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Oza, HH, Fisher, MB, Abebe, L et al. (8 more authors) (2020) Application of tools to monitor environmental conditions, identify exposures, and inform decision-making to improve infection prevention and control practices in Malawian maternity wards. Environmental Monitoring and Assessment, 192 (2). 134. ISSN 0167-6369

https://doi.org/10.1007/s10661-020-8089-5

Application of tools to monitor environmental conditions, identify exposures, and inform decision-making to improve infection prevention and control practices in Malawian maternity wards

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Acknowledgements

The Water Institute and the Institute of Global Health and Infectious Diseases at UNC-Chapel Hill thank members of UNC Project-Malawi and the Malawi Ministry of Health and Population for their in-country organization and guidance. This project was made possible with funding from P&G Children's Safe Drinking Water Program and the Office for Undergraduate Research at UNC-Chapel Hill.

Abstract

Healthcare acquired infections (HAIs) contribute to maternal and neonatal morbidity and mortality, especially in low- and middle-income countries (LMICs). Deficient environmental health (EH) conditions and infection prevention and control (IPC) practices in healthcare facilities (HCFs) contribute to the spread of HAIs, but microbial sampling of sources of contamination is rarely conducted nor reported in low-resource settings. The purpose of this study was to assess EH conditions and IPC practices in Malawian HCFs and evaluate how EH deficiencies contribute to pathogen exposures and HAIs, and to provide recommendations to inform improvements in EH conditions using a mixed-methods approach. Thirty-one maternity wards in government-run HCFs were surveyed in the three regions of Malawi. Questionnaires were administered in parallel with structured observations of EH conditions and IPC practices and microbial testing of water sources and facility surfaces. Results indicated significant associations between IPC practices and microbial contamination. Facilities where separate wards were not available for mothers and newborns with infections and where linens were not used for patients during healthcare services were more likely to have delivery tables with surface contamination (*Relative Risk = 2.23; 1.49,*

3.34). *E. coli* was detected in water samples from seven (23%) HCFs. Our results suggest that Malawian maternity wards could reduce microbial contamination, and potentially reduce the occurrence of HAIs, by improving EH conditions and IPC practices. HCF staff can use the simple, low-cost EH monitoring methods used in this study to incorporate microbial monitoring of EH conditions and IPC practices in HCFs in low-resource settings.

Keywords: Clinic, hospital, cleaning, ATP fluorescence, sanitation, hygiene

Introduction

Deficiencies in environmental health (EH) conditions in healthcare facilities (HCFs), such as inadequate availability of soap, unreliable access to sufficient and safe water, unclean surfaces, unsanitary spaces, and the lack of effective infection prevention and control (IPC) practices contribute to the prevalence of healthcare acquired infections (HAIs) and to maternal and neonatal morbidity and mortality associated with infectious diseases (Benova et al., 2014; WHO UNICEF, 2018). Many HCFs in low- and middle-income countries (LMICs) have inadequate EH conditions and insufficient basic supplies for cleaning and IPC practices, including soap, surface disinfectants, disposable gloves, and other personal protective equipment (WHO & UNICEF, 2019).

An estimated 50% of HCFs in LMICs lack on-site piped water, which is critical for provider and patient hygiene, facility cleaning, and procedures, and 33% lack on-site improved sanitation facilities. Even where such facilities exist, they are often inadequate with respect to their construction, management, cleaning, and/or use (Cronk & Bartram, 2018). Babies born in LMICs are three to 20 times more likely to develop infections than those born in high-income countries. Most infant morbidity and mortality, of which up to half may have infectious causes among populations with high neonatal mortality, occurs in the first weeks of life, during which access to safe, clean, and functional HCFs is critical to survival and healthy development (Leach et al., 1999; WHO, 2015b; Zaidi et al., 2005).

Adequate EH conditions and IPC practices, in part demonstrated by the availability of the 'six cleans,' have been shown to reduce HAIs in HCFs (Blencowe et al., 2011). The 'six cleans', developed by the World Health Organization (WHO), describe clean birthing practices that reduce newborn sepsis and death (Blencowe et al., 2011; Winani et al., 2007). These comprise clean hands of the attendant, clean surfaces, clean blades, clean cord ties, clean towels to wrap and dry the newborn, and a clean cloth to wrap the mother (WHO, 2007). One study reported that the implementation of IPC teams and programs, including the 'six cleans', in HCFs reduced HAIs by at least 30% (Haley et al., 1985). Guidelines have been established for EH conditions and IPC practices in HCFs, and these include guidance on hand hygiene, surface disinfection, and waste management (WHO, 2004, 2016). However, data from LMICs on these practices are scarce, in part because there is little monitoring and evaluation in these contexts. Moreover, most monitoring that is conducted omits some of these components, such as water quality and wastewater/excreta management practices (Cronk & Bartram, 2018). Where monitoring does occur, it is often limited to confirmation of workers and their formal job descriptions, confirmation of workers' knowledge of cleaning and IPC best practices, and observations of the presence of basic cleaning materials in the facility (MoH, 2014). Observations of adherence to IPC practices, monitoring of microbial contamination, and other EH status indicators are uncommon (Gon et al., 2017). Improved monitoring is necessary to ensure adequate and high-quality implementation, uptake, and sustained adoption of IPC practices, and that these measures lead to measurable improvements in EH conditions in HCFs (Smith et al., 2008).

There are approximately 9,500 HCFs in Malawi that provide free services. These include dispensaries, village clinics, health posts, outreach clinics, health centers, and hospitals. These HCFs are managed by the Christian Health Association of Malawi, private entities, non-governmental organizations, or the Malawian Ministry of Health. Hospitals and health centers provide maternity care, while dispensaries and health posts do not. As of 2016, there were a total of 85 hospitals and 542 health centers providing maternity care (Malawi Ministry of Health, 2017). A governmental ban on traditional birth attendants in Malawi from 2007 to 2010 succeeded in its stated aim of reducing at-home births and increasing the number of mothers attending HCFs for deliveries (Sarelin, 2014). As a result, the number of births attended by a skilled attendant increased from 56% in 2000 to 87% in 2016 (National Statistical Office, 2017; Sarelin, 2014), a change that placed increased pressure on maternity wards in HCFs. With over 670,000 annual births in Malawi, the recent increase in patient loads has made the need for (and potential benefits of) improved IPC practices and EH conditions even greater (UNICEF, 2015).

The purpose of this study was to examine EH conditions in maternity wards in government-run HCFs in Malawi to identify potential sources of exposure to environmental microbial contamination as risk factors for acquiring HAIs, and to inform decision-making to mitigate these risks. A mixed-methods survey and structured

observations were used to evaluate EH conditions in Malawian HCFs, in addition to indicators of surface microbial contamination and measurements of microbial contamination in water.

Methods

Data were collected from 31 purposively selected government-run healthcare facilities (HCFs) in Malawi that had maternity wards. The HCFs were located in the Northern, Central, and Southern regions, and the sample comprised central hospitals, district hospitals, and health centers (Table 1).

Table 1: Surveyed healthcare facilities in Malawi by region and facility type

		Facility Type		
		Central/District Hospital	Health Centers	Total by Region
Facility Region	North	4 (13%)	3 (10%)	7 (23%)
	Central	6 (19%)	6 (19%)	12 (39%)
	South	7 (23%)	5 (16%)	12 (39%)
	Total by healthcare facility type	17 (55%)	14 (45%)	*n = 31*

The sampling of HCFs and the development and application of the survey instruments are described in McCord et al., 2019 and Reuland et al., 2019. Briefly, facilities were selected to ensure geographical representation and to provide insight into regional variation. The number of districts included per region was based on regional populations, and one district hospital and one health center were selected per included district. Representatives from the Malawian Ministry of Health and Population and staff from UNC Project-Malawi selected one central hospital within each region (McCord et al., 2019; Reuland et al., 2019).

A mixed-methods survey was developed based in part on questions from the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP), and the 'six cleans' (WHO & UNICEF, 2018). Additional survey questions were adapted from tools developed for HCFs and IPC monitoring by the World Health Organization (WHO), UNICEF, and the health ministries of Ethiopia, Kenya, and Malawi (Ethiopia Ministry of Health, 2015; MoH, 2014; The Soapbox Collaborative, 2014; WHO, 2008; World Bank Group, 2013; World Health Organization, 2017). The survey was used to evaluate access to basic water supply, basic sanitation, access to or adoption of basic hand hygiene, and basic infection prevention and control (IPC) practices in HCFs. Data were collected using the mWater mobile survey tool.

Surface swab tests and water quality testing were conducted within the maternity wards using Hygiena UltraSnap™ (Hygiena Camarillo, CA, USA) swab kits. These samples were collected from four surfaces: light switches, delivery room mattresses, sink handles, and forceps from a sterile delivery pack. These are considered 'critical sites' for microbial contamination based on their potential to transmit infections through contact or use in sensitive patient care procedures (CDC, 2014). Surfaces were swabbed according to the swab manufacturer's instructions, and swabs were immediately analyzed using a Hygiena adenosine triphosphate (ATP) fluorescence meter. Fluorescence results were read and recorded in relative light units (RLU). Surface samples were considered to be low risk if ATP surface swab tests produced fluorescence values of less than 30 RLU and were considered to be contaminated if fluorescence values exceeded 30 RLU (Hygiena, 2016).

Water samples were collected from one or two on-site water sources or water storage containers in each HCF to determine the microbial quality of water available for hygiene and medical procedures. These sources were used for purposes such as drinking, bathing, surface cleaning, as well as healthcare services such as deliveries. The Aquagenx® (Chapel Hill, NC, USA) Compartment Bag Test (CBT) was used to estimate the Most Probable Number (MPN) of detectible *E. coli* in a 100 mL sample (Stauber, Miller, Cantrell, & Kroell, 2014). Sample incubation at ambient temperature began on the day of collection, and samples were incubated for approximately 48 hours to ensure maximum accuracy given ambient temperatures in Malawi at the time the work was conducted. Samples were considered in conformity with guideline values if both samples had an MPN of less than one colony

forming unit (CFU) /100 mL and were considered contaminated if either or both samples had an MPN greater than or equal to one CFU/100 mL (WHO & UNICEF, 2015).

Survey data were cleaned in Stata (V13, StataCorp, College Station, TX, USA), and summary statistics were calculated for select determinants and outcomes. Variable relationships were examined using univariable regressions to investigate associations between surface and water contamination and EH conditions, IPC practices, and infrastructure. Risk ratios and 95% confidence intervals were calculated in Stata.

Ethical approval and all relevant research permits were received from the University of North Carolina at Chapel Hill's Office of Human Research Ethics (IRB# 16-1682) and the Malawi Ministry of Health and Population Health Sciences Research Committee (approval number 16/7/1624). No personal identifying information was obtained from respondents except for contact information.

Results

Of the 31 maternity wards surveyed (Table 1), 26 (84%) reported insufficient beds for patients seeking care. Soap at handwashing stations was observed in 29 (94%) wards, and two (6%) wards provided hand-drying materials (Table 3). Reusable obstetrical delivery packs were wrapped and sterilized at the HCF, of which six (19%) were found to be contaminated (Table 2). While ATP fluorescence results for forceps from sterilized delivery packs indicated that the majority were not contaminated, most delivery tables, handwashing station tap handles, and light switches were contaminated (Table 2).

Thirty (97%) of the 31 maternity wards reported using piped water sources, and one facility used water from a local tubewell/borehole. Most facilities stored water (97%) in drums, water tanks, and/or buckets. In facilities where water was stored, 10 (32%) used containers without a spigot, five (16%) stored water in containers without a cover, and no HCFs stored water in containers with a narrow opening (diameter smaller than 10 cm to prevent hands from entering). *E. coli* were detected in water samples from seven (23%) HCFs (Table 2). Twenty-five (81%) facilities indicated their water was not treated further on-site; chlorination was used at all facilities that treated their water. Eighteen (64%) facilities did not conduct on-site testing of water quality (Table 3). Water stored in containers without lids was 1.6 times more likely to be contaminated than water stored in containers with lids, however this was not a statistically significant finding (Table 4).

Table 2: Surface contamination of four surfaces and microbial contamination of water source samples collected from drinking water points.

Source (sample size)	Number of facilities (percentage of facilities)	
	Safe	Contaminated
Surface Sources [a]		
'Sterile' forceps (n=31)	25 (81%)	6 (19%)
Delivery tables (n=31)	1 (3%)	30 (97%)
Light switch (n=30)	7 (23%)	23 (77%)
Handwashing station tap handles (n=31)	4 (13%)	27 (87%)
Water Samples [b]		
Water samples (n=31)	24 (77%)	7 (23%)

[a] Based on Hygiena UltraSnapTM Swab samples: surface samples were reported to be low risk if ATP surface swab tests produced fluorescence values of <30 relative light units (RLU) and were considered contaminated if fluorescence values exceeded 30 RLU.

[b] Based on Aquagenx® Compartment Bag Test: Samples were collected from one or two drinking water points; samples were considered in conformity with guideline values if both samples had an MPN < 1 CFU/100 mL and were considered contaminated if either or both samples had an MPN ≥ 1 CFU/100 mL.

Latrine types that hygienically separate feces from human contact are considered improved, and these include: flush or pour flush to piped systems or pit latrines; ventilated pit latrines, pit latrines with slabs, or composting toilets (WHO & UNICEF, 2017). Four facilities had unusable toilets or unusable improved latrines, and two facilities had no improved toilets or latrines available within the HCF. Of the 25 facilities that had a usable toilet or improved-type latrine, 16 (52%) facilities had flush toilets, seven (23%) facilities used a combination of flush

toilets and pit latrines with slabs, and two (6%) had pit latrines with slabs. Twenty of 31 latrines (65%) were visibly clean. One facility had at least one toilet that provided women with the means to manage their menstrual hygiene needs (Table 3).

Of the 14 (47%) facilities where linens were used to cover delivery tables during deliveries, 12 facilities provided linens for their patients and two facilities required patients to bring their own linens (Table 3). Sixteen HCFs (52%) did not have a separate area designated for mothers or newborns with infections, 16 (53%) did not use linens for patients during visits, and 15 (54%) did not have methods to confirm sterility of sterilized equipment.

Table 3: Survey results of EH conditions and IPC practices for 31 maternity wards in Malawi

Category	Number of facility (percentage of facilities)	
	Yes	No
Was a separate ward or area designated for mothers or newborns with infections? (n=31)	15 (48%)	16 (52%)
Were bed linens used for patients to cover delivery tables during healthcare services? (n=30)	14 (47%)	16 (53%)
For equipment that was sterilized, were methods used to confirm sterility (i.e. autoclave tape)? (n=28)	13 (46%)	15 (54%)
Was the main source of water for the facility piped? (n=31)	30 (97%)	1 (3%)
Was water treated on-site? (n=31)	6 (19%)	25 (81%)
Did water storage containers have a spigot? (n=29)	19 (66%)	10 (34%)
Did water storage containers have a lid? (n=29)	24 (83%)	5 (17%)
Was water quality tested for water used on site? (n=28)	10 (36%)	18 (64%)
Were handwashing stations available within 5 meters of latrines? (n=31)	18 (58%)	13 (42%)
Were latrines available exclusively for staff use? (n=31)	25 (81%)	6 (19%)
Were observed latrines visibly clean [c]? (n=31)	20 (65%)	11 (35%)
Did at least one toilet provide means to manage menstrual hygiene needs? (n=29)	1 (3%)	28 (97%)
Where enough beds available for patients seeking care? (n=31)	5 (16%)	26 (84%)
Was soap available at handwashing stations? (n=31)	29 (94%)	2 (6%)
Was hand-drying material available at handwashing stations? (n=31)	2 (6%)	29 (94%)

[c] Free from visible excrement, no pests, no trash on the floor, minimal odor.

Hospitals were more likely than health centers to have separate wards for mothers and newborns with infections and more likely to have handwashing stations less than five meters from latrines within the ward. However, hospitals were more likely than health centers to have delivery tables with contamination. Facilities that had separate wards for mothers and newborns with infections, facilities that tested water quality, facilities with handwashing stations within five meters of their latrines, and facilities where bed linens were used for patients were each less likely to have contaminated delivery tables. Maternity wards with visibly clean latrines were less likely to have contaminated light switches and delivery tables (Table 4).

Table 4: Significant findings of cross-tabulated water quality, surface contamination, and survey results with risk ratios, associated 95% confidence intervals, and sample size

	Hospitals vs. health centers	Separate wards for infected vs. no separate ward	Bed linens used for patients vs. not used	Handwash station 5 m from latrines vs. > 5 m	Visibly clean latrines vs. not visibly clean	Water quality tested at HCF vs. not tested	Stored water covered with lid vs. not covered
Sterile forceps	1.80 (0.56, 5.83) 31	0.96 (0.39, 2.36) 31	2.40 (0.76, 7.57) 31	1.92 (0.60, 6.18) 31	0.96 (0.51, 1.82) 31	0.39 (0.17, 0.90) 28	1.12 (0.62, 2.02) 29

Delivery tables	1.88* (1.34, 2.62) 31	2.14* (1.46, 3.14) 31	2.23* (1.49, 3.34) 30	1.76* (1.29, 2.41) 31	1.58* (1.20, 2.41) 31	3.00* (1.76, 5.12) 28	<0.01 - 29
Light switches	1.79 (1.06, 3.02) 30	0.90 (0.34, 2.33) 30	0.97 (0.5, 1.64) 30	1.64 (1.00, 2.69) 30	1.77* (1.24, 2.53) 30	1.22 (0.43, 3.48) 27	0.83 (0.51, 1.37) 28
Handwash station tap handles	1.45 (0.74, 2.83) 31	0.48 (0.08, 2.74) 31	1.07 (0.58, 1.97) 31	1.93* (1.34, 2.77) 31	1.19 (0.63, 2.25) 31	1.50 (0.48, 4.65) 28	0.89 (0.49, 1.61) 29
Water samples	1.36 (0.54, 3.41) 31	1.90 (0.56, 6.46) 31	0.99 (0.58, 1.69) 31	1.02 (0.49, 2.11) 31	0.68 (0.43, 1.07) 31	0.64 (0.23, 1.74) 28	1.59* (0.83, 3.06) 29
Hospitals vs. health centers	-	3.29* (1.15, 9.40) 31	1.19 (0.74, 1.91) 31	2.88* (1.22, 6.79) 31	1.24 (0.71, 2.14) 31	0.58 (0.21, 1.61) 28	0.69 (0.49, 0.96) 29

*Significant at $\alpha = 0.05$

Discussion and Recommendations

According to Sustainable Development Goal 3.1, countries have committed to reduce the global maternal mortality ratio to less than 70 maternal deaths per 100,000 live births. Goals 6.1 and 6.2 call for countries to achieve equitable and universal access to safe and affordable drinking water and adequate sanitation and hygiene for all (WHO, 2015a; WHO & UNICEF, 2015). Maintaining safe and sanitary conditions in HCFs will play an important role in achieving these goals. The WHO minimum standards for EH conditions in HCFs include: convenient access to safe and sufficient water for the intended purpose of use, adequate and accessible toilets for both patients and staff, and clean laundry and surfaces in healthcare environments (WHO, 2008). A report published by WHO and UNICEF based on evidence from over 60,000 HCFs across 54 LMICs found that 38% of facilities lacked an improved water source and 35% did not provide soap or a suitable substitute for handwashing (WHO & UNICEF, 2015).

In a 2018 report on its national environmental health policies, the government of Malawi outlined a framework to improve EH conditions in HCFs. Aims included strengthening water quality monitoring training for District and Assistant Environmental Health Officers who are responsible for the implementation and status of EH conditions within Malawi's HCFs. Other areas of interest included improving on-site and point-of-use water treatment, leveraging data-driven findings to advocate for funding and resources at the district level, and increasing sectoral coordination and collaboration. These efforts had been initiated or were ongoing as of 2018 and were the responsibility of the Ministry of Health and Population (Ministry of Health and Population, 2018).

We examined environmental health conditions (EH) and infection prevention and control (IPC) practices in 31 governmental Malawian maternity wards. *E. coli* was detected in water samples at seven (23%) HCFs, and delivery tables in 30 (97%) facilities were found to be contaminated. Hospitals were more likely to have contaminated delivery tables than health centers. Facilities where water was tested on site, where bed linens were used for patients, and where a separate ward was provided for mothers and newborns with infections were less likely to have delivery tables with contamination. While we cannot demonstrate causal associations and did not explore

confoundment, the associations between IPC practices and environmental health data are mechanistically plausible and robust given our findings of strong, significant associations.

Water quality and safe storage

Access to clean and reliable water sources affects quality of care and maternal and child health and survival rates (Benova et al., 2014). After adjusting for gross national income, fertility per woman, maternal mortality rate, and region of the world as potential confounders, an observational cross-sectional study of 193 countries found increased access to improved water sources and improved sanitation was significantly associated with decreased rates of infant and maternal mortality (Cheng et al., 2012). In our study, a quarter of drinking water samples were contaminated. While we did not correlate these results to patient health outcomes, access to clean water has been linked to maternal and child health as seen in Benova et al. To ensure clean water, on-site testing and subsequent treatment, if needed, should be increased from current rates.

We defined safe storage of water as using a container with a lid, spigot, and narrow opening (Mintz, Bartram, Lochery, & Wegelin, 2001). Because none of the facilities used storage containers with narrow openings, none were considered to be practicing safe storage of water. A study in Mali found that 50% of facilities did not use adequate water storage methods and that 70% of facilities had poor water quality (WHO, 2014). Similarly, we found that 34% and 17% of the Malawian facilities stored water without a spigot and without a lid, respectively, and facilities that stored water without lids were 1.6 times as likely to have detectable *E. coli* in water samples. However, this was not a statistically significant finding. As seen in other studies, improper water storage containers (lack of lids, spigots, narrow openings to storage containers) and longer storage time increase likelihood of contamination (Shields, Bain, Cronk, Wright, & Bartram, 2015). Proper storage, including spigots, lids, narrow openings, and chlorination are needed for water storage to decrease the likelihood of contamination.

Latrines

Increasing the frequency and effectiveness of latrine cleaning and providing separate latrines for patients and staff has been reported to improve the environmental health conditions of maternity wards (WHO, 2008). A qualitative study in 17 rural Rwandan HCFs found half of all latrines to be unhygienic (Huttinger et al., 2017). In our study, about one third of HCF latrines were visibly unclean. Studies have reported on the importance of facility cleanliness, and more specifically latrine cleanliness, and its effects on patients' care-seeking behavior (Bouzid, Cumming, & Hunter, 2018). Providing clean and usable latrines is important to patient satisfaction and quality of care. Latrines within these facilities should be repaired and maintained daily.

Surface contamination

Our findings are consistent with previous studies of EH conditions and IPC practices in HCFs in other LMIC settings. A study of Indian HCFs found that about 10% of patient care equipment and supplies were contaminated (Dadhich, Arya, & Kapil, 2014). Gon et al. (2017) report a mixed methods study conducted across in 37 facilities with maternity units in Zanzibar using a structured facility questionnaire, direct observations, water sample testing, surface sample testing, and semi-structured interviews to assess the status of maternity ward hygiene (Gon et al., 2017). They found that birthing surfaces in six of the seven facilities tested positive for multiple pathogens. Similarly, we found one fifth of facilities had sterilized forceps that had detectable contamination, and all but one of the 31 (97%) tested delivery tables had microbial contamination. However, unlike the Zanzibar study, in which more complex and costlier laboratory-based analyses were required, the water quality compartment bag test and surface cleanliness adenosine triphosphate (ATP) swab test methods used in our study could be implemented in maternity wards and at a relatively low cost without the need for clinical laboratory facilities. Briefly, we estimate that such methods could be implemented in a typical facility in approximately one week at an estimated startup cost of USD $2,000 per facility and an estimated operating cost of USD $200 per year for monthly monitoring. Facility staff and District and Assistant Environmental Health Officers could adopt these suitable methods for rapid testing of equipment and surfaces to confirm sterility and cleanliness.

Handwashing stations

In the previously mentioned Zanzibar study, about half met infrastructural requirements for handwashing (the availability, access and maintenance of the infrastructure, access to water supplies, and equipment required to perform IPC practices properly) (Gon et al., 2017). A project in Zambian HCFs installed handwashing stations with soap and water treatment within facilities, and this reportedly quick and inexpensive change resulted in an increase in handwashing and water treatment and increased satisfaction with healthcare services as indicated by patients (WHO & UNICEF, 2015). A similar trend was also seen in Kenya (Parker et al., 2006). In our study, 13 of the 31 (42%) facilities lacked handwashing stations within five meters of the latrines, and 29 (94%) of the facilities surveyed had soap available at handwashing stations, a higher proportion than reported in previous studies. Staff and government health officials should ensure that handwashing stations are availability, accessible and appropriately maintained. Furthermore, soap or alcohol rubs should be continually available at all handwashing stations to promote proper hand hygiene among staff and patients which may help to reduce the prevalence of healthcare acquired infections (HAI).

Linens

Various studies have found evidence that supports the use of clean laundry and linens to keep healthcare environments hygienic (WASH UNICEF, 2018; Velleman et al., 2014). Bed cleaning is associated with lower occurrence of multi-drug resistant organisms (Backman et al., 2012; Pathak et al., 2018). In a study of HCFs in Cambodia, six of 10 facilities used plastic sheets for delivery tables (Bazzano et al., 2015). Rather than plastic sheets, our survey asked about the usage of linens, which were not used to cover delivery tables during healthcare services in 16 of 30 (53%) facilities. We found that the Malawian wards in which linens were used were less likely to have contaminated delivery tables. Facility staff should provide clean linens for each patient.

Separate maternity wards

The WHO recommends providing separate rooms for mothers and newborns with infections (WHO, 2008). Over half of the Malawian HCFs surveyed in this study did not have a separate ward for mothers and newborns with infections, and district and central hospitals were over three times more likely to have a separate ward for those with infections. This is likely a reflection of the higher capacity and amount of resources available to hospitals. Delivery tables in HCFs with separate wards for infected mothers and newborns were less likely to be contaminated which supports WHO's recommendations to utilize separate wards for infectious mothers and newborns.

EH conditions, IPC practices, and monitoring

A 2009 study used criteria-based audits followed by resolution of identified deficiencies at 29 Malawian health centers to improve the quality of care within maternity wards. Overall satisfaction of women patients increased by 9% following the implementation of these audits and resulting recommendations. The recommendations were associated with a higher quality of care in maternity wards and lead to the allocation of additional district-level resources for maternity care (Kongnyuy, Mlava, & van den Broek, 2009). The results of our study could also be used as means to advocate for further funding and resource allocation to HCFs in Malawi and other LMICs to further improve EH conditions and IPC practices and therefore reduce HAIs. These tools could also aid in enhancing monitoring and management of EH conditions and IPC practices by facility staff and EH officials, in addition to increasing regular cleaning of surfaces, provision of clean water, and sterilization of all instruments. This could reduce the occurrence of HAIs, and potentially maternal mortality due to sepsis. Furthermore, improving monitoring and testing of surface cleanliness and water quality is crucial to ensuring adequate implementation.

Low-cost, rapid monitoring methods, such as the tools used in this study are appropriate in HCFs in similar contexts. Ensuring adequate frequency, content, and quality of training on EH conditions and IPC practices for appropriate personnel, coupled with adequate oversight and monitoring of such training, will be an essential requirement to support these efforts. An urgent next step will be the development and standardization of EH and IPC operating procedures for different facility types and personnel roles, where there are none currently available.

Limitations

Because some survey questions within our study rely on HCF staff to recall and report on EH conditions and IPC practices, parts of the data may depend on staff memory and knowledge of the facility. However, most of the survey data were supplemented by structured observations. A significance-level correction was not applied in our analysis to account for the number of comparisons made. We also did not explore confoundment and did not aim to demonstrate casual associations between the variables analyzed. However, the associations between the variables explored are mechanistically plausible and robust.

Health centers that were surveyed in each district were, in part, chosen based on their proximity to district hospitals. Because of this sampling approach, remote HCFs are likely to have been under-sampled. Furthermore, this study focused on governmental hospitals and governmental health centers and may not be generalizable to all facility types and other non-governmental HCFs. However, the results of this study are generalizable to governmental hospitals and health centers across all three regions of Malawi.

Conclusions

Our study of 31 maternity wards across the three regions of Malawi, incorporating both hospitals and health centers, provides insight into the deficiencies and consequences of poor environmental health (EH) conditions and infection prevention control (IPC) practices in maternity wards in low-resource settings. Facilities where clean linens were used for patients during deliveries and facilities where separate wards are available for mothers and newborns with infections were less like to have delivery tables with surface contamination.

All the surveyed facilities had access to a water supply, but we found contamination in nearly one-fourth of water samples, including from 'improved' or piped sources. These results confirm that not all 'improved' sources are safely managed, particularly where continuously pressurized piped water is not available on site, and highlight the importance of ensuring the availability of safely managed water in healthcare facilities (HCF). Opportunities for improving access to safely managed water within HCFs include safe on-site storage of drinking and bathing water. Monitoring of water quality can be improved with regular testing of water using suitable field-based methods, including compartment bag tests (CBT).

Implementation of simple, low-cost, and high-impact interventions, such as ensuring adequate cleaning supplies for latrines or training on proper cleaning, supplying linens to patients during visits, regular testing of water prior to use, and training staff on IPC practices, may contribute to improvement in care. However, it is important for District and Assistant Environmental Health Officers to understand and address how challenges and their possible solutions vary based on facility types. Implementation of simple, low-cost, and high-impact interventions may contribute to improvement in quality of care and a reduction in healthcare acquired infections and maternal mortality.

The low-cost, field-based ATP swab/fluorescence tests and CBT methods used in this work yielded results that were consistent with prior studies and associated with determinants of interest, suggesting that these robust, low-cost procedures for detecting environmental contamination in HCFs may be suitable for routine monitoring in Malawian HCFs or in other LMICs.

This work sought to assess the associations between EH conditions, IPC practices, and HCF characteristics such as infrastructure, resources, microbial exposure, and environmental management practices. We hope to encourage low-cost monitoring and improvement of EH and IPC practices in HCFs in Malawi and other LMICs to which they may be applicable. Such improvements have the potential to contribute to achieving Sustainable Development Goal 3 and Goal 6, enhancing the quality of care in HCFs, and improving maternal and newborn health outcomes in Malawi and other LMICs.

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