4	28 ± 4	31 ± 4	56 ± 4	73 ± 4	63 ± 4	22 ± 4	11 ± 2	56 ± 3	50 ± 4
IPC/WaSH focal person has been designated for the facility. (%)	31 ± 4	67 ± 4	85 ± 4	56 ± 4	67 ± 4	70 ± 4	55 ± 4	60 ± 4	80 ± 4	50 ± 4	37 ± 4	15 ± 3	47 ± 3	58 ± 4
WaSH committee exists at the facility, and has met in the past 6 months. (%)	22 ± 3	44 ± 4	79 ± 5	51 ± 4	44 ± 4	41 ± 4	50 ± 4	39 ± 4	45 ± 4	29 ± 3	26 ± 4	12 ± 2	50 ± 3	43 ± 4
Community-composed oversight committee exists at the facility, and has met in the past 6 months. (%)	17 ± 3	59 ± 4	88 ± 4	55 ± 4	59 ± 4	66 ± 4	65 ± 4	69 ±3	71 ± 4	53 ± 4	47 ± 5	23 ± 3	46 ± 3	56 ± 4
At least one training on IPC has been held in the past year. (%)	88 ± 3	54 ± 4	57 ± 6	88 ± 3	54 ± 4	36 ± 5	44 ± 5	54 ± 4	65 ± 5	63 ± 4	63 ± 5	28 ± 4	94 ± 2	79 ± 4
WaSH training is provided for healthcare providers in the facility. (%)	32 ± 4	52 ± 4	42 ± 6	62 ± 4	52 ± 4	34 ± 4	44 ± 4	43 ± 4	61 ± 1	50 ± 4	36 ± 4	23 ± 3	63 ± 3	67 ± 4
A sufficient budget has been allocated for IPC/WaSH supplies. (%)	6 ± 2	19 ± 3	5 ± 2	23 ± 3	18 ± 3	39 ± 2	15 ± 1	10 ± 2	19 ± 4	7 ± 2	5 ± 2	1 ± 0.1	41 ± 3	18 ± 3

Table 4. Factors associated with statistically significant changes in conformity with WHO guideline value for E. coli, across all 14 aggregated countries in a multivariable logistic model. *Overall model p = 0.0030, based on n = 1,479, and* $\bar{\chi}^2$ *for LR vs. logistic model < 0.0001. Note: Asterisks (*) indicate statistically significant associations at the 95% confidence level, p < 0.05.*

Variable	Odds Ratio (95% CI)	p-value
Average daily number of patients served by the facility	1.001 (0.999, 1.003)	0.111
Facility manager's level of medical training		
None	1.000	
Doctor	3.415 (0.923, 12.558)	0.065
Nurse	3.686 (1.021, 13.313)	0.046*
Community health worker/health extension worker	5.789 (1.335, 25.110)	0.019*
Midwife	8.977 (1.862, 43.285)	0.006*
Other	4.140 (1.123, 15.177)	0.032*
Primary water source type		
Unimproved source	1.000	
Piped to facility or yard	1.459 (0.970, 2.194)	0.070
Borehole (with handpump/pump)	1.742 (1.161, 2.613)	0.007*
Other improved source	1.442 (0.961, 2.164)	0.077
Water treatment at the facility		
No, water is not treated	1.000	
Yes, treated with chlorine, boiling, filtration, etc.	1.257 (0.978, 1.616)	0.074
Number of sanitation facilities present	1.030 (0.991, 1.071)	0.130
Presence of a protocol for O&M of the facility		
Yes, a protocol exists	1.000	
No, a protocol does not exist	0.775 (0.599, 1.002)	0.052
WaSH training for healthcare providers at the facility		
No, healthcare providers are not trained in WaSH	1.000	
Yes, healthcare providers are trained in WaSH	1.148 (0.902, 1.461)	0.263