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Stewarding the hospital sink drain: a narrative review of practical approaches for controlling gram negative pathogens in low- and middle-income countries

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Abstract

In low- and middle-income countries (LMICs), gram-negative bacteria cause over half of intensive care unit (ICU) infections, with up to 50% mortality associated with multidrug-resistant (MDR) strains. Hospital sink drains are increasingly recognized as reservoirs for MDR organisms and are well-documented sources for nosocomial infections, yet effective and sustainable decontamination strategies—particularly for resource-limited facilities—remain elusive. This narrative review synthesizes evidence on sinks as pathogen reservoirs, evaluates limitations of existing remediation approaches, presents pilot data from our tertiary hospital in Botswana, and outlines research priorities for LMICs. We identify five dimensions that complicate control of gram-negative pathogens in sink drains: (1) poor visibility of drain interiors limiting awareness of biofilm growth extent; (2) nutrient inputs from non-hand-hygiene uses that can encourage microbial growth; (3) design barriers to cleaning and disinfection; (4) inconsistent pathogen detection methods; and (5) uncertainty about optimal regimens for cleaning and disinfection. We share data from pilot studies assessing treatment interventions for neonatal ICU sinks with high baseline contamination—including periodic addition of boiling water, sodium hypochlorite, and a commercial probiotic cleaner. Carbapenem-resistant Enterobacterales growth was suppressed by treatment with boiling water and sodium hypochlorite, but the highest prevalence of extended-spectrum beta-lactamase-producing Enterobacterales (ESBL-E) and *Acinetobacter* spp. was observed for sinks treated with sodium hypochlorite; probiotic cleaning was associated with the lowest ESBL-E prevalence. Findings from our literature review and pilot studies collectively support the need for a framework for hospital sink-drain stewardship that shifts away from routine chemical disinfectants and toward effective thermal or microbial strategies (e.g., probiotics, bacteriophages) that could reduce pathogen burden without selecting for more virulent or drug-resistant strains. Future work should define concentrations/regimens, safety precautions, and pathogen monitoring strategies for these approaches and embed them within sink-drain stewardship frameworks suitable to LMIC settings.

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Background

Healthcare-associated infections are a persistent and deadly threat worldwide, with incidence in intensive care units (ICUs) up to 20-fold higher in low- and middle-income countries (LMICs) than in wealthier nations, due in part to limited infection prevention and control (IPC) infrastructure [1]. In LMICs, gram-negative bacteria are responsible for over 50% of infections in ICUs, with mortality rates ranging from 30 to 50% for infections caused by multidrug-resistant (MDR) strains [2]. Many of these gram-negative bacteria thrive in moist environments and persist within mature biofilms in hospital plumbing, enabling sustained bacterial transmission to patients through retrograde droplet dispersal and surface contamination [3–5]. Molecular and epidemiologic data suggest that up to 75% of healthcare-associated acquisitions of gram-negative pathogens in ICUs are linked to contaminated sink drains [6]. In a review of 23 hospital outbreaks involving carbapenem-resistant organisms, contaminated sink or wastewater drains were implicated as the source in every case [7].

Despite increasing recognition of sink drains as ubiquitous pathogen reservoirs in hospitals, effective and sustainable interventions for decontamination remain undefined. Chemical disinfectants often fail to penetrate biofilms and may paradoxically select for MDR bacterial strains [8, 9]. Hardware-intensive interventions—such as self-disinfecting sinks or plumbing replacement—are expensive, logistically challenging, and frequently result in rapid recontamination or unintended taxonomic shifts resulting in dominance of other, sometimes more virulent or resistant pathogens [10–12].

In LMICs, the role of hospital sinks as reservoirs of pathogens has been well-reported [13–16], but strategies to mitigate the risk in these settings remain insufficiently studied. In this review, we explore five dimensions of the hospital sink drain as pathogen reservoirs and share our experience of piloting low-cost interventions at a tertiary hospital in Botswana, where sinks were found to be major reservoirs for MDR organisms [13] and were likely contributing to a protracted outbreaks of carbapenem-resistant *Acinetobacter baumannii* and extended-spectrum beta lactamase (ESBL)-producing *Klebsiella pneumoniae* bloodstream infections among hospitalized newborns [17, 18].

1. The sink drain is seldom visualized

The internal structures of sink drains vary widely and remain poorly understood by clinical staff and IPC teams [19, 20]. Furthermore, sink drains are under-appreciated as pathogen reservoirs because they lie beyond the reach of routine surface cleaning and are not addressed in standard IPC protocols. Common configurations of sink

drains include a smooth-walled metal, plastic, or rubber tailpiece beneath the strainer leading into U-shaped water seal, bottle traps, or multi-piece assemblies with threaded couplings and gaskets; many basins also have overflow channels that join the tailpiece above the trap and pop-up stopper linkages. These features create low-shear, nutrient-retaining niches where biofilms readily establish and persist; furthermore, intermittent flow produces feast–famine cycles. Warm, organic-rich inputs (e.g., formula, medication residues, body fluids) accelerate accrual of biomass primed for exchange of antimicrobial resistance genes (ARGs) and intermittent periods of nutrient starvation promotes antibiotic tolerance in bacteria [21]. Moreover, sporadic introduction of new bacterial strains through patient sink use can further drive biofilm evolution and horizontal gene transfer [22].

Although biofilm density is an unreliable proxy for pathogen or ARG burden [23], inspecting the drain interior helps counter the ‘out of sight, out of mind’ bias present in many hospital cleaning frameworks [23]. Using a flexible scope camera (DXZtoz, AGC430N) we explored sink drains in the abovementioned study hospital, where food scraps and foreign objects like needles were readily seen within plumbing traps. (Fig. 1) Photographs of sink drains with visible buildup of debris encouraged IPC teams and hospital management to consider exploring radical measures to maintain sink hygiene, including piloting of the interventions described in the remainder of this review. These simple visualization tools may serve not only to guide decontamination efforts but also to motivate integration of sink-drain hygiene into IPC protocols across other LMIC healthcare settings.

2. Sink drain biofilms receive nutrients through non-hand hygiene use

In addition to hand hygiene, hospital sinks in clinical spaces may also be used for discarding food waste, body fluids, intravenous fluids, and medications—all rich in nutrients which can nourish biofilms [24]. Although some evidence suggests radical measures, such as “water-free patient care” (removing sinks entirely from patient areas) [25], these approaches may be impractical in resource-limited settings and are not yet supported by robust evidence. Behavioral change around sink use can be seen as a “low hanging fruit” for hospitals in LMICs which lack the resources for more intensive remediation strategies. In pediatric and neonatal units within the study hospital, we created visual aids designating sinks as “handwashing only” or “utensil cleaning only” and discouraged the discarding of food scraps and medications in the drain (Fig. 2a). However, such behavioral interventions are only effective when reinforced through regular monitoring and feedback; without these mechanisms,

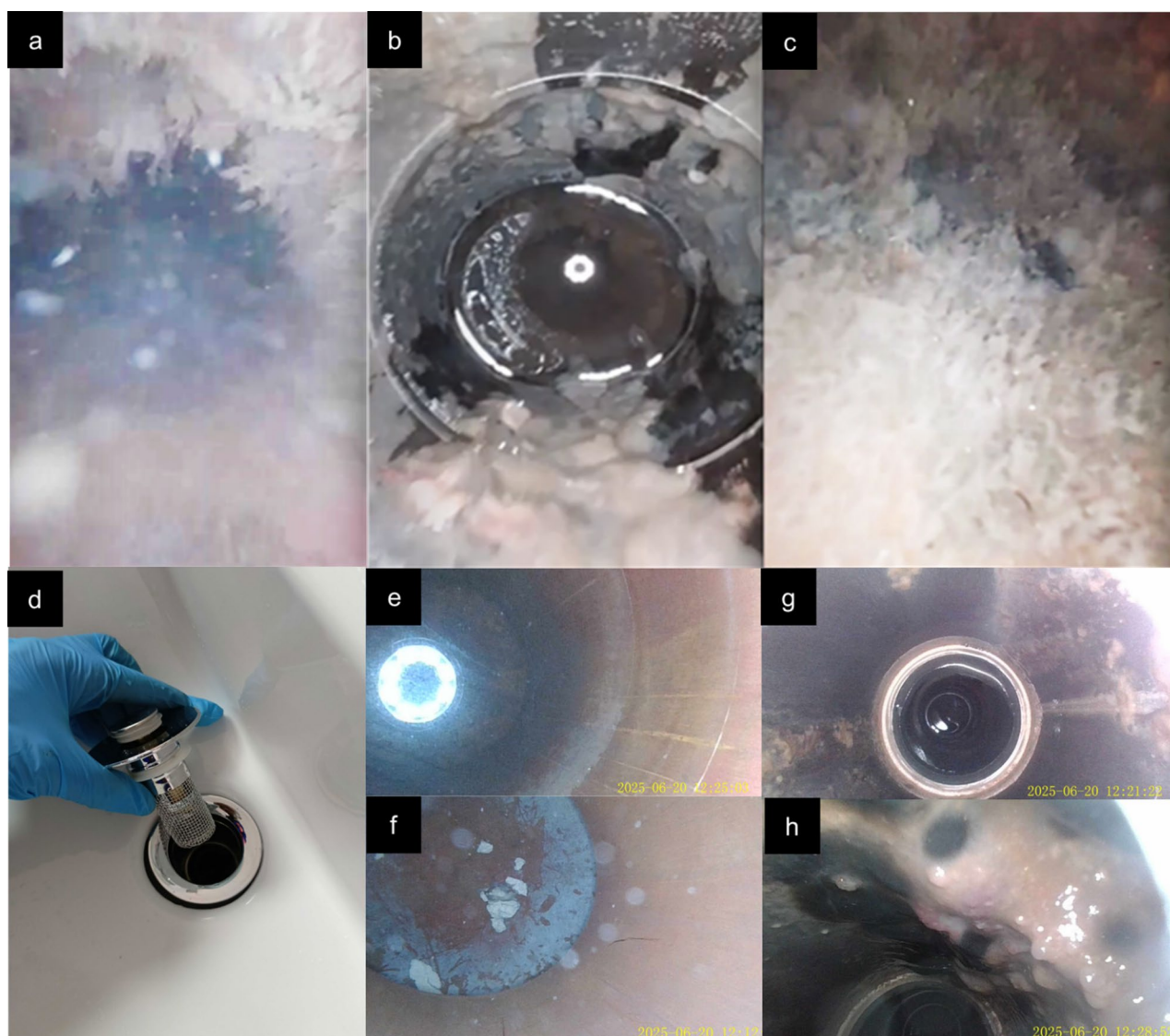


Fig. 1 Photographic visualization of hospital sink drains with flexible scope camera. Untreated sink drain in neonatal unit with a high burden of visible film and debris (A–C). Removable sink strainer installed to allow access to drain for regular cleaning (D) and sink drains with (E, F) and without (G, H) removable strainer treated with boiling water

visual aids risk becoming background fixtures that fade into the surroundings.

3. Standard sink designs limit effective cleaning and treatment

The physical design of hospital sinks plays a major role in how easily they can be cleaned and disinfected, as well as how effectively they can mitigate droplet dispersal. Splash-reducing basins, flow reducers and offset taps may reduce droplet dispersal [26, 27]. The material composition of sink traps may also play a role in biofilm formation. In the LMIC setting, most traps are made of rubber, plastic, or metal. Copper, known for its antimicrobial properties, has been used successfully in hospital

plumbing to prevent biofilm formation [28]; however, copper-coated sink drains are expensive and not widely available. Most hospital sink traps are not accessible for cleaning without complete disassembly due to securely attached sink strainers. We installed removable sink strainer plates on select sinks which allowed for weekly mechanical cleaning using a scrub brush and household detergent containing surfactants but no added biocides (Fig. 1d). Shields were positioned above drain openings to prevent droplet dispersion during cleaning. Sinks equipped with removable strainers for cleaning displayed visibly less film and debris than sinks without removable strainers despite both being regularly treated with boiling water (Fig. 1e–h). However, sinks with removable



Fig. 2 Updates to hospital ward hand washing sinks to reduce drain contamination rates with drug-resistant Gram-negative organisms. Visual aids placed above sinks to indicate intended use (A) and installation of sink drain with ball valve on distal side of the trap to allow obstruction of flow and adequate contact time with disinfectant (B)

strainers were noted to be frequently clogged due to trapped debris with food waste.

Most hospital sink drains are not equipped with a mechanism of halting flow during remediation treatments. As a result, decontamination products pass rapidly through the drain without sufficient contact time to disrupt biofilms. Some studies have shown that foam-based disinfectants can improve penetration into drain biofilms, increasing the efficacy of chemical agents [29, 30]. Unfortunately, these products are not readily accessible in resource-limited settings. In our pilot study, we installed ball valves at the distal end of several sink drains to increase contact time and permit soaking with the selected disinfecting agents (Fig. 2b).

4. Inconsistency in Pathogen Detection Methods

Across LMIC and high-income settings, there is no standardized method for sink-drain pathogen surveillance; approaches include culture-based methods using

selective media (lowest cost, operationally simple but limited for biofilm/ARG detection), targeted polymerase chain reaction (PCR) panels (modest incremental cost for priority pathogens/ARGs), and shotgun metagenomics. In practice, LMIC programs most often use selective culture or targeted PCR, with metagenomics deployed sparingly [13–15]. In our pilot study, samples from sink drains were collected using sterile nylon flocked swabs and were inoculated onto chromogenic agar (CHROMagar™ ESBL, Super-Carba, *Acinetobacter*, Paris, France) selective for ESBL-producing Enterobacterales (ESBL-E), carbapenem-resistant Enterobacterales (CRE), and *Acinetobacter* spp. While this approach enabled the identification of key pathogens using a low-cost method, previous studies have noted limited specificity using selective culture media [31]. Furthermore, this approach did not provide information on the overall microbial burden or shifts in microbial communities. To address this limitation, the use of quantitative PCR (qPCR) to characterize changes in pathogen and metagenomics sequencing to track

broader taxonomic changes can offer insights into the impacts of specific interventions [23]. In future studies, combining culture-based, molecular, and metagenomic approaches in parallel may yield a more comprehensive understanding of how specific interventions affect not only pathogen abundance but also the overall ecological makeup of hospital wastewater niches. A pragmatic, sustainable approach to pathogen monitoring in sink drains of LMIC hospitals is a tiered strategy: routine selective culture plus total-burden qPCR for longitudinal monitoring, reflex targeted PCR when thresholds are exceeded or interventions are trialed, and periodic metagenomics to audit community structure and resistance reservoirs.

5. The appropriate treatment dose, frequency, and agents used to treat sink drains are unclear

There is no consensus regarding which disinfecting agents, if any, are effective and safe in clinical settings. A summary of published evidence on chemical, thermal, and microbial approaches to sink drain decontamination is presented in Table 1.

Chemical decontamination

Commercially available drain cleaning products may be highly alkaline or corrosive, damaging plumbing and

posing inhalation risks to staff and patients. Chemical disinfectants such as sodium hypochlorite or quaternary ammonium compounds may not penetrate biofilms [29, 32]. Of mounting concern is the contribution of widespread use of chemical disinfectants to antimicrobial and biocide resistance, potentially worsening disease burden [9, 33]. Previous analysis of *K. pneumoniae* isolates collected from a neonatal ICU in Botswana demonstrated that the minimum inhibitory concentration of sodium hypochlorite was over 10 times higher than standard IPC guidelines, suggesting the presence of significant biocide resistance [34].

Acetic acid has been proposed as a low-cost alternative to conventional disinfectants. In outbreak settings, weekly cleaning of contaminated hospital sinks with 25% acetic acid has been shown to reduce sink colonization and interrupt nosocomial transmission of MDR *Pseudomonas aeruginosa*, including metallo- β -lactamase producers [35–37]. However, high acetic acid concentrations can be corrosive to plumbing, and no study has yet evaluated the sink-drain resistome following acetic-acid decontamination.

Thermal decontamination

Thermal disinfection (using steam or boiling water at > 80 °C) has been shown to outperform chemical disinfectants

Table 1 Summary of evidence of low-cost sink decontamination approaches

Category	Agent/approach	Effectiveness for pathogen reduction	Effect on resistome/pathogen shifts	Key reference(s)
Chemical	Sodium hypochlorite	Mixed/limited – poor biofilm penetration, recolonization common	Potentially unfavorable—may select for ESBLs, biocide tolerance	Rolbiecki 2022 [9]; van Dijk 2022 [33]; Bourdin 2024 [8]; Ntshonga 2025 [34]
	Foam-based disinfectants	Moderate-improved penetration, reduces colonization but effects often transient without frequent dosing	Limited data: metagenomic profiling found persistent ARGs with a shift toward <i>Pseudomonas</i> ; an isolate-WGS trial showed strain turnover without new resistance signatures	Jones 2020 [29]; Vanstokstraeten 2024 [47]; Newcomer 2025 [48]; Snell 2024 [49]
	Quaternary ammonium compounds	Mixed/limited—drain biofilms remain recalcitrant even with repeated QAC exposure	Potentially unfavorable—QAC use can select for qac efflux/integron genes and co-select ARGs; drain resistomes may persist despite disinfection routines	McBaine 2004 [50]; Jechalke 2013 [51]; Henebique 2025 [23];
	Acetic acid (~ 25%)	Strong-effective in outbreak control; plumbing corrosion risk	Unknown – resistome not assessed	Stjärne Aspelund 2016 [35]; Smolders 2019 [36]; Nurjadi 2021 [37]
Thermal	Boiling water	Moderate-strong—suppresses GNB, requires frequent dosing	Potentially favorable—heat degrades DNA; resistome data limited	Bourdin 2024 [8]; James 2021 [38]; Ramos-Castañeda 2019 [39]
Microbial	Probiotic cleaning (<i>Bacillus</i> -based)	Mixed – lowers total load, diversity increases; pathogen changes modest	Favorable signal—fewer ARGs, more diversity	Klassert 2022 [42]; Denkel 2024 [41]
	Bacteriophage cocktails	Limited peer-reviewed data. Promising—disrupts biofilms, lyses gram-negative bacteria.	Limited data. Theoretical neutral/beneficial—no chemical selection; resistome unknown ARG-bearing phages are plentiful in hospital wastewater, but phages' generally narrower host range than plasmids probably makes them less effective vectors for ARG dissemination.	Santiago 2020 [45]; Huang 2019 [46]; McCallum 2025 [44]

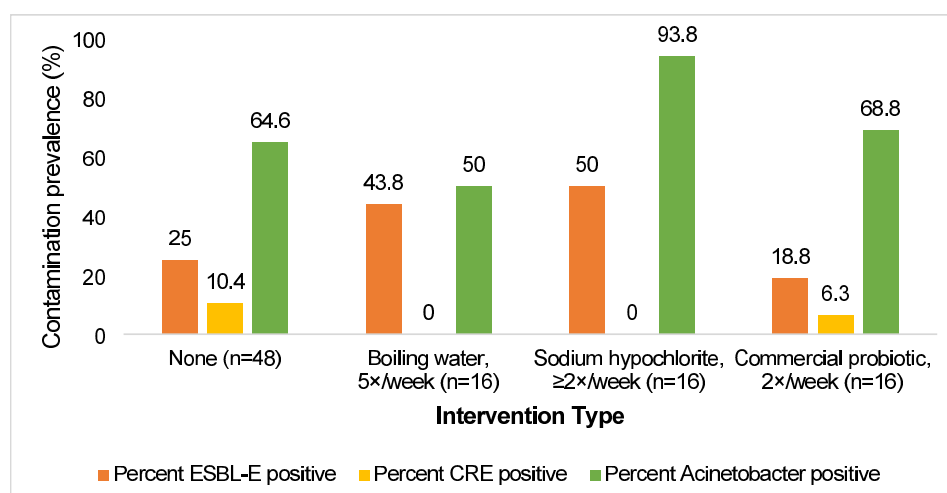


Fig. 3 Qualitative comparison of sink drain contamination with presumed extended-spectrum beta-lactamase producing Enterobacterales (ESBL-E), carbapenem-resistant Enterobacterales (CRE) and *Acinetobacter* spp. in a neonatal unit by intervention type using culture-based detection: Gaborone, Botswana, 2024

in pathogen reduction, and there is no evidence to suggest that MDR bacterial strains are more heat-resistant than susceptible strains [8, 38]. Optimal treatment frequencies for thermal disinfection are not well-established, with one study suggesting that treatments every five days are needed for preventing contamination with gram-negative organisms [39]. Thermal-based strategies also require appropriate safety protocols to prevent staff burns/scalding and to minimize aerosolization of contaminated droplets during high-powered steaming (e.g., heat-resistant personal protective equipment, splash/spray control, controlled pour rates, and temporary area restrictions).

Microbial decontamination

There is a need to explore microbial maintenance strategies that preserve or restore sink drain eubiosis—a commensal-dominant, low-ARG state—without routine disinfectants. Probiotic approaches are promising because they aim to re-engineer the environmental microbiome rather than repeatedly sterilize it [40]. Non-pathogenic strains may occupy attachment sites, compete for nutrients, and secrete biosurfactants and enzymes that disrupt pathogen biofilms, lowering overall bioburden while avoiding the problem of biocide and antimicrobial resistance [41–43]. However, drain-specific trials with probiotics remain limited, and further research is needed to identify key species which can reliably persist in plumbing and competitively exclude gram-negative pathogens. Probiotic cocktails suited to low-resource settings should be spore-forming, shelf-stable, and revivable in simple media (e.g., nutrient broth) with basic quality control methods feasible in LMIC labs.

Among re-emerging strategies, bacteriophages (phages)—non-pathogenic viruses that infect bacteria—represent a biologically targeted approach with growing evidence of efficacy in environmental decontamination. Phages amplify where their hosts are abundant yet are self-limiting as bacterial density falls. Many phages carry ARGs, raising a concern for expansion of ARGs through enhanced exchange of mobile genetic elements, but their narrower host range than plasmids probably makes them less effective vectors for ARG dissemination [44]. Pilot studies have demonstrated the ability of phages to disrupt drain-associated biofilms through phage-encoded depolymerases and bacterial lysis [45, 46], and their natural abundance in hospital wastewater suggests potential for on-site harvesting and application using basic microbiological methods. Practical considerations include establishing local phage banks, standardizing quality control (titers, host range), and developing safe application protocols for plumbing systems. More research is needed to determine how such banks in LMIC laboratories can be operationalized and how phage-based strategies compare in durability and cost-effectiveness to existing chemical approaches.

Pilot data of low-cost drain decontamination methods

In a pilot study conducted in a neonatal ICU in Botswana, we assigned 6 sinks to undergo treatments over four months with 0.04% sodium hypochlorite (bleach)-based disinfectant, boiling water, and a commercial probiotic cleaning solution (Super EM, South Africa, containing multiple *Bacillus*, *Lactobacillus*, *Bifidobacterium*, and *Saccharomyces* spp.) and compared sink drain contamination to control (i.e., untreated) sinks weekly using culture-based detection (Fig. 3). Among 48 samples from

12 control sinks with no treatments, prevalence of contamination with ESBL-E, CRE, and *Acinetobacter* was 25.0% [12/48], 10.4% [5/48], and 64.6% [31/48] respectively. Boiling water (five times per week) and sodium hypochlorite treatments (two times per week) applied for 10 min of contact time using the previously described distal drain ball-valve, both consistently suppressed CRE (0% recovery overall). However, sinks assigned to sodium hypochlorite treatment had the highest prevalence of ESBL-E and *Acinetobacter* spp. than either of the other treatments and controls (ESBL-E, 50.0% [8/16]; *Acinetobacter*, 93.8% [15/16]), reaffirming concerns regarding the risk of chemical disinfectants in selecting for other MDR strains. ESBL-E contamination was lowest (18.8% [3/16]) in sinks assigned to probiotic treatments (10 min, two times per week) but the effect of probiotic treatments on CRE and *Acinetobacter* spp. contamination was mixed (CRE 6.3% [1/16]; *Acinetobacter* spp. 68.8% [11/16]). Although we attempted to select control sinks that were comparable in terms of location, clinical function, and anticipated traffic, we were unable to fully control how each sink was used in practice. Variation in sink use—such as disposal of biological fluids, medication residues, food waste, or cleaning products—likely introduced transient changes in nutrient availability and microbial load that may have influenced contamination levels. These unmeasured factors, combined with the small number of sinks included in each treatment group, limit the ability to draw definitive conclusions about intervention efficacy. Nonetheless, these findings provide a valuable foundation for designing larger, controlled studies to optimize and evaluate feasible decontamination approaches, and incorporate quantitative microbiome or resistome endpoints to better understand sink ecosystem dynamics.

Conclusions

This review and pilot study results underscore the persistent challenge of controlling gram-negative pathogens in hospital sink drains, particularly within resource-constrained settings. We identified five interrelated dimensions that complicate remediation: limited visibility of drain interiors, nutrient inputs from inappropriate sink use, structural design barriers, inconsistent detection methods, and uncertainty regarding optimal treatment regimens. Our findings suggest that while simple measures—such as design modifications, visual inspection tools, and routine thermal or probiotic treatments—may help reduce contamination, their effects are inconsistent. Interpretation of our pilot data was limited by the small number of sinks, variability in sink use, and reliance on culture-based detection, which could not capture variability in burden between treatments. Similarly, as a narrative review, our synthesis is constrained by

heterogeneous methodologies and publication bias in the existing literature.

Despite these limitations, this work highlights the urgent need for pragmatic, sustainable, and biologically informed approaches to sink-drain stewardship. Future interventional trials of sink-drain decontamination should prioritize low-cost, scalable strategies—such as thermal, probiotic, or phage-based approaches—while prospectively accounting for key confounders. These include plumbing-related factors (e.g., trap type, drain material), ward context (e.g., intensive care unit versus general ward), and intensity and variation of sink use, including disposal of nutritional waste, medications, chemical disinfectants, or biological fluids. Trials should therefore integrate careful characterization of these factors alongside mechanistic evaluation of interventions as well as explicitly consider of how effective approaches can be translated into broader IPC frameworks suited to low-resource settings.

Author contributions

a) Conceptualization S.M., J.S., T.G., C.H. and M.K.A. b) Data curation T.G.c) Analysis S.M., J.S. and T.G. d) Investigation S.M., J.S. and T.G. e) Methodology S.M., J.S., M.R.-G. and T.G. f) Visualization S.M. and J.S. e) Writing – original draft S.M., J.S. and T.G. f) Writing – review & editing B.G., C.V.T., T.K., S.E.C., M.R.-G., M.K.A., C.H., E.B., A.M. and P.P.

Data availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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