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Source: Environmental Health Insights, 18(2)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/11786302241271554

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Environmental Health Insights
Volume 18: 1–13

DOI: 10.1177/11786302241271554

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ABSTRACT: Infrastructure for water, sanitation, hygiene, cleaning, and waste management is essential for supporting safe environmental conditions in healthcare facilities. Routine maintenance is important for preventing infrastructure breakdowns, but few studies have examined healthcare facility maintenance practices. This study documented environmental maintenance tasks in healthcare facilities in Niger, described bottlenecks to maintenance, and assessed strategies for coping with breakdowns. At 34 rural healthcare facilities in Niger, we conducted quantitative surveys to assess frequency of maintenance tasks and held qualitative interviews with healthcare facility staff to understand bottlenecks to maintenance. On at least a monthly basis, 4% of healthcare facilities inspected their water source and pump for the purpose of detecting and replacing worn parts, 15% inspected water taps and basins, and 29% inspected incinerators. Healthcare facility staff described barriers to accessing government funds for maintenance. Instead, they paid out of their own salaries or raised funds through appeals to community members or revenue generation initiatives. Other bottlenecks included ill-defined management responsibilities and difficulty of finding skilled technicians for maintenance. Findings highlight opportunities to support healthcare facilities in budgeting, advocacy, and training skilled technicians. Initiatives to install infrastructure at healthcare facilities will be more sustainable if they are accompanied by postconstruction planning, training, and funding for maintenance.

KEYWORDS: Healthcare facilities, low-income, WASH, infection control, maintenance, sustainability

RECEIVED: February 20, 2024. **ACCEPTED:** July 1, 2024.

TYPE: Original Research

FUNDING: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Funding for this study was provided by World Vision through the Water Institute at UNC. World Vision supported study sampling, fieldwork logistics, and supervision of the data collection consultant. The funders had no role in data collection, analysis, or decision to publish. LKT is supported by a grant from the National Science Foundation Graduate Research Fellowship (DGE-2040435). DMA is supported by a grant from the National Institute of Environmental Health Sciences (T32ES007018).

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Introduction

Achieving and maintaining access to safe environmental conditions in healthcare facilities is difficult in low-resource settings. Infrastructure for water, sanitation, hygiene, waste management, and cleaning supports a safe healthcare environment by preventing and controlling the spread of infectious diseases. However, global estimates indicate that this infrastructure is inadequate or entirely lacking in many healthcare facilities.[1] In 2022, only 53% of healthcare facilities in least-developed countries had basic water services, 21% had basic sanitation services, and 32% had basic hand hygiene services.[1] True service levels may be even lower, as infrastructure is subject to breakdowns and outages. Across 6 countries in sub-Saharan Africa, up to 22% of rural healthcare facilities reported that they had experienced a water system breakdown in the 2 weeks preceding the survey, and up to 52% reported repair problems with sanitation infrastructure.[2] Infrastructure breakdowns undermine the wellbeing of healthcare workers and patients and may contribute to increased risks of healthcare-associated infection.[3,4]

Maintenance plays a central role in sustaining safe environmental conditions and preventing infrastructure breakdowns. However, healthcare facilities experience constraints related to financing, management, and access to technical expertise for maintenance.[5] Maintenance comprises a large portion of the cost of infrastructure, but costs of maintenance at healthcare facilities often go unmeasured.[6] Low-resource healthcare facilities may lack the funding to hire and train capable maintenance staff, and many do not offer maintenance training.[7-9] Administrative oversight, planning, and management is essential for maintenance, but many facilities lack systems to monitor, plan, and prioritize maintenance tasks.[10,11] Management- and oversight-related barriers may also arise if responsibilities for planning and funding maintenance are not clearly delineated among facility and government actors, based on evidence from sanitation system maintenance in community settings.[12] Finally, when infrastructure breaks down, replacement parts are expensive or difficult to access, particularly in rural low-income settings.[12,13]

Improving environmental infrastructure in healthcare facilities is a global priority,[14] but there is little research into the

strategies that are used to routinely maintain infrastructure and respond to breakdowns. The baseline availability and condition of environmental infrastructure in healthcare facilities has been well-characterized in numerous cross-sectional assessments, often using standardized indicators such as those provided by the World Health Organization Water and Sanitation for Health Facility Improvement Tool (WASH FIT).[15-20] However, these assessment approaches typically do not consider maintenance and sustainability and provide minimal insight into how to improve documented deficiencies.

Research that goes beyond baseline assessments to explore underlying barriers and drivers of successful maintenance is needed to improve program sustainability. For example, a study of healthcare facilities in Malawi found that delays in reporting and addressing infrastructure breakdowns posed a barrier to healthcare worker infection prevention and control behavior.[21] Global guidelines for environmental conditions in healthcare facilities describe maintenance as an important component of infrastructure improvement, but do not include in-depth guidance for establishing and sustaining maintenance, such as recommendations for routine maintenance tasks or frequencies with which facilities should perform these tasks.[15,22,23] While environmental maintenance practices have been characterized in school and community settings,[12,13,24] healthcare facilities differ in terms of their management structures, financing mechanisms, and integration with the health system.

We expand on prior literature which has documented poor baseline environmental health services in Niger[25,26] to explore infrastructure maintenance as a contributing factor and potential intervention point to improve access. Our specific objectives of were to (1) document maintenance practices at small, rural healthcare facilities in Niger, (2) assess bottlenecks for maintaining environmental infrastructure, and (3) describe the ways in which healthcare workers cope when infrastructure breaks down.

Methods

Study design and definitions

This study was a mixed-methods evaluation of infrastructure maintenance practices and bottlenecks in small, rural healthcare facilities in Niger. We conducted quantitative surveys to document the frequency of maintenance tasks and performed qualitative semi-structured interviews to evaluate maintenance bottlenecks and healthcare worker coping mechanisms. Interviews took place during 2 rounds of data collection in March and October 2022. Quantitative surveys took place only during the second round of data collection in October 2022.

We defined "environmental conditions" as water, sanitation, hygiene, waste management, and environmental cleaning, following standard definitions from international guidelines.[1] We defined maintenance as preventive tasks to avoid breakdowns (eg, inspecting infrastructure, replacing worn parts, and flushing water pipes) and reactive tasks to fix breakdowns after they occurred (eg, repairing structural damage and overhauling broken infrastructure).[27] Our definition of maintenance also encompassed routine tasks to operate infrastructure (eg, water testing and treatment, cleaning tasks), maintain functionality throughout its lifespan, and upgrade and/or rehabilitate infrastructure at the end of its lifespan.[28] We focused on maintenance tasks that occurred within healthcare facilities, and did not examine tasks occurring outside facilities such as off-site waste management. We examined potential bottlenecks to maintenance including schedules and protocols, financing, supplies, human resources, and institutional supports.

Study sites and population

This study occurred in conjunction with a program by the nongovernmental organization World Vision to improve environmental conditions at healthcare facilities. We collected data at 34 small, rural healthcare facilities in the Dosso and Maradi regions of Niger that were receiving the program at the time of study. The Dosso region has a population of 2.16 million, while the Maradi region has a population of 3.98 million.[29] Ninety-one percent of the population of these regions is rural.[29] In 2019, 61% of the Dosso region population and 65% of the Maradi region population was living in poverty.[30]

The small healthcare facilities included in this study were health centers and health posts. Each facility served a catchment population of approximately 5000 to 40 000. All were public facilities receiving government funding. Most facilities had 3 to 4 beds, employed 4 to 5 clinical staff members, and provided inpatient and outpatient primary care to a general population.

World Vision installed or renovated healthcare facility water, sanitation, hygiene, and waste management infrastructure beginning in March 2022. At the time of study data collection, facilities were in different stages of World Vision program implementation, and therefore had varying levels of infrastructure access. Table 1 describes environmental conditions at study sites during survey data collection in October 2022. Most facilities had gained access to environmental supplies (eg, hand hygiene materials and cleaning materials) and infrastructure in the previous 6 to 12 months as part of the World Vision program, though some also had older infrastructure in place prior to the program. This study examined maintenance practices for all environmental infrastructure at facilities, including older and newer infrastructure.

Healthcare facilities in this study had, on average, greater access to environmental conditions than regional and national averages. Among healthcare facilities in Dosso, 85% had improved sanitation, 67% had an improved water source, and 40% had an energy source, according to a 2016 assessment.[26] In Maradi in 2016, 74% of healthcare facilities had improved sanitation, 77% had an improved water source, and 37% had an energy source.[26] However, most of the facilities included in this

Table 1. Environmental conditions at study healthcare facilities in Niger, 2022.

ENVIRONMENTAL CONDITION	FACILITIES REPORTING AVAILABILITY (PROPORTION)
Improved water source available on-site (borehole or tubewell)	0.64
Water tower on-site	0.28
Improved sanitation (ventilated improved pit latrine or pit latrine with slab)	0.92
Water and soap always available for handwashing	0.40
Hygienic hand drying materials available	0.00
Disposed of sharps waste in an incinerator or burner	0.50
Disposed of infectious waste in an incinerator or burner	0.44

Improved water sources are defined as sources which are designed to deliver safe water, while improved sanitation facilities are defined as facilities that can safety prevent human contact with waste.[1] Water towers are elevated structures for storing water and delivering pressurized piped water.

assessment were larger and located in urban settings; access in smaller rural clinics is likely lower.[26] Across all regions of Niger in 2021, an estimated 25% of healthcare facilities had basic water services, 0% had basic sanitation services, 4% had basic hand hygiene services, 5% had basic cleaning services, and 36% had basic waste management services.[1]

Sampling

World Vision selected healthcare facilities for inclusion in their program based on need and convenience. For this study, we purposively selected all healthcare facilities that were participating in World Vision's program. At each study site, facility directors identified one clinical staff member (ie, a staff member involved in direct patient care and/or cleaning duties in clinical rooms) and one non-clinical staff member (ie, an administrator, procurement officer, or supervisor) who were knowledgeable about environmental conditions to participate in interviews. Healthcare facility directors also nominated a staff member who was knowledgeable about the facility's environmental maintenance practices (eg, a nurse, environmental health officer, or maintenance worker) to complete the survey. If the selected respondent was unable to answer all survey questions, the research team asked the respondent to identify another knowledgeable staff member who could supply additional information.

Data collection

During the first round of data collection in March 2022, we conducted qualitative interviews to assess maintenance practices, barriers to performing maintenance, and measures taken to cope with breakdowns. In the second round of data collection in October 2022, we used similar guides but revised questions to elicit additional detail. Both rounds of data collection took place at the same study sites. Some individuals were interviewed during both rounds, while others were interviewed during only 1 round based on their availability at the time of data collection. Interview guides were designed to capture information on maintenance practices and bottlenecks both before and after implementation of the World Vision intervention. Qualitative research teams, consisting of 1 interviewer and 1 note-taker, administered interviews in French, Hausa, or Zarma. Interviews took place in private locations within healthcare facilities and were approximately 45 min to 1 h in duration. Where participants gave permission (n = 90, 98%), research teams audio-recorded interviews. All recordings, including recordings of interviews conducted in Hausa or Zarma, were transcribed in French. Transcripts were translated into English for thematic coding and analysis. For participants who did not consent to audio-recording (n = 2), research teams took handwritten notes during interviews. We reviewed interview notes but did not include them in the thematic coding process.

We also implemented quantitative surveys during the second round of data collection in October 2022. Surveys asked respondents to report on frequency of performing common maintenance tasks and roles of personnel involved in maintenance. To define common maintenance tasks for the survey, we reviewed international guidelines for environmental conditions in healthcare facilities[31] and identified maintenance tasks that were described within these guidelines (eg, cleaning water pump solar panels, fixing leaking pipes, inspecting incinerator for cracks and repairing as needed). We added questions about additional tasks based on descriptions from the first round of qualitative interviews. The list of survey questions is available in Supplemental Material S1, including a listing of all maintenance tasks assessed. Surveys were programed in French onto an electronic mobile survey platform (mWater). Enumerators verbally translated surveys into Hausa or Zarma as needed at the time of survey for non-Francophone participants and recorded responses in French.

Data analysis

Using quantitative data from surveys, we calculated the proportion of facilities that reported performing each maintenance task daily, weekly, monthly, a few times a year, once a year or less often, or never. We also calculated the proportion of facilities reporting that maintenance tasks were performed by a maintenance worker, cleaner, clinical staff (eg, doctor, nurse, or midwife), administrative staff (eg, facility director) patient or caregiver, community member, or no one.

For thematic analysis of qualitative interview data, we developed a codebook with inductive codes informed by the

Context and Implementation of Complex Interventions (CICI) framework.[32] The CICI framework has previously been applied to assess water, sanitation, and hygiene interventions and healthcare facility-based interventions in low-resource settings.[33,34] It proposes that intervention effectiveness is influenced by contextual dimensions (ie, geographical, epidemiological, socio-cultural, socioeconomic, ethical, legal, and political characteristics).[32] We hypothesized that these contextual dimensions would influence maintenance. To classify bottlenecks to maintenance, we performed preliminary coding using all CICI domains, then developed specific inductive codes for the salient domains. The CICI framework also proposes that interventions are characterized by implementation-related dimensions (ie, implementation theory, process, strategies, agents, and outcomes).[32] We adapted the implementation dimensions of the CICI framework to create inductive codes to classify maintenance practices and coping strategies (Supplemental Material S2).

One researcher developed an initial codebook, and three researchers then applied the codebook to a preliminary set of four interviews to refine definitions and develop additional data-driven codes based on emergent themes. To establish reliability of the codebook, the researchers independently coded interviews, compared coding outputs, and clarified code definitions where necessary.[35] Then, one researcher used the revised codebook to re-code the preliminary set and code all remaining interviews. We used NVivo software (Version 14) for coding. We reviewed interview coding results to characterize prevailing themes and interviewee perspectives.

Ethics

We obtained approval from facility administrators prior to initiating data collection. All survey and interview participants provided informed consent. We did not collect identifiable private information from study participants. This study was designated as "not human subjects research" by the University of North Carolina Institutional Review Board and was approved by the Niger Ministry of Public Health.

Results

Survey results: Routine maintenance procedures and personnel

Our survey sample comprised 34 healthcare facilities. Respondents reported infrequent performance of most maintenance tasks. Tasks performed more frequently included cleaning and emptying waste. On at least a monthly basis, 91% (n = 29) of facilities cleaned toilets and latrines, 72% (n = 21) cleaned showers, and 94% (n = 17) emptied waste from bins. Preventive maintenance tasks—such as inspecting infrastructure to detect and replace spare parts—were performed less often. On at least a monthly basis, 4% (n = 1) of facilities performed a detailed inspection of water infrastructure to detect worn or damaged parts, for the purpose of replacing these parts when necessary to prevent breakdowns. Eight percent (n = 2) performed a detailed inspection of shower heads and water taps, 15% (n = 4) performed a detailed inspection of water taps and basins, and 29% (n = 5) performed a detailed inspection of incinerators on at least a monthly basis. No facilities reported testing their water for contamination, cleaning their water tower, or performing a detailed inspection of water pipes on at least a monthly basis (Table 2).

Cleaning staff at healthcare facilities often performed environmental cleaning and maintenance tasks. Cleaners reportedly cleaned water containers at the point of care at 27% of facilities (n = 9), cleaned toilets and latrines at 59% of facilities (n = 19), and collected and packed waste from the point of care at 71% of facilities (n = 24). More rarely, a maintenance staff member performed cleaning and maintenance tasks. Six percent of facilities (n = 2) reported that a maintenance staff member was involved in testing and treating water, cleaning water containers, cleaning latrines or toilets, and collecting waste from the point of care.

Healthcare facility staff members, patients, and community members were also involved in cleaning and maintenance. Staff in clinical roles, such as doctors, nurses, and midwives, reportedly cleaned latrines or toilets at 19% of facilities (n = 6) and cleaned infectious waste and spills at 47% of facilities (n = 16). Twenty-one percent of facilities (n = 7) reported that patients or caregivers cleaned infectious waste and spills. Infectious waste includes waste that may transmit disease due to contamination with bodily fluids, blood, or excreta.[36] Maintenance of the water tower and pipe system was performed by a maintenance staff member at 23% of facilities (n = 7), a community member at 13% of facilities (n = 4), a cleaner at 3% of facilities (n = 1), and a clinical staff member at 3% of facilities (n = 1). Sixty-one percent of facilities (n = 19) said that "no one" performed maintenance of the water tower and pipe system (Table 3).

Interview results

Qualitative interviews took place with 92 staff members across 26 healthcare facilities; 8 healthcare facilities did not have sufficient staff to complete both interviews and surveys, and in these cases we prioritized surveys. Interview participants included facility directors, administrators, health management committee members, clinicians, and cleaners (Table 4).

We characterized healthcare facility processes for environmental maintenance, bottlenecks, and coping strategies. Figure 1 summarizes processes for responding to infrastructure breakdowns and bottlenecks to locating maintenance supplies, personnel, and funds.

Table 2. Frequency of maintenance tasks at 34 healthcare facilities in Niger, 2022.

MAINTENANCE TASK	FREQUENCY, NUMBER (PROPORTION)					
	DAILY	WEEKLY	MONTHLY	A FEW TIMES/YEAR	YEARLY OR LESS OFTEN	NEVER
Water infrastructure						
Clean solar panels for pump	2 (0.12)	6 (0.35)	4 (0.24)	0	0	5 (0.29)
Disinfect pump	1 (0.04)	0	0	0	0	25 (0.96)
Clean and grease pump mechanism	0	3 (0.12)	0	1 (0.04)	0	21 (0.84)
Inspect water source and pump to detect worn parts	0	0	1 (0.04)	1 (0.04)	0	22 (0.92)
Inspect the water tower to detect worn parts	0	0	1 (0.04)	2 (0.09)	0	20 (0.87)
Treat water	0	0	1 (0.03)	0	0	32 (0.97)
Clean the water tower	0	0	0	1 (0.20)	0	4 (0.80)
Test water for microbial contamination	0	0	0	0	0	34 (1.00)
Test water for chemical contamination	0	0	0	0	0	34 (1.00)
Disinfect borehole	0	0	0	0	0	24 (1.00)
Remove pump to flush silt and debris from borehole	0	0	0	0	0	26 (1.00)
Flush and clean water distribution pipes	0	0	0	0	0	26 (1.00)
Inspect water pipes to detect old seals	0	0	0	1 (0.04)	1 (0.04)	24 (0.92)
Sanitation infrastructure						
Clean toilets/latrines	10 (0.31)	13 (0.41)	6 (0.19)	0	2 (0.06)	1 (0.03)
Clean showers	10 (0.31)	9 (0.31)	2 (0.07)	1 (0.03)	2 (0.07)	5 (0.17)
Clean menstrual hygiene management rooms	3 (0.13)	0	0	0	0	20 (0.87)
Inspect shower heads and water taps to detect old and worn parts	2 (0.08)	0	0	0	0	23 (0.92)
Empty latrine pits or septic tanks	0	1 (0.03)	0	2 (0.06)	1 (0.03)	27 (0.87)
Fix structural damage to the latrine pit or septic tank	0	0	0	3 (0.09)	3 (0.09)	26 (0.81)
Hygiene infrastructure						
Clean sinks or wash basins	16 (0.59)	7 (0.26)	1 (0.04)	0	0	3 (0.11)
Inspect taps and basins to detect old and worn parts	3 (0.12)	0	1 (0.04)	1 (0.04)	0	21 (0.81)
Replace damaged parts on water taps and basins after damage or failure	0	0	0	5 (0.19)	1 (0.04)	21 (0.78)
Waste management infrastructure						
Empty waste from collection bins	13 (0.72)	4 (0.22)	0	0	1 (0.06)	0
Inspect waste collection bins for damage	3 (0.23)	3 (0.23)	3 (0.23)	1 (0.08)	0	3 (0.23)
Inspect incinerator to detect cracks	2 (0.12)	1 (0.06)	2 (0.12)	0	0	12 (0.71)
Sweep out and dispose ash	1 (0.06)	4 (0.22)	4 (0.22)	2 (0.11)	0	7 (0.39)

(Continued)

Table 2. (Continued)

MAINTENANCE TASK	FREQUENCY, NUMBER (PROPORTION)					
	DAILY	WEEKLY	MONTHLY	A FEW TIMES/YEAR	YEARLY OR LESS OFTEN	NEVER
Clean and disinfect tools used during incineration	1 (0.06)	3 (0.18)	0	1 (0.06)	0	12 (0.71)
Check and replace seals	1 (0.06)	0	0	1 (0.06)	0	15 (0.88)
Scrape off and dispose melted glass/plastics adhered to grates, walls, and floor	0	2 (0.12)	2 (0.12)	1 (0.06)	1 (0.06)	11 (0.65)
Cover old ashpit and dig a new pit	0	3 (0.19)	0	3 (0.19)	2 (0.13)	8 (0.50)
Inspect waste transportation carts or trolleys to detect old and worn parts	0	1 (0.08)	0	1 (0.08)	0	10 (0.83)
Inspect furnace and boiler to detect old or worn parts	0	0	0	2 (0.13)	0	14 (0.88)
Strip out and replace all bricks as a major overhaul	0	0	0	1 (0.06)	1 (0.06)	14 (0.88)

Proportions exclude facilities that had no response or where infrastructure was unavailable.

Table 3. Personnel roles in maintenance at 34 healthcare facilities in Niger, 2022.

MAINTENANCE TASK	PERSON PERFORMING MAINTENANCE TASK, NUMBER (PROPORTION)						
	MAINTENANCE WORKER	CLEANER	CLINICAL STAFF	ADMIN. STAFF	PATIENT OR CAREGIVER	COMMUNITY MEMBER	NO ONE PERFORMS
Water testing and treatment	2 (0.06)	0	2 (0.06)	0	0	0	29 (0.88)
Maintenance of water tower and pipe system	7 (0.23)	1 (0.03)	1 (0.03)	0	0	4 (0.13)	19 (0.61)
Cleaning water containers at point of care	2 (0.06)	9 (0.27)	2 (0.06)	1 (0.03)	0	0	19 (0.58)
Cleaning latrines or toilets	2 (0.06)	19 (0.59)	6 (0.19)	0	1 (0.03)	3 (0.09)	1 (0.03)
Collecting and packing waste from point of care	2 (0.06)	24 (0.71)	10 (0.29)	0	0	1 (0.03)	0
Treatment of waste	0	5 (0.15)	1 (0.03)	1 (0.03)	0	0	26 (0.76)
Monitoring levels of stock of hand soap	0	3 (0.09)	14 (0.41)	19 (0.56)	0	0	0
General cleaning in non-clinical spaces	2 (0.06)	24 (0.71)	10 (0.29)	1 (0.03)	1 (0.03)	3 (0.09)	0
Cleaning of infectious waste and spills	1 (0.03)	22 (0.65)	16 (0.47)	2 (0.06)	7 (0.21)	0	0
Cleaning of patient areas	2 (0.06)	23 (0.68)	7 (0.21)	0	0	4 (0.12)	0

Clinical staff roles are: nurse, doctor, midwife, assistant, and community health worker. Administrative staff roles are: director, deputy director, preceptor, and hygienist. At some facilities, multiple staff roles performed a maintenance task. Proportions exclude facilities that had no response or where infrastructure was unavailable.

Table 4. Demographics of key informant interview participants (n = 92) at healthcare facilities in Niger, 2022.

DEMOGRAPHIC CATEGORY	SAMPLE SIZE, N (PROPORTION)
Gender	
Male	58 (0.63)
Female	34 (0.37)
Staff role	
Nurse	22 (0.24)
Director/nurse	19 (0.21)
Other facility administrator	14 (0.15)
Cleaner	13 (0.14)
Health management committee member	11 (0.12)
Facility director	8 (0.09)
Doctor	3 (0.03)
Community health worker	1 (0.01)
Maintenance worker	1 (0.01)
Years worked in position	
<3 y	33 (0.36)
3-5 y	24 (0.26)
6-10 y	17 (0.18)
>10 y	16 (0.17)
No response	2 (0.02)

Processes for performing maintenance

Preventive maintenance. Facilities did not routinely perform maintenance to prevent infrastructure breakdowns. Most respondents perceived basic environmental cleaning tasks—such as sweeping floors, cleaning toilets, and disposing of waste—to be sufficient as preventive maintenance. Facilities routinely inspected infrastructure, but these inspections were primarily concerned with whether the infrastructure was clean and functional. Inspections did not appear to prompt facilities to perform preventive maintenance:

> "The only procedure is to go and inspect from time to time. . . to know if there is maintenance to be done or if it's dirty." -Cleaner

Each healthcare facility was overseen by an elected management committee. Health management committees often included senior administration and community leaders. Some facilities also had water, sanitation, and hygiene (WASH) committees comprising administrators and community members. Health management committees and WASH committees were involved in monitoring and inspecting water towers and other large infrastructure:

> "The WASH committee takes care of [inspection] because they take care of all the infrastructure. As soon as they detect a problem, they report it to the head of the [healthcare facility]." -Tax collector

Reactive maintenance. Planning and decision-making for maintenance typically occurred after healthcare facility staff members noticed a problem with infrastructure. If the healthcare facility director determined that it was necessary to address the problem, they next determined whether to perform repairs independently or seek help from local leadership. These decisions were made based on current availability of funds and personnel at the facility, rather than a pre-defined protocol. If a maintenance need could be fixed quickly and with available resources, the facility sometimes addressed it on its own, paying for maintenance expenses out of a petty cash fund:

> "If you know how to repair you do it, otherwise you say that you are incapable." -Cleaner

Sub-national (commune-, department-, and region-level) government authorities and traditional leaders were also involved in reactive maintenance. For larger problems, such as breakdowns that required skilled technicians or overhauls of infrastructure, the healthcare facility director notified the health management committee. Through in-person meetings and visits to the facility, the management committee would determine what type of maintenance was needed, identify a technician to perform maintenance, and allocate funds. Some respondents said that they notified the village chief, mayor, or members of the town hall when there was a larger breakdown that the facility could not repair on its own. While village chiefs held traditional roles rather than official government positions, they were influential in advocating for communities and guiding resource allocation. Local authorities would communicate via phone or visit the facility to determine what kind of maintenance was needed. In some cases, local governments could provide funds to pay for maintenance when the facility could not pay on its own:

> "If a [mason] has come to repair it, we have to go to the town hall with the mason. [The mason] will say all the expenses they have to do and then we come back together." -Preceptor

Bottlenecks to maintenance

Management and ownership. Most facilities did not have protocols for preventive maintenance or plans for responding to breakdowns. Responsibilities for funding and performing maintenance were not well-delineated. Facilities often attempted to contact different institutions in sequence to

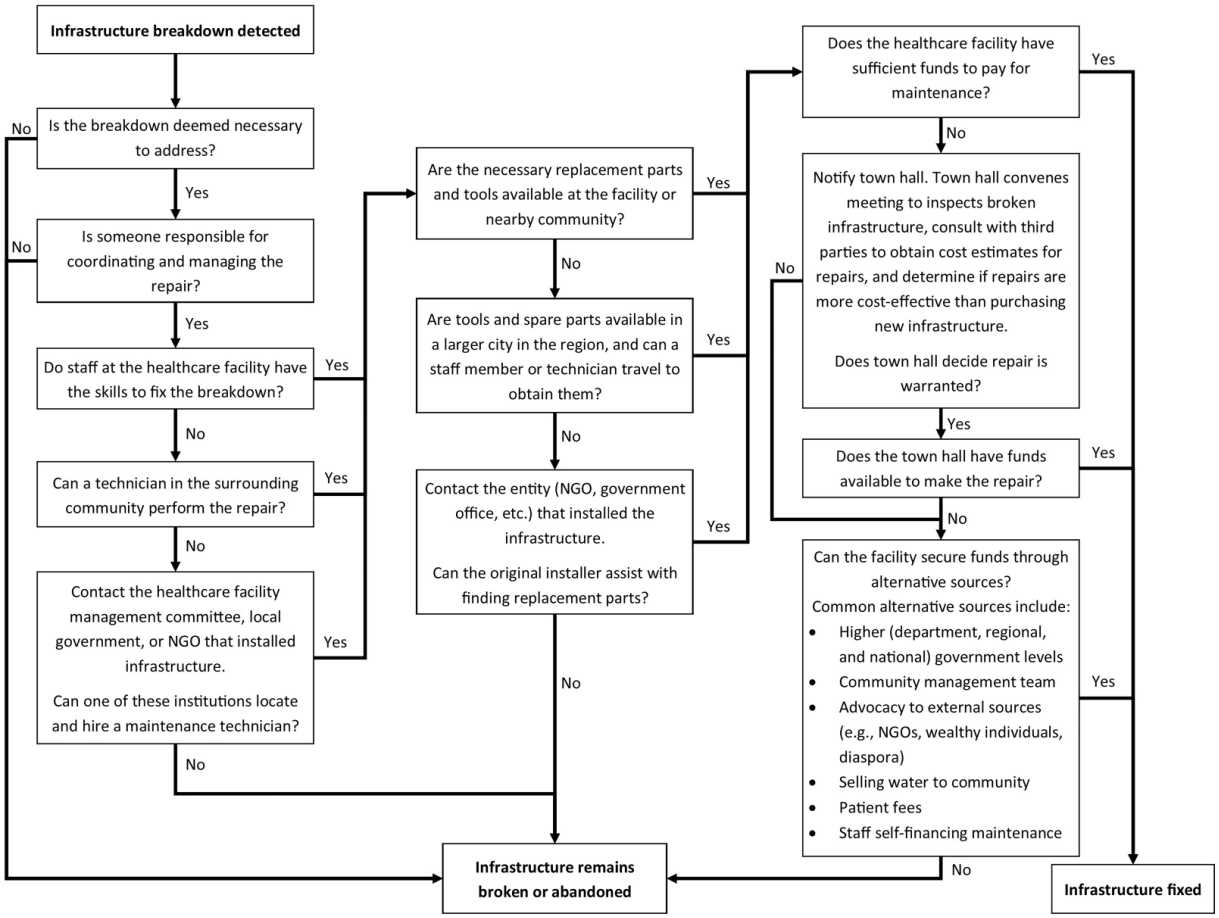

Figure 1. Decision-making strategies and bottlenecks for performing environmental infrastructure maintenance at healthcare facilities in Niger, 2022.

request funds or technical support for maintenance, contributing to delays in responding to breakdowns (Figure 1). Some respondents felt that the healthcare facility administration should oversee maintenance, while others felt that maintenance should be organized by the nongovernmental organization that had installed the infrastructure. Many expressed the sentiment that the healthcare facility "belonged to" the community, so the community should play a role in managing environmental conditions:

> "The materials of the [healthcare facility] are for the whole population so we must maintain them well. . . Everyone gets to work and takes care of the materials." -Preceptor

Some facilities did not have their own water source and relied on water sources in the community. These facilities did not have control over water infrastructure maintenance. At one facility, staff said that they had paid for their own water for several days waiting for a private owner to fix a water system.

Personnel. Facilities had a limited ability to hire and retain skilled maintenance staff. Most facilities employed a cleaning or maintenance staff member who performed basic tasks like sweeping and cleaning surfaces, but facilities did not employ technicians who could address more complex maintenance needs or fix breakdowns. Most respondents said that their facilities needed additional cleaning and maintenance staff. Payment for cleaners and maintenance staff was also a frequent issue. At some facilities, maintenance workers were unpaid volunteers; at several others, maintenance workers were employed by the facility in a paid position but experienced monthslong delays in receiving salary payments. Salary payment problems undermined maintenance staff members' ability and willingness to perform their work:

> "There is too much delay in our wages. . .If you don't have peace of mind the work won't be a success." -Cleaner

Financing. Facilities encountered bottlenecks to procuring funds for maintenance. In many cases, projects to install infrastructure at healthcare facilities were not accompanied by funding for long-term maintenance. Instead, participants said that they had tried to construct infrastructure well and keep it clean to prevent breakdowns from occurring. Most facilities did not have a dedicated budget for operations and maintenance of environmental infrastructure, and instead had to raise funds after a breakdown occurred. Virtually all facilities reported that they struggled to raise funds for maintenance. Most respondents said they had been unable to perform necessary maintenance due to a lack of funds, and many had simply

abandoned aging infrastructure when they were unable to make repairs. In addition to maintenance, facilities also experienced funding shortfalls for their other operating costs, such as purchasing essential medicines:

> "We do not have a dedicated fund for these repairs. It is the [health management committee] and the [healthcare facility director] who do this. And in case of a situation where they are not able, we are stuck." -Deputy director

Politics and public financial management. Since healthcare facilities were publicly-funded, many respondents expected the government to provide financial support for maintenance when infrastructure broke down. Healthcare facilities made budget requests to national government on an annual basis and made additional requests for supplies on a monthly basis. The government's decision to fund these budgets depended on overall availability of funds and political decisions around which aspects of the health system and regions of the country to prioritize. District health offices also played a role in financing: districts assessed healthcare facility needs and made recommendations for budgetary allocation and resource distribution. While national government was sometimes able to provide funding for repairs, the process of accessing government funds for maintenance was unreliable and burdensome for facilities. The annual nature of budgeting and funding contributed to delays, as governments required several stages of deliberation and discussion before approving a budget increase. Furthermore, facilities' requests for budget increases were not always granted. Several respondents said either that government funding for maintenance had been slow to arrive, or that the government had not fulfilled their funding requests:

> "I'm always saying that the building's leaking. The [health management committee] is aware, and they speak with you. Each time they tell us that they are going to fix it. It's been 3 winter seasons. . . We are always complaining." -Nurse

Locating supplies and technicians. Replacement parts for environmental infrastructure were sometimes unavailable in the rural areas where healthcare facilities were located. Several respondents said that they had been unable to find specialized parts and tools that were needed for long-term infrastructure operations and maintenance, such as welding equipment, light bulbs, and water pump replacement parts. Similarly, skilled maintenance technicians often had to travel considerable distances from larger cities. Facilities experienced waits of days or weeks for maintenance technicians and supplies:

> "There had been a delay. It took two days to even find the maintenance worker. Then when he came, there were materials that he could not find, and we had to search for the materials in Niamey [capital city 3 hours away], which were delayed before arriving." -Nurse

Facilities faced barriers to obtaining environmental cleaning supplies (such as chlorine, soap, and personal protective equipment) through official government channels. At most facilities, respondents said that government-provided supplies were delayed by weeks or months, or the amount of supplies provided was inadequate.

Coping strategies to overcome bottlenecks

Advocacy and social capital. Facilities and individual healthcare workers attempted a range of coping strategies to perform maintenance when they encountered bottlenecks. When facilities were unable to pay for maintenance, they made appeals to community leaders and nongovernmental organizations to raise funds. Some also appealed to wealthy individuals from the community or members of the diaspora. Nearly all facilities had advocated to at least one of these groups to pay for an environmental maintenance need. Respondents at approximately half of facilities said that advocacy had been effective in raising funds for maintenance. At other facilities, however, respondents reported that advocating for maintenance was unsuccessful. Potential donors either did not have sufficient funds, were slow to respond to requests or did not respond at all, or did not follow through on their commitments.

The outcome of advocacy depended on socio-cultural factors. Some facility directors were well-integrated with community social structures, speaking at local government meetings or reaching out to individuals in their network to ask for funding. Other facilities appeared to have lower social capital, as respondents complained that they did not have partners who could provide funding when needed. Facilities that had close relationships with communities and donors described how these relationships facilitated their fundraising and advocacy efforts:

> "We have a population that is really open. These are people who are there to support us, and often they even come to us to ask us about our needs. If we express our needs they satisfy them." -Director

Generating revenue. In addition to raising funds in response to a breakdown, facilities created savings accounts to pay for maintenance. As part of the World Vision intervention, facilities had established initiatives to raise funds for maintaining the water tower by selling water to the community. Many also raised money for maintenance and supplies by adding a small fee to patient services. Most respondents were supportive of revenue-generation schemes. One respondent expressed misgivings, saying that the facility might create tension with the community if they sold water rather than giving it away for free. Several others were skeptical that the amount of funds raised would be sufficient to cover a major maintenance expense.

Community participation. Beyond financially supporting maintenance, community members sometimes participated in construction and maintenance projects at healthcare facilities. At many facilities, groups of women, young people, or other community members volunteered to help clean the facility and

maintain the grounds. Some facilities had also found skilled technicians from the community who addressed maintenance problems on a "case-by-case basis." However, community technicians had other commitments and were sometimes unavailable to assist the facility when needed, and respondents said that they had experienced delays of 2 to 3 days while waiting for the technician to arrive.

Self-financing. Facility staff sometimes paid for maintenance when other sources of funding were unavailable. Many respondents recounted instances where doctors or administrators had paid to fix infrastructure breakdowns using their personal funds. Facility administrators described a feeling of obligation and responsibility to pay for maintenance, with one explaining that he paid for maintenance because "health is priceless." Nearly all respondents said that staff regularly paid for their own soap, alcohol-based hand rub, and environmental cleaning materials when these were unavailable at the facility. Senior staff and supervisors often purchased these supplies for more junior staff. When water infrastructure broke down, staff sometimes coped by purchasing water or paying a community member to bring water to the facility with personal funds.

Discussion

Healthcare facilities in rural Niger face barriers to performing maintenance of environmental infrastructure and fixing breakdowns in a timely manner. This study found that facilities rarely replaced worn parts on infrastructure, monitored water quality, or performed other preventive maintenance tasks. As healthcare facilities did not have protocols or roles in-place for maintenance, staff spent considerable time and effort to hire skilled technicians and locate spare parts when breakdowns occurred. Facilities experienced delays in accessing government funding for maintenance. However, they were also resourceful and had developed coping strategies to overcome challenges with formal government systems. Many successfully made repairs by appealing to communities for support or self-financing. Even so, some facilities had abandoned broken infrastructure because they could not raise the funds to repair it.

This study provides insight into bottlenecks related to planning, funding, and performing maintenance at Nigerien healthcare facilities. Prior to installing environmental infrastructure, researchers, policymakers, and practitioners should seek to understand existing maintenance practices at healthcare facilities and identify potential bottlenecks. Tailoring programs to address barriers and coping mechanisms may improve programmatic efficiency and effectiveness.[37] In this study, we identified several possible pathways to mitigate barriers (eg, by reducing delays between recognizing, reporting, and fixing breakdowns) and strengthen existing coping strategies (eg, advocacy, revenue generation, and community support) to improve efficiency of maintenance practices and enhance the sustainability of environmental infrastructure. Maintenance bottlenecks related to management and responsibility, personnel, and financing in Nigerien healthcare facilities align with results of prior studies conducted in Nigeria and Rwanda,[8,38] indicating that our findings may be generalizable to other small, rural healthcare facilities in low-resource settings. Larger facilities may experience different barriers to maintenance, as these facilities often possess a more advanced level of environmental infrastructure and have access to more internally generated revenue for managing infrastructure.[39] Access to skilled technicians and supplies may differ for urban facilities compared to rural facilities, requiring further study.

While many of the healthcare facilities in this study had recently received installations of environmental infrastructure, few had established plans for long-term operations and maintenance. A lack of planning for maintenance may contribute to the low frequency of preventive maintenance tasks reported by survey respondents. Research from healthcare facilities in Uganda has similarly found that healthcare facilities lack staff who are responsible for maintenance, undermining the ability to effectively and sustainably manage environmental infrastructure.[40] Our findings highlight a need for postconstruction planning, training, and financial support to accompany infrastructure implementation in healthcare facilities. While many facilities were able to fund maintenance through advocacy and fundraising, the process of reporting breakdowns and financing repairs was time-consuming. Governments and partners installing infrastructure should evaluate the existing maintenance capacity of healthcare facilities and consider how to sustain maintenance activities after external funding support expires. Ongoing technical support for maintenance planning, financial decision-making, and routine monitoring could improve infrastructure maintenance and sustainability.[41,42] Further research could examine healthcare facilities with well-established maintenance programs to understand processes for maintenance and identify facility characteristics that may drive success.

As many facilities did not employ maintenance personnel, non-maintenance staff and community members played important roles in maintenance. Surveys indicate that clinical staff, administrators, patients, caregivers, and community members participated in cleaning and maintenance tasks at healthcare facilities. Some interview respondents said that they had identified dependable community members who could repair infrastructure when needed, but others struggled to find skilled technicians. Given the range of personnel involved in maintenance at healthcare facilities, those installing environmental infrastructure should clearly delineate responsibilities for planning, supervising, and executing maintenance tasks. Implementers could also establish systems to professionalize maintenance at healthcare facilities, including by identifying dedicated service providers, training local community members, and creating agreements for long-term preventive maintenance.[42] Professionalized maintenance programs could

leverage existing maintenance expertise in communities and improve facilities' ability to sustain infrastructure. For instance, circuit rider programs, involving professional maintenance technicians who travel to facilities to perform maintenance on a regular basis, may be feasible to support maintenance in rural healthcare facility settings.[43] Circuit rider programs may be advantageous for healthcare facilities in Niger as their centralized nature could integrate with district-level health system budgeting and management structures.[44] However, a circuit rider model can result in long waiting times for repairs if breakdowns occur between scheduled maintenance visits.[44] In comparison, demand-driven maintenance models such as guaranteed-service models, where facilities establish contracts with maintenance technicians and then request services as needed, may support more timely repairs.[44,45] However, the efficiency of guaranteed-service models depends on facilities recognizing and reporting maintenance needs in a timely manner, and these models may be inefficient in rural areas where it is time-consuming and costly for maintenance technicians to travel to facilities on an as-needed basis.[44] Research from community settings indicates that professionalized maintenance improves water quality, enhances the functionality of water infrastructure, and reduces the frequency of breakdowns.[45-47] In the long term, costs associated with professional maintenance may be lower than the costs of abandoning and replacing broken infrastructure.[48] In community settings the success of professionalized maintenance arrangements depends in part on local government buy-in and integration with existing processes.[44,49] Establishing and sustaining professionalized maintenance programs in healthcare facilities would similarly require oversight at the facility and district health office level and coordination with government for budgetary allocation. Further research into the frequency of common breakdowns and costs associated with repairs could support planning and budgeting for professionalized maintenance models in healthcare facilities.

Healthcare facilities experienced political and financial bottlenecks to maintenance, and interview participants reported that their appeals for national government funding were often time-consuming and unsuccessful. Instead, facilities relied on local-level governments, traditional leaders, and community members as a coping strategy. These findings suggest that a tiered approach to systems change, including responsibilities at the facility, community, and policy level, may be feasible for improving and sustaining maintenance. In Niger and other fragile contexts, locally-led solutions for maintenance may be more feasible and successful in the short term compared to solutions dependent on central government support. This study found that community involvement was instrumental for performing routine cleaning tasks, identifying skilled maintenance technicians, and raising funds for maintenance in healthcare facilities. Healthcare facilities could formalize community member roles and responsibilities in maintenance to garner more reliable support. Policy development is also necessary to define the role of regional and national government institutions in overseeing and funding maintenance. Advocacy to governments can lead to the establishment of new policies and budgets for operations and maintenance of environmental services, contributing to long-term improvement.[50]

Many of the healthcare facilities in this study had established programs to generate revenue for maintenance by selling water to communities. A similar intervention to introduce water kiosks at healthcare facilities in Rwanda found that kiosks were feasible for returning a profit and meeting consumer demand, but profits were insufficient to cover long-term capital costs.[51] Water system maintenance programs in community settings in Africa similarly indicate that water user payments fall short of recovering all operational costs, suggesting that subsidies are necessary to supplement revenue from sales.[52] Further research should evaluate the sustainability and profitability of revenue-generation schemes at healthcare facilities in Niger to determine whether this is a viable solution for financing maintenance and whether continued subsidization of operations and maintenance costs is necessary. Moreover, research to determine costs of environmental maintenance could aid healthcare facilities in budgeting, planning, and advocating for maintenance. Funding for maintenance may comprise a large portion of overall investment needs for improving environmental conditions at healthcare facilities.[53] However, few studies have explored costs of maintenance in healthcare facilities to date.[6] Healthcare facilities could use information about maintenance costs both to create internal budgets for repairs and to advocate for government funding.

Maintenance practices have implications for the wellbeing of individual workers and patients, as well as for the strength of the health system more broadly. Functional infrastructure plays a role in healthcare worker wellbeing; having a water source that had not broken down in the past 2 weeks is associated with higher healthcare worker satisfaction with environmental conditions.[54] Inadequate environmental conditions also increase risks of healthcare-associated infection, contribute to patient dissatisfaction, and undermine willingness to seek care at healthcare facilities.[55,56] Patient experiences during healthcare visits play a role in their confidence in the health system.[57] Frequent infrastructure breakdowns and delayed repairs therefore are likely to have a negative impact on the overall effectiveness of the health system. Improved maintenance practices will contribute to healthcare facilities' ability to uphold patient safety and deliver high-quality care.

Limitations

This study is subject to limitations. Bias may arise from our use of self-reported surveys to assess frequency of maintenance tasks and interviews to describe maintenance systems and barriers. Interview and survey participants could have

overstated the frequency of maintenance to protect their facility's reputation, or highlighted the problems that their facility faced to garner additional support. Furthermore, our survey asked participants only about the frequency of maintenance tasks. We did not observe the tasks nor collect further qualitative information to evaluation whether the specific tasks, when performed, were performed correctly or completely.

Data collection coincided with implementation of environmental infrastructure at healthcare facilities. At many facilities, infrastructure was less than a year old and breakdowns had never occurred. In these cases, facilities may have been unable to determine and report the frequency of maintenance for new infrastructure. Future research could document the longevity of newly-installed infrastructure and examine the strategies that facilities use to maintain infrastructure over time.

Conclusions

This study described maintenance practices, bottlenecks, and coping strategies at healthcare facilities in Niger. We found that facilities faced political and financial barriers to maintenance, contributing to infrastructure breakdowns that detrimentally impacted the functionality of the health system and the wellbeing of workers and patients. This study contributes to an understanding of the factors that impede sustainability of environmental infrastructure in low-resource healthcare facilities. Documentation of maintenance practices can highlight opportunities for interventions to overcome bottlenecks and strengthen effectiveness of coping mechanisms. Programs to support healthcare facilities in planning for maintenance, locally generating revenue to fund repairs, and training technicians in the community may be feasible in the context of rural Niger. Post-construction support for maintenance—including for creating protocols, accessing funds, and locating skilled technicians—should accompany installation of infrastructure to improve long-term functionality. Further research to strengthen maintenance practices and evaluate impacts of performing adequate maintenance can inform interventions to improve safety and wellbeing among healthcare facility staff and patients in Niger.

Acknowledgements

We gratefully acknowledge Kaida Liang, Ben Tidwell, Seth Marcus, and Peter Hynes for their roles in funding acquisition, project management, and supervision of data collection. We thank the enumerators and staff of CERISES consulting firm for their assistance with data collection. We thank Irving Hoffman for his input on data collection tools, and also thank Ryan Cronk, Silvia Landa, and Sarah Lebu for their feedback on the draft manuscript. We acknowledge and thank the healthcare facility staff in Niger for their time and participation in this study.

Author Contributions statement

LKT: Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. EM and KOBM: Data curation, Investigation, Project administration. VB: Conceptualization, Methodology, Writing - review & editing, Project administration. EYS: Investigation, Writing – review & editing. AS: Conceptualization, Writing - review & editing, Supervision, Funding acquisition. DMA: Conceptualization, Methodology, Data curation, Writing - review & editing, Project administration.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author, L.K.T. The data are not publicly available due to privacy concerns.

Supplemental Material

Supplemental material for this article is available online.

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