INTRODUCTION OF A NOVEL CHLORINE GENERATOR IN GHANA, UGANDA, AND ETHIOPIA HEALTH SYSTEMS

Learning brief: Financing national adoption of the Aqua Research STREAM™ Disinfectant Generator in Ghana

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STREAM devices and supplies heading to Ghana health centers for installation, training, and monitoring.

This document is part of the STREAM learning brief series and presents cost-effectiveness estimates and financial information to inform national adoption and scale-up of the Aqua Research STREAM™ Disinfectant Generator (STREAM) across national health care systems. Using Ghana as an example, this brief explores how the STREAM can be a financially attractive solution supporting the delivery of safe and effective infection prevention and control services.

Millions face preventable infections due to lack of chlorine in health care settings

Health care–associated infections (HAIs) affect hundreds of millions of individuals worldwide and lead to significant patient treatment costs for health systems. Available data show a 12.6% HAI rate in Ghana, which is substantially high.[1] The total economic cost of HAIs in the country in 2022 was US$1.57 billion, which equates to 1.98% of gross domestic product.[2] Most HAIs are preventable and can be reduced by an estimated 35% to 70% following effective infection prevention and control (IPC) practices.[3–5]

Chlorine is a widely used and effective chemical disinfectant recommended for IPC in health care settings. However, despite its proven effectiveness, the lack of consistent chlorine availability and quality limit the ability of health care workers to provide a safe and hygienic environment for patients. In Ghana, an analysis of chlorine stock records from 12 health facilities over a year found those facilities faced an average of 65 days per year without chlorine. The primary factors that contribute to such supply gaps include weak supply chains; burdensome forecasting, procurement, and transportation processes; and insufficient budgets.[6–8] Furthermore, long exposures to sunlight and warm temperatures

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due to improper storage and transportation can lead to degradation of the chorine concentration. Finally, health care workers have reported challenges with calculating accurate dilution ratios to convert commercial chlorine solutions, which range from 3.5 mg/L to 12 mg/L, down to a 0.5 mg/L solution as recommended in IPC guidelines.

The STREAM Disinfectant Generator: An innovation for the Ghana health system

PATH and the Ghana Health Service (GHS) are collaborating to introduce the Aqua Research STREAM™ Disinfectant Generator (STREAM) into the Ghana public health system. Results from a 2019–2022 observational study found that STREAM units could eliminate chlorine stockouts, generate a 36% cost savings at district hospitals over a 5-year period compared to commercial chlorine, and significantly improve IPC practices in health facilities, as reported by staff. From June through December 2023, PATH and Ghana Health Service's Institutional Care Division (GHS/ICD) launched a second pilot to evaluate 18 STREAM devices across 12 health facilities in Central, Ahafo, and Volta Regions. The study objectives included (1) assess changes in chlorine availability and quality; (2) validate reliability of the STREAM system using a mean time between failures approach; and (3) model the STREAM's total cost of ownership compared with commercial chlorine costs.

Key findings showed improvements in chlorine availability and quality, strong reliability, and potential cost savings.

Availability and quality: Analysis of chlorine stock cards indicated health facilities experienced an average of 37 days per year without chlorine. Health centers (n=7) faced longer stockout periods—nearly five times as long (56 versus 11 days) and twice as often per year—as compared to district hospitals (n=5). Chlorine quality analysis revealed that 83% (n=10) of facilities were using degraded chlorine. The degraded chlorine samples contained an average of 53% of their stated chlorine content (mg/L). Baseline samples from all 18 STREAM units (100%) fell within the device's target range of 5,000 ± 1,000 mg/L concentration.

Half of the health facilities using STREAM devices saw an increase in chlorine availability by an average of 763 liters per month. Lower chlorine production in the remaining facilities was due to the STREAM's production capacity limit, functionality issues, and user challenges with forecasting STREAM chlorine production volume.

Reliability: A total of 67% (n=12) of STREAM units functioned without failure. Six devices (33%) experienced one component failure and averaged 60.8 days before the failure (range 16–96 days). No devices experienced more than one component failure. The mean time to component replacement was 8 days (range 1–24 days). Overall, STREAM units remained functional for nearly 95% of the study period. All failed components were replaced and all devices were functional at the study conclusion.

Cost: Modeling indicated that 5-year STREAM total cost of ownership would range from $3,000 to $5,000. District hospitals would see a 17% savings in chlorine supply costs, and health centers would see a 48% cost increase. Comparing ongoing STREAM and commercial chlorine consumables costs, STREAM use would lead to significant cost savings: between 64% and 83%. In June 2024, the GHS issued a tender for 400 STREAM units for the country, based in part on these study findings.[9] More on the device can be found here.

In parallel with these successes, PATH and GHS leaders sought to estimate the effect of on-site STREAM chlorine production on HAI rates and treatment costs, while also generating financial data to inform national scale-up strategies for Ghana's health care system. By addressing these challenges and providing a reliable, cost-effective chlorine supply, STREAM has the potential to significantly improve IPC and generate substantial financial savings.

Cost-effectiveness

Using a decision model, we evaluated the STREAM's potential for reducing HAI prevalence rates, HAI treatment costs, and associated disability-adjusted life years (DALYs), exploring two scenarios: (1) in which a facility uses commercially purchased chlorine and (2) in which a facility produces chlorine on-site using the STREAM device. Effectiveness primarily focused on change in availability of chlorine as the result of on-site chlorine production. This was measured as a reduction in chlorine stockout days with the assumption that disinfection efforts are not effective during stockout periods. Primary data from a 2019–2023 evaluation in Ghana were used to estimate changes in chlorine stockout days at a health facility. Among the range of HAIs, we focused on surgical site infections as the most relevant condition whose infection and prevention pathways are associated with environmental cleanliness and medical equipment reprocessing/disinfection. Reductions in HAI incidence due to increased chlorine availability was estimated using international studies on the efficacy of chlorine and IPC. We also accounted for other risk factors for HAIs, such as nonadherence to IPC disinfection standards and quality of chlorine used for disinfection. Finally, the evaluation focused on two costs: that of chlorine production and that of HAI treatment.

In Ghana, district hospitals using the STREAM disinfectant generator could avert 972,185 health care–associated infections and save $90.9 million in treatment costs and productivity loss.

Analysis showed that in Ghana, all district hospitals relying on a STREAM device for on-site chlorine production could generate an annual reduction of 972,185 HAIs from surgical site infections (see Table 1). Average DALYs averted equaled 44,149, and the annual cost savings was estimated to be $90,872,049. Cost savings of every DALY averted ranged from $795 to $3,917.

[9] PATH. Learning brief: The role of government champions in national adoption of the Aqua Research STREAM™ Disinfectant Generator. PATH; 2024. https://tinyurl.com/6fvf7uew

TABLE 1. **Cost-effectiveness estimates resulting from STREAM use in all district hospitals in Ghana.**

Reduction in HAIs	Averted DALYs	DALY cost savings
SSIs potentially averted as the result of using effective IPC practices and high-quality chlorine	DALYs for every case of SSI were based on Global Burden of Disease estimates for maternal sepsis	Treatment cost savings were estimated as the averted costs associated with length of stay due to SSI multiplied by cost per inpatient day
972,185	44,149	$90,872,049

Abbreviations: DALY, disability-adjusted life year; HAI, health care–associated infection; IPC, infection prevention and control; SSI, surgical site infection.

Findings indicate the STREAM device has the potential to significantly reduce HAI and treatment costs in Ghana. STREAM is more cost-effective for health facilities with higher chlorine demand volumes, as the up-front cost of the STREAM is outweighed by the long-term cost savings from fewer chlorine purchases.

Budgeting for national scale-up: Rationale and cost estimates

Along with understanding the potential health benefits that could result from STREAM use, we sought to calculate the financial requirements and benefits for the Ghana health system of national STREAM introduction. We compared the annual and 5-year costs of STREAM chlorine production with those of locally available commercial chlorine, determining both annual cost savings and break-even points. STREAM chlorine costs include up-front costs, such as device, shipping, taxes, and additional items (e.g., spoon, cup, bucket, jerrycans), and operational costs, including cleaning, vinegar, salt, water, and electricity. Commercial chlorine costs include chlorine and water for dilution. Large facilities, such as regional and national referral hospitals, were excluded from this analysis due to their higher chlorine demand, which requires either larger-capacity chlorine generators or multiple STREAM devices, each allocated to a specific ward. Instead, the results focus on district hospitals (n=163), polyclinics (n=66), and health centers (n=1,148), as their chlorine demand volumes align more closely with the STREAM's production capacity. The break-even analysis identifies the point at which the accumulated cost of purchasing commercial chlorine equals the total accumulated cost of STREAM chlorine, which includes up-front and recurrent costs. Beyond this point, STREAM chlorine offers annual cost savings.

District hospitals

- **Annual district facility cost savings: $732**
- **Total savings for all district hospitals across the country over 5 years: $596,015**

Impact in individual district hospitals:

District hospitals require 40,000 liters of 0.5 mg/L chlorine solution per year, on average. To meet this demand, two STREAM units would need to operate for 8 hours daily. Under these assumptions, district hospitals can expect cost savings of $732 per year compared to purchasing commercial chlorine (see Table 2). Excluding the initial capital cost investment, recurrent STREAM chlorine production costs would generate even greater savings, amounting to $1,905 annually. Factoring in capital costs, the STREAM devices at district hospitals would reach the break-even point in an average of 3.1 years. These savings demonstrate STREAM's potential as a cost-effective solution for district hospitals.

TABLE 2. **Chlorine costs and years to the break-even point at the district level in Ghana.**

Annual cost of commercial chlorine	Annual cost of chlorine using STREAM	Annual cost savings	Years to the break-even point
$2,442	$1,710	$732	3.1

Green: Highlights the positive financial outcomes of using the STREAM device, including the annual cost savings compared to commercial chlorine and the number of years it would take to reach the break-even point.

Impact across all district hospitals:

At the national level, the introduction of STREAM units across all 163 district hospitals would require an up-front investment of $963,410. The recurrent annual cost is expected to average $537 per facility to produce 40,000 liters of 0.5 mg/L chlorine, compared to $2,442 for commercial chlorine procurement. This equates to $0.04 per liter for STREAM-produced chlorine, compared to $0.06 per liter for commercial chlorine. Over 5 years, the total cost savings from STREAM implementation is projected to reach $596,015 (see Table 3).

TABLE 3. **STREAM chlorine costs and estimated annual expenditure in Ghana district hospitals.**

Annual chlorine demand per hospital	Capital cost per liter	Recurrent cost per liter	Total up-front cost	Annual recurrent cost	Total savings over 5 years
40,000 liters	$0.0296	$0.0134	$963,410	$87,493	$596,015

Chlorine demand extrapolated from data reviewed from chlorine stock cards and capital costs per liter = up-front costs of STREAM amortized over 5 years and divided by the number of liters per facility. We assume that hospitals will require two STREAM devices each and health centers will require one STREAM unit per facility.

Polyclinics and health centers

Polyclinics and health centers have annual chlorine demands of 10,200 liters and 7,000 liters, respectively. Polyclinics would reach breakeven in 4.3 years and achieve annual cost savings of $90. Health centers would incur additional costs of $314 per year. Excluding the initial capital investment, recurrent costs alone would result in average annual savings of $677 for polyclinics and $273 for health centers.

Health center hub-and-spoke would break even in 3.2 years producing ~14,000 liters/year of 0.5% STREAM chlorine.

To improve cost-effectiveness for these facilities, adopting novel production and distribution models such as a **hub-and-spoke system** could be transformative. In this model, polyclinics or well-equipped health centers (hubs) produce surplus stabilized chlorine and distribute it to other facilities (spokes). This approach would not only reduce costs but also improve availability by reducing stockouts and logistical delays.

For health centers with limited chlorine demand, breakeven within 5 years is unlikely under current conditions. However, increasing production at health centers to more than 9,030 liters annually or adopting a hub-and-spoke model could lead to cost savings for these health facilities. For instance, meeting the combined demand of two health centers under this model could result in breakeven in 3.2 years, with annual recurrent costs of $189, compared to $1,123 for commercial chlorine (see Table 4).

TABLE 4. **Chlorine costs and years to the break-even point.**

Facility type	Average annual chlorine demand	Annual cost of commercial chlorine	Annual cost of chlorine using STREAM	Cost savings	Years to the break-even point
Health center hub-and-spoke model (2 health centers)	14,000 liters	$1,123	$776	$347	3.2
Health center	7,000 liters	$370	$684	–$314	10.8

Green: STREAM provides cost savings when compared to commercial chlorine. **Red:** STREAM is more costly when compared to commercial chlorine.

Next steps: Financing approaches for STREAM scale-up in Ghana

While the initial investment in STREAM is important, it is also important to carefully consider and budget for the costs of capital equipment, operation, and maintenance and repair. The STREAM device requires a one-time capital investment of $2,955. This includes the device cost plus shipping, taxes, spoon, cup, bucket, and jerrycan costs. Operating costs primarily consist of consumables, such as salt, vinegar, water, and electricity. These supplies are relatively inexpensive and can be sourced locally.

PATH and the GHS/ICD are piloting STREAM hub-and-spoke evaluations across an additional 25 health facilities to generate a total cost of ownership analysis that incorporates maintenance, repair, spare parts, and chlorine transportation into the overall costing calculation. The costing tool, break-even analysis, total cost of ownership, and cost-effectiveness models are available upon request.

For more information

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This project directly contributes to the Sustainable Development Goals 3 and 6, as well as global WASH in health care facility targets.

6 CLEAN WATER AND SANITATION

Ensure availability and sustainable management of water and sanitation for all

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