Variability of water, sanitation, and hygiene conditions and the potential infection risk following cesarean delivery in rural Rwanda

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ABSTRACT

Safe water, sanitation, and hygiene (WASH) is critical for the prevention of postpartum infections. The aim of this study was to characterize the WASH conditions women are exposed to following cesarean section in rural Rwanda. We assessed the variability of WASH conditions in the postpartum ward of a district hospital over two months, the WASH conditions at the women's homes, and the association between WASH conditions and suspected surgical site infection (SSI). Piped water flowed more consistently during the rainy month, which increased availability of water for drinking and handwashing ($p < 0.05$ for all). Latex gloves and hand-sanitizer were more likely to be available on weekends versus weekdays ($p < 0.05$ for both). Evaluation for suspected SSI after cesarean section was completed for 173 women. Women exposed to a day or more without running water in the hospital were 2.6 times more likely to develop a suspected SSI ($p = 0.027$). 92% of women returned home to unsafe WASH environments, with notable shortfalls in handwashing supplies and sanitation. The variability in hospital WASH conditions and the poor home WASH conditions may be contributing to SSIs after cesarean section. These relationships must be further explored to develop appropriate interventions to improve mothers' outcomes.

Key words | Africa, cesarean section, environmental exposures, global surgery, postoperative infection, water, sanitation, and hygiene (WASH)

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HIGHLIGHTS

- Access to cesarean sections has substantially reduced maternal mortality across sub-Saharan Africa; however, postoperative infections are common. The contribution of water, sanitation, and hygiene (WASH) conditions in the hospital and home environment to postoperative infections is understudied.
- Most data on WASH in healthcare facilities in Africa come from cross-sectional surveys which fail to capture variability in access and quality. In our study, we observe hourly, daily and seasonal variation in WASH conditions in a postpartum ward.
- We found that women exposed to as little as one day without running water in the hospital were significantly more likely to develop a suspected surgical site infection (Odds Ratio = 2.6, $p = 0.027$).
- Postpartum exposure risk continued after hospital discharge as 92% of women returned to homes with inadequate WASH conditions.

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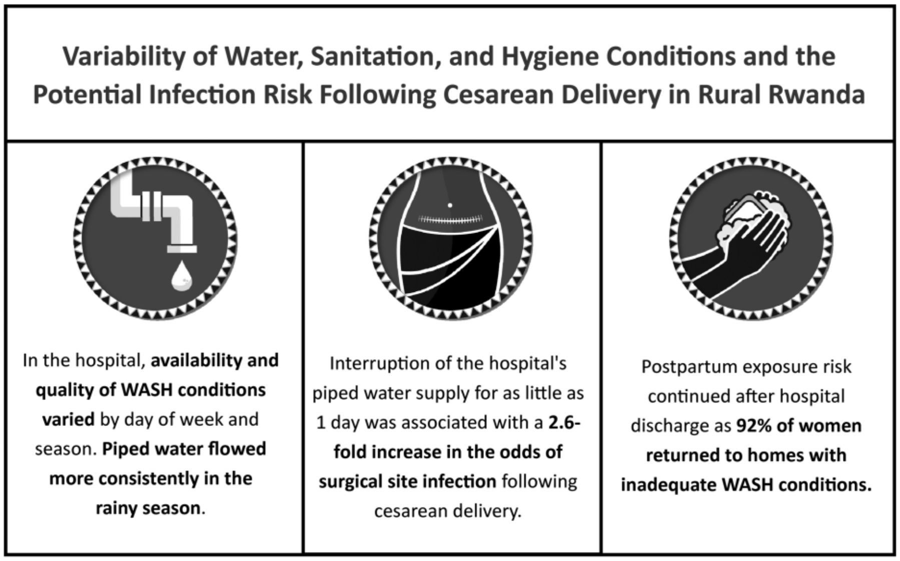
- We demonstrate that characterizing WASH conditions and their variability in healthcare and home environments can identify gaps and facilitate improvements.

GRAPHICAL ABSTRACT



INTRODUCTION

Cesarean section is the most frequently performed surgery globally (Jauniaux & Grobman 2016), constituting 23–63% of all surgeries in district hospitals in sub-Saharan Africa (SSA) (Galukande *et al.* 2010; Kushner *et al.* 2010). Increased access to cesarean delivery has played a major role in improvements in maternal health over the last two decades (Molina *et al.* 2015; Betrán *et al.* 2016). Nevertheless, surgical site infection (SSI) rates following cesarean deliveries in SSA are high, ranging from 7 to 33% (Koigi-Kamau *et al.* 2005; Chu *et al.* 2015; Nguhuni *et al.* 2017; Wodajo *et al.* 2017). In Rwanda, two-thirds of all SSIs at a tertiary hospital led to severe morbidity or death (Rwabizi *et al.* 2016). These infections may result from several causes, but the contribution of water, sanitation, and hygiene (WASH) conditions remains understudied.

A 2018 analysis across 78 low- and middle-income countries (LMICs) found that 50% of healthcare facilities lacked piped water, 33% lacked improved sanitation, 39% lacked soap, and 73% lacked sterilization equipment (Cronk & Bartram 2018). In the least developed countries, 17 million women each year give birth in healthcare facilities with inadequate WASH conditions (WHO/UNICEF 2019). Moreover, in a systematic review of hospital-acquired infections in SSA, half of SSIs were caused by fecally transmitted bacteria (Allegranzi *et al.* 2011). Current efforts to improve maternal health have focused on demand for facility-based birth and healthcare workforce development (Campbell & Graham 2006; Bustreo *et al.* 2013; Molina *et al.* 2015), with little consideration for WASH conditions surrounding delivery (Velleman *et al.* 2014). While the WHO's Safe Childbirth Checklist includes clean water and soap (WHO 2015), the Standards for Maternal and Neonatal Care do not (WHO 2007), and WASH is absent from the WHO recommendations for postpartum care, with the exception of counseling postpartum women on perineal and hand hygiene (WHO 2013). Similarly, initiatives to increase access to and quality of surgical care in LMIC have placed little attention on hospital infrastructure and safety of postoperative conditions (Chawla *et al.* 2016).

Further, our knowledge about WASH-related risks for postoperative infection rarely extends beyond hospital discharge. Yet, we know that postpartum exposure to poor WASH conditions continues for many women at home (JMP 2012; Benova *et al.* 2014b), posing barriers to following through on postpartum hygiene recommendations.

Our understanding of the contribution of WASH to postoperative infections is also limited by the methods used to study WASH conditions. Most data on WASH in healthcare facilities come from cross-sectional surveys (Cronk & Bartram 2018) which fail to capture continuous availability and quality. The few studies on water variability are mostly based on self-report (WHO/UNICEF 2019). Stockouts of supplies like gloves, seasonal water outages, malfunctioning toilets, and other factors could contribute to variable service provision by time of day, day of week, or season.

To this end, the aim of this study was to characterize the WASH conditions to which women are exposed following cesarean delivery, both at the hospital and at home, in rural Rwanda. The results of this study identify gaps in access to or quality of WASH conditions necessary for infection prevention within the healthcare and household environments and the potential influence of these gaps on the development of SSIs.

METHODS

Study site

This study was conducted at Kirehe District Hospital, a 233-bed facility located in the Eastern Province of Rwanda. The hospital is managed by the Rwandan Ministry of Health with support from the international non-governmental organization, Partners In Health-Inshuti Mu Buzima (PIH-IMB). In Kirehe district, nearly all women (91%) deliver in a healthcare facility (NISR 2016). Women most commonly present to their nearest health center for delivery, but in the case of an emergency during labor or a high-risk pregnancy are referred to the district hospital. In 2017, an average of 169 vaginal deliveries and 122 cesarean sections occurred each month at Kirehe District Hospital (hospital administrative records). In rural Rwanda, cesarean section is the most common surgery performed in district hospitals (Petroze *et al.* 2012) and 7.8% of babies born in Kirehe district between 2014 and 2015 were delivered via cesarean section (NISR 2016). After a cesarean section, women are admitted to the postoperative maternity ward and stay an average of 3 days before discharge.

This study was nested within a randomized control trial assessing in-hospital and postoperative care for women delivering via cesarean section, particularly as it relates to developing SSIs (Sonderman *et al.* 2018). In the parent study, women delivering by cesarean section at Kirehe District Hospital were eligible for enrollment between November 2017 and November 2018. In Arm 1, a community health worker (CHW) visited the patients' homes on postoperative day 10 (±3 days) to administer an SSI screening protocol (fever, pain, or purulent drainage). For Arm 2, the CHW administered the screening protocol by phone. For both Arms 1 and 2, the CHW referred patients with suspected SSI or other concerns to a health facility. In Arm 3, patients did not receive follow-up screening by a CHW. The primary outcome of the parent study was the impact of the CHW intervention on the rate of return to care for patients with an SSI. Patients across all three arms were tracked in health center records and by phone at postoperative day 30 to determine any SSI diagnosis (hence forth called 'suspected SSI'). Results from an earlier phase of this study showed that 10.9% of enrolled women developed an SSI, as confirmed by a physical exam, by postoperative day 10 (Nkurunziza *et al.* 2019).

Data collection

The WASH data included this study were collected through two independent data collection activities: (1) a two-month WASH variability assessment in the postoperative maternity ward; and (2) an assessment of WASH conditions in women's homes following delivery. Both data collection tools are available in the Supplementary material: Supplementary material 1: Facility variability observation checklist and Supplementary material 2: Household survey – WASH risk factors for surgical site infection.

WASH variability assessment

The WASH variability assessment took place in the postpartum ward designated for women who delivered by cesarean section. Data were collected from February 1st through March 31st, 2018, two months that span the end of a short dry season (February) and the beginning of a long rainy season (March). Data on the variability in WASH conditions within the postpartum ward were collected using a 19-item observation checklist, adapted from Emory University's WASH in Healthcare Facility Assessment Tool (Emory University 2016) and the WHO Core Indicators for WASH in Healthcare Facilities (JMP 2017a). The checklist included observations of the availability of water sources, the presence of handwashing and infection prevention and control supplies, the cleanliness of the ward and toilet block, whether medical waste was properly managed, and whether bed-sharing occurred. Data were collected three times each day, including weekends, by study-trained local personnel. The time points – 9am, 2pm, and 7:30pm – were selected to capture the range of activities occurring in the postpartum ward, while balancing considerations for feasibility, acceptability, and safety with regard to study staff, hospital staff, and patients. During the morning observation, medical rounds were occurring. The afternoon observation was done following visiting hours. The evening observation took place during patients' dinner-time.

Household WASH assessment

The household WASH condition data were collected between February 1st and March 31st, 2018. Women enrolled in the parent study and randomized to a study arm where they received either a home visit (Arm 1) or phone call (Arm 2) from a CHW were included in this study. During the phone call or home visit, in addition to using the SSI screening tool, the CHW asked women about their wound care practices, bathing and drinking water sources, and type of toilet, using a 15-item survey. An improved water source was defined as one that, by nature of its construction, is likely to be protected from outside contamination; improved sanitation was defined as a toilet facility that hygienically separates human excreta from human contact (JMP 2012). During the home visits (Arm 1), the presence of a handwashing station and environmental cleanliness indicators were also observed and recorded.

Data entry and statistical analysis

Hospital WASH data were collected using paper-format checklists and entered into ONA, an online database (ONA Systems, Nairobi, Kenya). Household WASH data were collected using REDCap software (Vanderbilt University, USA) on Samsung Galaxy tablets. The presence of items on the WASH variability checklist was compared by time of day (morning, afternoon, evening), day of week (weekday, weekend), and season (rainy, dry) using Chi-squared tests. Household data were analyzed to generate descriptive statistics and differences between intervention arms were assessed using Chi-squared tests to examine possible reporting bias by type of data collection.

For each study participant enrolled between February 1st and March 31st, 2018, a variable was generated for whether for any day during her hospitalization, the water stopped flowing for an entire day (e.g., no flow during the morning, afternoon, and evening observations). Similar variables were created for the presence or absence of latex gloves and soap for an entire day. Associations between WASH conditions in the postpartum ward (lack of water, gloves, or soap) during a study participant's stay and the development of a suspected SSI were tested using Chi-squared tests. The association between WASH conditions in the home (lack of an improved water source, improved sanitation, or handwashing facilities) and the development of a suspected SSI was tested using Fisher's exact tests. The Fisher's exact test was used due to the smaller sample size for the household WASH assessment, which yielded expected frequencies of less than 5. We report odds ratios as measures of the strength of association between WASH conditions in the hospital and home environment and development of a suspected SSI. Analyses were performed using Stata v14 (StataCorp, College Station, TX, USA).

Ethics approval

The parent study and this substudy were approved by the Rwanda National Ethics Committee (Rwanda, No. 848/RNEC/2016) and Partners Institutional Review Board (USA, No. 2016P001943/PHS).

RESULTS

WASH infrastructure and variability within the postoperative maternity ward

The cesarean-section postpartum ward

Figure 1 shows the layout of the postoperative maternity ward and location of key items. The ward contained 16 patient beds. There was no piped water connection in the ward; however, piped water could be accessed in the adjacent toilet block. This adjacent toilet block contained three toilets for patients, one toilet for staff, two showers for patients, and a handwashing sink. Drinking water within the ward was provided in a 20-liter jerry can treated with a chlorine solution. Each patient was supplied with a cup. At the beginning of the study period, there was no handwashing station in the ward. A portable station was added by the hospital staff at the end of February, midway through the study.

WASH condition variability results are presented in Table 1, with the most important findings highlighted below.

Water access

Rain was reported on the previous day during 47% of observations in March, compared to 26% of observations in February ($p = 0.006$). During February, water was less likely to be flowing, drinking water was less likely to be available, and water was more likely to be stored compared to March (Figure 2(a), $p < 0.001$ for all). Water access (piped, drinking, and stored) did not vary significantly by time of day ($p = 0.536$, $p = 0.567$, $p = 0.880$, respectively), but drinking water was more likely to be available on the weekends compared to weekdays (77% versus 100% of observations, $p < 0.001$).

Handwashing supplies

The availability of handwashing supplies (soap *and* water) did not vary by time of day ($p = 0.996$ for ward, $p = 0.647$ for toilet block) or weekday versus weekends ($p = 0.422$ for ward, $p = 0.752$ for toilet block). However, handwashing supplies increased significantly between February and March in both the postpartum ward (from 1% to 75%, $p < 0.001$) due to the addition of a handwashing station and in the postpartum toilet block (from 65% to 84%, $p = 0.006$) due to increased availability of running water.

Infection prevention and control supplies

Latex gloves were available during 82% of observations, ethanol during 47% of observations, and hand sanitizer during 24% of observations. Latex gloves and hand sanitizer were more likely to be available on the weekends compared to weekdays ($p = 0.022$ gloves, $p < 0.001$ sanitizer). Ethanol was more likely to be available on the weekdays ($p < 0.001$). The availability of latex gloves, ethanol, and hand sanitizer did not vary significantly by time of day (Table 1). There was no variability in these items by dry or rainy month (Table 1).

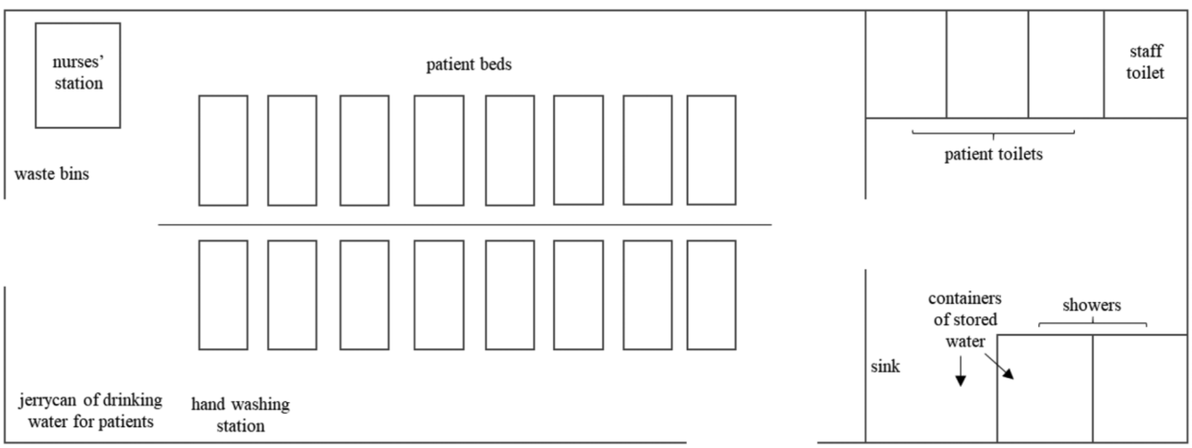


Figure 1 | Layout of postoperative maternity ward.

Table 1 | Variability in water, sanitation, and hygiene conditions in cesarean section postpartum (percent of time item was observed)

	Overall ($n = 175$)	February ($n = 84$)	March ($n = 91$)	Chi-square p-value	Morning ($n = 59$)	Afternoon ($n = 58$)	Evening ($n = 58$)	Chi-square p-value	Weekday ($n = 124$)	Weekend ($n = 51$)	Chi-square p-value
Drinking water	84.0	73.8	93.4	<0.001*	79.7	86.2	86.2	0.536	77.4	100	<.001*
Piped water flowing	76.6	60.7	91.2	<0.001*	81.4	74.1	74.1	0.567	77.4	74.5	0.68
Stored water for patient bathing	69.7	89.3	51.7	<0.001*	71.2	67.2	70.7	0.88	71.0	66.7	0.574
Soap for handwashing in ward	40.0	2.4	74.7	<0.001*	39.0	39.7	41.4	0.964	37.9	45.1	0.377
Soap for handwashing near toilet	93.1	95.2	91.2	0.292	93.2	94.8	91.4	0.763	93.6	92.2	0.741
Water for handwashing in ward	50.8	6.0	92.3	<0.001*	49.2	51.7	51.7	0.95	46.8	60.8	0.092
Water for handwashing near toilet	80.6	67.9	92.3	<0.001*	84.8	74.1	82.8	0.306	79.0	84.3	0.422
Soap and water for handwashing in ward	39.4	1.2	74.7	<0.001*	39.0	39.7	39.7	0.996	37.9	43.1	0.52
Soap and water for handwashing near toilets	74.9	65.5	83.5	0.006*	78.0	79.7	75.9	0.647	74.2	76.5	0.752
Latex gloves	81.7	82.1	81.3	0.888	88.1	79.3	77.6	0.285	77.4	92.2	0.022*
Ethanol	46.9	41.7	51.7	0.186	54.2	48.3	37.9	0.203	54.8	27.5	0.001*
Hand-sanitizer	24.0	22.6	25.3	0.681	22.0	24.1	25.9	0.889	12.9	51.0	<.001*
Proper waste segregation	66.9	66.7	67.0	0.959	61.0	70.7	69.0	0.494	62.9	76.5	0.083
Electricity	98.9	97.6	100.0	0.139	100	100	96.6	0.13	99.2	98.0	0.514
Clean floors	93.7	97.6	90.1	0.041*	94.9	89.7	96.6	0.278	94.4	92.2	0.586
Clean patient toilet	81.1	78.6	83.5	0.403	79.7	86.2	77.6	0.464	79.8	84.3	0.492
Clean staff toilet	100	100	100	–	100	100	100	–	100	100	–

*Statistically significant at $\alpha = 0.05$.

Environmental cleanliness and waste segregation

Patient toilets were more likely to be dirty compared to staff toilets (toilets were clean during 81% of observations of patient toilets and 100% of observations of staff toilets, $p < 0.001$). Cleanliness did not vary by time of day, day of week, or month (Table 1). Ward floors were clean during 94% of observations and were more likely to be clean during the dry month (98% in February compared to 90% in March, $p > 0.041$). Waste was properly segregated in 67% of observations and did not vary by time of day, day of week, or month (Table 1).

Bed occupancy and sharing

Of 16 available beds, an average of 12 were occupied across each observation (ranging from 0 to 19 postpartum women). Occupancy did not vary by time of day, day of week, or month (Table 1). No bed sharing between postpartum women and caregivers was observed. During three

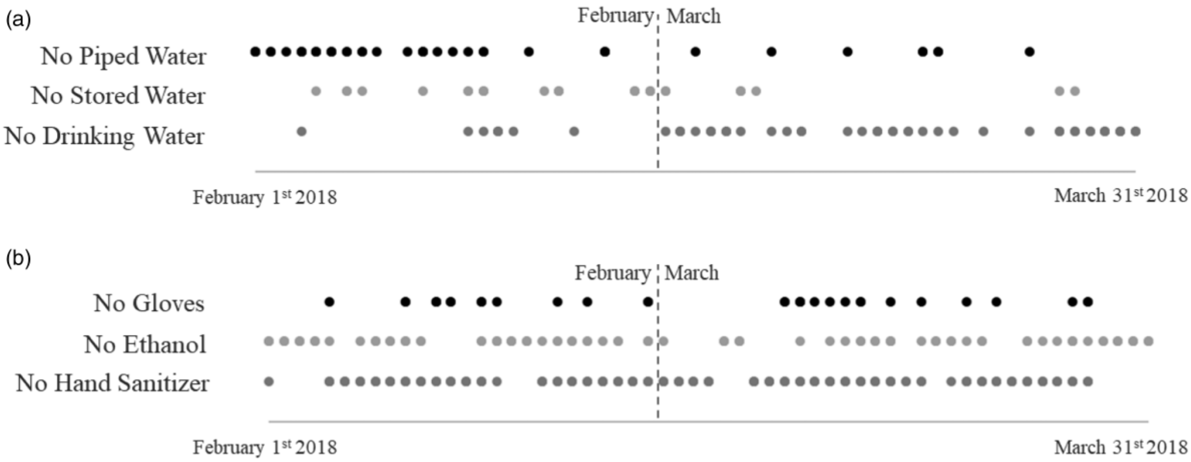


Figure 2 | Water (a) and Infection Prevention and Control Supplies (b) Variability by Month. *Note*: Circle marks indicates condition was absent during observation.

observations, one bed was shared by more than one postpartum woman. During one observation, two beds were shared by more than one postpartum woman.

WASH conditions in the homes of postpartum women

Household WASH conditions were collected for 96 women, 68% of whom received a home visit and 32% of whom received a phone call. There was no statistical difference in survey responses for women who received a home visit versus a phone call.

Water

The majority of postpartum women (86%) reported using an improved water source for drinking and bathing (Table 2).

Table 2 | Household WASH conditions

Household WASH condition	% of households ($n = 96$)
Use improved water source	86.4
Report treating drinking water	67.7
Report could not bathe in last 10 days due to lack of water	2.2
Use improved sanitation	13.5
Share toilet with other households	8.3
Have handwashing station (soap and water)[a]	7.7
Have feces in yard (animal or human)[a]	20.0

[a]$n = 65$, these were observations conducted only in Arm 1 during household visits.

The most common water sources were public tap or standpipe (45%), piped water to yard/plot (22%), protected spring (12%), and surface water (6%). Boiling of drinking water was reported by 67% of women and 1% reported treating drinking water with chlorine. The remaining 32% did not treat their water.

Sanitation

Only 14% of postpartum women reported a form of improved sanitation at home. Those with improved sanitation used pit latrines with a slab. Those without improved sanitation used pit latrines without a slab or an open pit. Upon latrine inspection, 19% had visible feces, 19% had foul smells, 39% had flies, and 40% had none of these characteristics. Only 8% of women reported sharing their toilet with other households. In 20% of households, human or animal feces were observed in the yard.

Hygiene

Handwashing stations with soap and water were observed in 8% of households. Lack of water for bathing since leaving the hospital was reported by 2% of women. Most women, 88%, reported covering their wound dressing when they bathed and 14% reported that their wound dressing had fallen off since leaving the hospital.

Association between WASH conditions and suspected surgical site infection

During the two-month study period, 250 women had a cesarean section at Kirehe District Hospital. Follow-up assessments were completed for 173 women, of whom 10% were documented to have a suspected SSI. Women exposed to at least 1 day with no water flowing from the tap during their hospitalization were 2.6 times more likely to develop a suspected SSI compared to women who were not exposed to a day or more without running water (odds ratio (OR) = 2.6, 95% CI: 1.1–6.3; $p = 0.027$). There was no significant association between exposure to a day or more with no gloves ($p = 0.159$) or no soap ($p = 0.316$) and the development of a suspected SSI (Table 3).

Of 96 women included in the household survey, 85 received follow-up assessments, of which eight were documented to have a suspected SSI. At the $\alpha = 0.05$ significance level, women with unimproved sanitation at home were not more likely to develop a suspected SSI compared to women with improved sanitation ($p = 0.081$). Women using an unimproved water source were not more likely to develop a suspected SSI compared to women using an improved water source ($p = 0.081$). There was also no association between absence of a handwashing station and the development of a suspected SSI ($p = 0.904$).

Table 3 | Association between WASH conditions and suspected surgical site infection

WASH condition	Odds ratio (95% confidence interval)	*p*-value
Exposure during hospitalization (*n* = 173)		
No water for at least 24 hours	2.6 (1.1–6.3)	0.027**
No gloves for at least 24 hours	2.4 (0.5–9.0)	0.159
No soap for at least 24 hours	1.6 (0.6–4.8)	0.316
Exposure at household (*n* = 85)		
Unimproved water source	4.5 (0.6–27.7)	0.081*
Unimproved sanitation	0.2 (0.04–1.7)	0.081*
No handwashing station	0.3 (0.01–28.2)	0.904

Note: An observed frequency of zero was replaced with 0.5 to calculate the odds ratio for the association between a handwashing station and suspected SSI.
**Statistically significant at $\alpha = 0.05$.
*Statistically significant at $\alpha = 0.1$.

DISCUSSION

In this study we found that overall WASH conditions in the postoperative maternity ward at Kirehe District Hospital were good and exceeded national and regional averages (NISR 2008; Cronk & Bartram 2018). However, WASH conditions were variable in the ward and poor in the household environment. Even with a limited sample size, deficits in WASH conditions and a risk of SSI were identified. To the authors' knowledge, this is the first study to examine the association between suspected SSI after cesarean section and WASH conditions in the hospital and home environments.

Through our variability assessments, we identified gaps in the availability of some WASH resources for patients hospitalized post-cesarean delivery. Most notably, seasonality was a major driver of the variability, with more consistent access to piped water during the rainy month (March), which in turn increased the availability of drinking water and water for handwashing. Given the importance of water for infection prevention and control, understanding how seasonality impacts WASH conditions can help facilities prepare and adapt for seasons with less or variable water supply. For example, hospitals can install portable bucket-tap handwashing stations (such as Veronica buckets or Tippy Taps) that can be refilled with stored water when water stops flowing from pipes (Watt 1988; The Hunger Project 2011). Simple handwashing stations, combined with hygiene education, have been shown to improve hand hygiene (Patel *et al.* 2012) and are already in use in many settings without running water or with limited availability of piped taps (Kimera *et al.* 2013).

Women hospitalized during a water outage that lasted a day or more were more likely to develop a suspected SSI. In this study, examination of the relationship between WASH conditions and suspected SSI was exploratory. With the small sample size, there was not sufficient power to explore beyond an early indication of effect. Further, the mechanism through which lack of water may influence suspected SSI (e.g., through lack of water for handwashing, lack of water for personal hygiene, etc.) was not studied. Nevertheless, this finding suggests a connection between WASH conditions in the postpartum ward and the development of SSI following cesarean section and that improving water access may reduce the risk of SSI.

Another important issue identified through the variability study was the effect of the weekday versus weekend on supply availability. The hospital's supply room was locked on weekends. Departments requested and received their supply orders on Fridays, resulting in greater availability of hand sanitizer and gloves on weekends. Over the course of the week, these supplies diminished. Ethanol was less likely to be available on weekends, but staff did not have a hypothesis as to why. While this finding regarding supplies may not be generalizable to other facilities, it indicates how studying variability can identify issues that are easily amenable to improvement. Knowing that stockouts in the ward occur towards the end of the week can be used to change policies around supply request timing or the quantity of supplies received each week.

This study demonstrates how monitoring WASH conditions can bring increased attention and facilitate improvements. Unprompted by the study team, the hospital staff installed a handwashing station in the postoperative maternity ward once that deficit was identified during this assessment. The study also highlights other areas for low-cost solutions, such as modifying supply request schedules or quantities to reduce outages. Incremental and iterative approaches to assessing WASH conditions, identifying priorities for action, implementing improvements, and monitoring progress are embedded in WASH in healthcare facility improvement tools such as the WASH FIT and Clean Clinic Approach (Save the Children 2016; WHO 2018). However, these approaches rely on cross-sectional data. A limitation of standard cross-sectional WASH assessments is that, while they are well suited to assess features with limited variation over time, such as sanitation infrastructure, they fail to capture WASH services and resources that can vary with time, such as water availability. While some tools do examine variability, they are based on hospital staff members' self-report, which is subject to biases (WHO/UNICEF 2019). Monitoring the variability in conditions through observation, especially related to the availability of water and infection prevention and control supplies, provides more than just a snapshot of conditions and could enhance the impact of tools designed to assess and improve WASH in healthcare facilities.

Additionally, standard healthcare-related WASH assessments focus on facilities and overlook the WASH-related risks at home for postoperative/postpartum recovery. In this study, most women did not return home to a safe WASH environment where they could practice proper hygiene, with the most notable shortfalls in access to handwashing supplies and improved sanitation. Poor WASH conditions at home have been linked to increased maternal mortality (Benova et al. 2014a) and the contribution of these exposures to postoperative outcomes should be further studied.

There was no association at the $\alpha = 0.05$ significance level between improved sanitation, improved water, or presence of a handwashing station in the household and the development of a suspected SSI. However, the marginal significance between sanitation type and water source, and suspected SSI warrants further exploration in a better powered study ($p < 0.10$ for both). Beyond a small sample size, it is possible that no significant effect was found because surgical wounds may have healed enough prior to hospital discharge, reducing the risk from household exposures. It is also possible that the duration of follow-up was insufficient to capture the contribution of household WASH exposures to SSI risk. Further, improved water and sanitation classifications are only proxies for lower risk of exposure to contamination (JMP 2017b). Water quality samples or swabs of frequently touched latrine surfaces would yield a better estimation of exposure risk. While most women reported an improved water source, only 22% of these women had access to this source in their house or plot. Water storage practices may further contaminate water used for hygiene and lack of a nearby supply may limit water use for handwashing (Wright et al. 2004) which may increase infection risk. Given that almost all women in this study lived in homes without handwashing stations and knowing handwashing can prevent infection, CHWs could promote handwashing behavior and provide hand sanitizers or soaps during the critical early postpartum period.

Limitations

This study had several limitations to consider when interpreting results. It is well-documented that individuals modify their behavior when they know they are being observed (the 'observer' or 'Hawthorne' effect), including in WASH-related studies (Hagel *et al.* 2015). In this study, the observer effect likely played a role, but we consider this both a limitation and a strength. Hospital leadership and maternity ward staff were aware that WASH conditions were being monitored. Therefore, staff likely paid greater attention to WASH conditions and this may have influenced the introduction of a handwashing station within the ward. While this biased our baseline assessment of WASH conditions, it also demonstrates that monitoring WASH conditions can bring increased attention and facilitate improvements. Another limitation of this study is social desirability bias. During the household surveys, women's responses may have been influenced by what they thought the CHW wanted to hear. To mitigate this effect, sanitation and hand hygiene conditions were directly observed; however, the remaining conditions relied on the woman's self-report.

Another set of limitations relates to the SSI analyses. We did not have physical exams to confirm the presence of SSIs. However, the prevalence of suspected SSIs collected through health center chart review and patient report were consistent with the previously estimated prevalence (Nkurunziza *et al.* 2019). Further, our study was not powered to explore beyond an early indication of association due to the relatively small sample sizes ($n = 173$ for the hospital WASH factors and $n = 85$ for the home factors) and suspected SSI incidence of 10%. For this reason, we did not examine possible confounders.

Lastly, this study is limited in scope. No microbiological samples were taken to determine whether exposure risk was greater when WASH conditions were poor. Future studies should include microbiological testing. Further, observations of WASH conditions occurred in one hospital and in one ward across two months at three time points each day. Notably, there were no observations of WASH conditions at night. While the results may not be generalizable to other hospitals, wards, seasons, or time points, the main recommendation – that WASH conditions, including their *variability*, be assessed at facilities *and* in homes to facilitate improvements – is generalizable to healthcare facilities across LMICs.

CONCLUSION

We demonstrate that WASH coverage is low in households and variable in the healthcare setting. Poor WASH conditions may increase the risk of SSI after cesarean delivery. Healthcare facility assessments should measure how WASH conditions vary throughout a day, week, or season and this information can be used to facilitate targeted improvements. More research is needed to explore how WASH conditions contribute to the development of SSIs and to understand what interventions might best mitigate these risks.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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