Evaluating the effectiveness of chlorination
by an innovative commercial rural water supplier in West Africa

The Aquaya Institute

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1. Background

Piped supplies in low- and middle-income countries often have microbial contamination, with a higher burden in rural areas.[1] Specifically, an estimated 57% of rural piped water users (or 22% of all rural inhabitants) in low- and middle-income countries in 2020 received contaminated drinking water,[2] indicating lack or ineffectiveness of treatment practices. A recent global assessment revealed only 55% of service providers reported regularly treating the water they supplied.[3] Insufficient chlorination, combined with unsafe household water storage practices, often leads to degraded water quality, increasing health risks. Given these challenges, identifying viable chlorination approaches for water supplies in low-resource, rural settings is critical for public health.

Uduma is a for-profit water utility that manages rural water infrastructure in Mali, Burkina Faso, Cote d'Ivoire, and Benin. They engage in public-private agreements with governments to manage small, piped rural systems, including small solar pumping systems. Currently, there is no chlorination of their systems in Mali, Burkina Faso, and Cote d'Ivoire, and their goal is to introduce chlorination in 100% of their systems within the next four years. Uduma is considering various chlorination technologies to pilot in a subset of their systems in Mali, including tablet/erosion and injection chlorinators. Uduma is designing the specific chlorination intervention for the pilot with technical support from UC Berkeley.

2. Objective

This study aims to **evaluate the effectiveness of Uduma's pilot approach for chlorinating rural water supplies** in Mali. We will also assess **consumer acceptance** of the pilot intervention and the estimated **number of consumers** at baseline and after the intervention.

3. Research Questions

1) What is the pilot's **specific approach to chlorination** of rural water supplies in Mali (RQ1)?

2) To what extent are the different chlorination technologies included in the piloted intervention **effective at improving water safety** at the consumer water points and in the household? (RQ2)

3) What factors influence

[1] Bain R, Johnston R, Khan S, Hancioglu A, Slaymaker T. Monitoring Drinking Water Quality in Nationally Representative Household Surveys in Low- and Middle-Income Countries: Cross-Sectional Analysis of 27 Multiple Indicator Cluster Surveys 2014–2020. Environ Health Perspect. 2021 Sep;129(9):097010.

[2] Cherukumilli K, Bain R, Chen Y, Pickering AJ. Estimating the Global Target Market for Passive Chlorination. Environ Sci Technol Lett. 2023 Jan 10;10(1):105–10.

[3] Nilsson K, Hope R, McNicholl D, Nowicki S, Charles K. Global prospects to deliver safe drinking water services for 100 million rural people by 2030. Oxford, UK: University of Oxford and RWSN; 2021 p. 68. Report No.: REACH working paper 12.

a. **consumer acceptance of chlorination** (messaging, involvement of leaders, types of services, third-party messages, etc.) and
b. **safe household water storage**? (RQ3)

4) What is the **estimated number of people consuming water** from standpipes before and after the chlorination intervention, and how does this change across the seasons? (RQ4)

4. Location

The study is planned for **10 rural water systems in Mali**, where Uduma is piloting chlorination. These systems will likely include seven medium-sized solar pumping systems and three larger systems that will use a mix of tablet/erosion chlorination and Dosatron injection chlorinators. Most of Uduma's systems in Mali are in the south, in the Sikasso region (Figure 1).

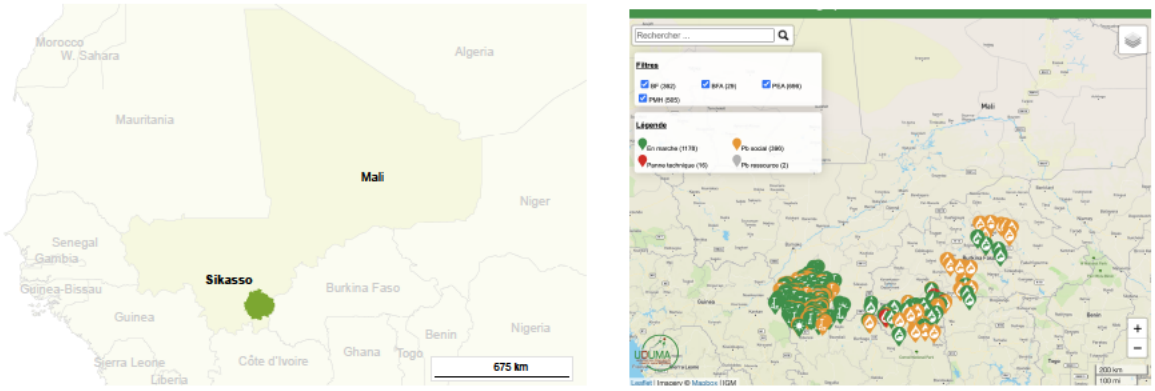

Figure 1: (a) Position of the Sikasso region where most facilities managed by Uduma in Mali are located (b) Water systems managed by Uduma in Mali.[4]

5. Study design

We will conduct a **quasi-experimental (before-after) study** to evaluate the effectiveness of a pilot chlorination program of ten systems in rural Mali. Our data collection will include the following activities:

1. **Chlorination approach** will be documented from interviews with Uduma staff and direct observations (RQ1),
2. **Chlorination effectiveness** will be evaluated via water quality testing at water points (i.e., household taps and/or public standpipes) and household storage containers (RQ2),
3. **Consumer acceptance** will be examined via household surveys and focus group discussions (RQ3), and
4. **Number of consumers** will be estimated via household surveys, observations, and metering data (RQ4).

5.1 Chlorination approach

[4] https://www.uduma.net/cartographie/

To examine Uduma's specific **approach to chlorination**, we will document the technical components (chlorination technologies and dosing strategy) and service delivery model (roles and responsibilities, management practices, operator performance, etc.). We will obtain this information from interviews with Uduma staff and direct observations. Previous research has found that management systems are critical to ensure proper operation and maintenance of chlorination technologies.[5]

5.2 Chlorination effectiveness

To examine **chlorination effectiveness**, we plan to measure water safety at baseline and after the chlorination intervention (RQ2). We will measure water safety via two water quality parameters: **free chlorine residual and *E. coli***, both measured at the **consumer water points** (i.e., household taps and/or public standpipes) and **household drinking water** (e.g., from storage containers) (Table 1). We will also sample water at the end of the **treatment plant** to determine if chlorine dosing is adequate at the point of distribution. Our proposed thresholds for adequate free chlorine residual are ≥0.5 mg/L at public standpipes and the water treatment plant, and ≥0.2 mg/L in household taps and household water, in line with the recent World Health Organization (WHO) Guidelines for small water supplies;[6] the exact threshold values will be determined in collaboration with Uduma based the chlorination treatment design conditions. Samples will be considered free of microbiological contamination if *E. coli* <1 CFU/100 mL. We will utilize a rigorously validated field method for microbial testing, such as CompactDry plates or Aquagenx Gel EC CFU kits.

We may be able to collaborate with Uduma on water testing logistics; they are planning for 3-4 water quality tests per year per system for various parameters, including free chlorine residual and *E. coli*. However, our preference is to conduct separate testing to ensure this assessment is independent from the intervention implementation.

Table 1: Outcome metrics

	Water quality: chlorination (RQ2)	**Water quality: microbiological (RQ2)**
Water points (point of collection)	Primary outcome % of water points with adequate free chlorine residual (≥0.2 mg/L for household connections and ≥0.5 mg/L public standpipes[i])	% of taps without microbiological contamination (<1 *E. coli*/100 mL at the water points)
Household / Consumers (point of consumption)	% of households with adequate free chlorine residual (≥0.2 mg/L in household water[i])	% of households without microbiological contamination (<1 *E. coli*/100 mL in household water)
Treatment plant	% of systems with adequate free chlorine residual at the treatment plant (≥0.5 mg/L[i])	% of systems without microbiological contamination at the treatment plant (<1 *E. coli*/100 mL)

[i] Exact threshold values will be determined in collaboration with Uduma based the chlorination treatment design conditions.

[5] Rayner, J.; Yates, T.; Joseph, M.; Lantagne, D. Sustained Effectiveness of Automatic Chlorinators Installed in Community-Scale Water Distribution Systems during an Emergency Recovery Project in Haiti. J. Water Sanit. Hyg. Dev. 2016, 6 (4), 602– 612, DOI: 10.2166/washdev.2016.068

[6] Guidelines for drinking-water quality: small water supplies. Geneva: World Health Organization; 2024. Licence: CC BY-NC-SA 3.0 IGO.

5.3 Consumer acceptance

Consumer acceptance of chlorination is critical for the intervention to be successful. Typically, Uduma undertakes substantial and ongoing community awareness to build acceptability for different service models, whereby communities must pay for the services on a regular basis (e.g., per month or per volume). They do not have experience building community awareness for chlorination, though they are planning to engage Community Engagement Officers to build awareness and buy-in for chlorination. Our baseline data collection will help inform the strategies for building community awareness that Uduma will implement.

We will obtain information on consumer acceptance via **household surveys** and **focus group discussions**. We will ask households about their experience / perception of chlorinated water and explore what factors (messaging, involvement of leaders, types of services, etc.) resonate with consumers to encourage acceptance. We will also consider including (i) discrete choice experiments into household surveys to measure household preferences for hypothetical scenarios, and/or (ii) blind taste tests to determine consumer detection and acceptability thresholds.[7] We will conduct 10 focus group discussions (one per water system) at the baseline, and 200 household surveys at both baseline and follow-up (20 per water system).

5.4 Estimated number of consumers

To estimate the number of consumers, we will first request data from Uduma on the **number of connections for each system**, stratified by number of household connections and public taps / standpipes. For **household connections**, we will estimate the number of people per connection based on **household surveys**. For **public taps / standpipes**, we explore data from the following sources, and the final methodology will be determined based on existing information.

i) *Meter data*: Uduma has indicated that their water connections are generally metered. Data from water meters will allow us to estimate the number of users based on volumetric consumption; however, this method will also require data on the average amount of water used per person (determined via household surveys and/or observation). If pre-paid meters are used, we may be able to use financial payment records to inform our estimates of water use.

ii) *Household surveys*: During the selection process for the household surveys, we will go to randomly selected GPS points. As part of the household screening, we will ask households about their main water source, alternative sources, and seasonal use patterns. This screening data from the randomly selected GPS points will create a population-representative sample of water source use, which can potentially be extrapolated to the broader community population. (After screening, we will do the full household survey with the piped water users.)

6. Sample size

[7] Crider Y, Sultana S, Unicomb L, Davis J, Luby SP, Pickering AJ. Can you taste it? Taste detection and acceptability thresholds for chlorine residual in drinking water in Dhaka, Bangladesh. Sci Total Environ. 2018 Feb 1;613-614:840-846. doi: 10.1016/j.scitotenv.2017.09.135. Epub 2017 Sep 21. PMID: 28942317.

Our sample size is calculated based on our primary outcome of chlorination effectiveness (RQ2). We estimate that a sample size of **200 water points** and **200 household water samples** (20 samples per each system at baseline and follow-up) will allow us to estimate the proportion of chlorination with a 12% margin of error, 95% significance, 0.1 intraclass correlation coefficient, and assuming 50% adequate chlorination levels at the water points and household level. The specific taps and households will be **selected randomly** via randomly generated GPS locations (skipping households that are not piped water users and linking taps and households). We will also test the water treatment plant for each system at each data collection round (2 samples per system at baseline and follow-up) and include an additional 10% of quality control / quality assurance samples. In total, we plan for 924 water quality samples [(20 water point samples + 20 household samples + 2 water treatment samples) x 10 systems x 2 data collection rounds x 110% for quality control/quality assurance samples].

7. Human subjects research

We will obtain ethical research approval from a **local ethical review board**. All participants will provide free and informed consent, and all data collected in this study will be kept confidential and will only be accessible by the research team on password-protected computers. No identifiable information will be used in the study outputs.

8. Impact

This proposal directly addressed GiveWell/Open Philanthropy's goal to ***"design and evaluate new approaches to improving the delivery and increasing adoption of chlorine"*** via evaluating a novel chlorination intervention as part of a public-private partnership. If our research indicates that this chlorination approach (RQ1) is successful at increasing water safety (RQ2), it could influence grantmaking to expand this approach to other contexts. Our research on consumer acceptance (RQ3) will ensure that chlorine interventions address specific community needs and preferences, thereby enhancing the success of the initiatives. Our research on the number of consumers served (RQ4) will enhance estimates of cost-effectiveness.

As a research institute, Aquaya produces and disseminates public outputs (reports, briefs, scientific publications, etc.) to **share our research findings to ultimately influence broader decision-making**. While this research primarily aims to inform Uduma's future work, we also plan to publicly disseminate our learnings for the broader sector, understanding that the pilot is Uduma's first attempt to introduce chlorination and that there will likely be challenges along the way.

9. Risks

There are **security risks** in Mali, and travel may be limited for international staff. Therefore, we will explore working with local data collection firms (two recommendations from Uduma include SDI and Alphalog) and/or conducting training activities in the capital, Bamako.

10. Timeline

Our timeline (Table 2) will be closely coordinated with Uduma's activities. In particular, we understand that Uduma's chlorination installation is currently planned for weeks 16 and 25; accordingly, our baseline data collection will start in the locations planned for the first

installations. Our current timeline and budget are both for 12 months, but we recognize that the study may be extended to 15 months to align with Uduma.

Table 2: Draft timeline

Activity	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Develop research protocol and ethics approval												
Conduct baseline assessment												
Uduma implements intervention												
Follow-up data collection												
Data analysis and reporting												

11. Budget