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Novel water treatment system in a low-resource community

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ABSTRACT

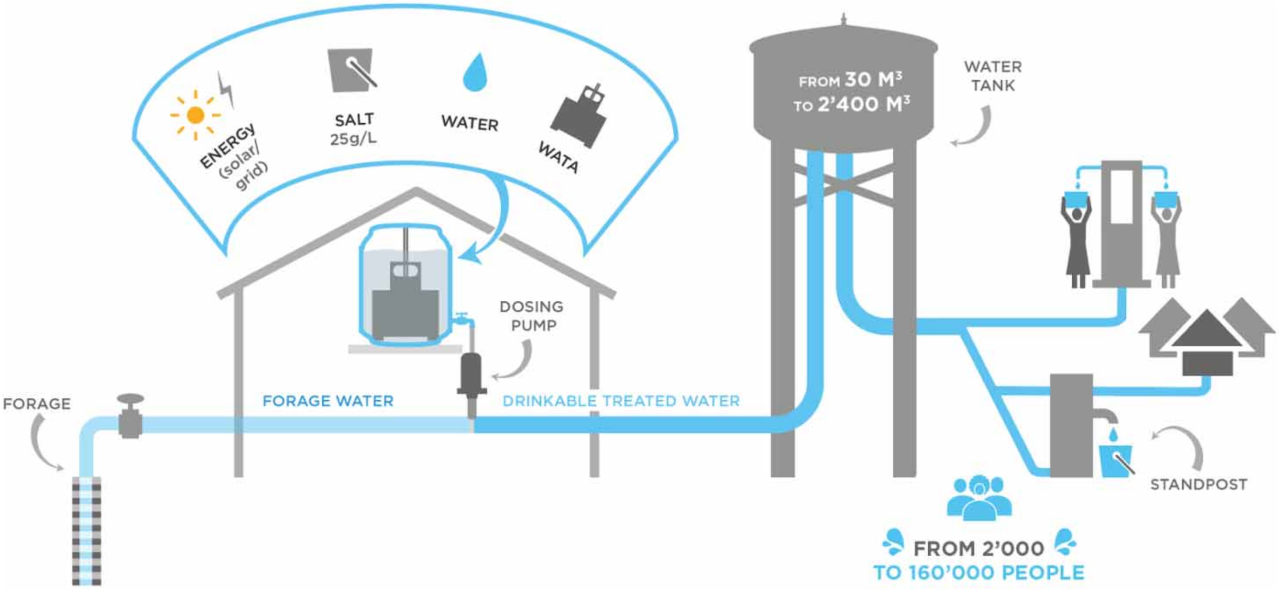
This paper evaluates the performance of a low-cost technology in rural Benin (West Africa) that locally produces chlorine (sodium hypochlorite) and then injects it into the community water tanks. Thirty-one water tanks were selected in cooperation with local authorities to receive electro-chlorinator devices (WATA™). Water samples were tested at two points: before chlorination and at the most distant terminal after chlorination. Residual chlorine control tests and microbiology control tests were performed. Water samples that tested positive for the presence of microorganisms were analyzed at a laboratory when possible. The water provided to the community was not always chlorinated, and over half of the tanks lacked access to chlorine powder. Among the sites using the technology, 30% (9/31) of them had structural problems that prevented the existing system from performing adequately. Furthermore, 60% of the water samples collected before chlorination were positive for microbiological contamination. All samples collected from systems where proper chlorination was taking place tested negative for microbiological contamination. However, the water from six tanks presenting structural problems continued to be distributed to the population despite contamination. The average residual chlorine level analyzed at the most distant terminal fountain was 0.29 ± 0.2 mg/L, which is within the country's reference level 0.1–0.8 mg/L. The installation of water-chlorinator devices (WATA™) produces water without microbiological contamination and with chlorine levels within the WHO's recommended values. However, the success of the technology depends on the pre-existing structure of the water tank.

Key words: electro-chlorinator device, low-income country, sodium hypochlorite, water tank, water treatment

HIGHLIGHTS

- Chlorine powder shortage was experienced by 52% of the 31 tanks studied.
- 60% of water samples collected before chlorination had microbiological contamination.
- After installation, the average residual chlorine level was 0.29 ± 0.2 mg/L.
- Infrastructural problems were present in 30% (9/31) of sites.

GRAPHICAL ABSTRACT



INTRODUCTION

In 2020, eight out of 10 people who lacked essential services lived in rural areas. Around half of them lived in developing countries, and over 380 million people still lacking drinking water services lived in sub-Saharan Africa. Globally, it is estimated that one in four people lacked safely managed drinking water which is defined as drinking water from an improved source that is accessible on premises, available when needed, and free from fecal and chemical contaminations (WHO 2021).

The demographic and health survey conducted in Benin between 2017 and 2018 found that the proportion of households with access to an improved water source is higher in urban areas (77%) than in rural areas (66%). More than a third of households (35%) get their water from a pump or borehole in rural areas and 17% from a public tap or fountain. Water is available on site for 20% of households in rural areas. In addition, for more than two out of five families (42%), the travel time to obtain drinking water is estimated at less than 30 min, but in 26% of cases, it exceeds 30 min. Overall, almost all households do not use any means to treat water (92%), whether in urban (91%) or rural (93%) areas (INSAE 2018).

Often, communities in low-resource areas have few options to treat their water. There is a pressing need for technology adapted to an unreliable electricity supply that is easy to operate and independent of external resources. Electro-chlorinator devices produce liquid chlorine from water, simple cooking salt, and electricity. This technology was previously tested in healthcare facilities in Burkina Faso (Duvernay *et al.* 2020), rural Chad (Nogueira *et al.* 2021), and university hospitals (Traoré *et al.* 2020) in Mali. It allowed access to sufficient sodium hypochlorite, which promoted compliance with hygiene practices and reduced the number of pathogenic germs on hospital surfaces. In a refugee settlement in Sudan, a decrease in waterborne diseases was observed after a centrally administered water treatment containing chlorine was added to intervention wells. They found that chlorination provided efficient and timely decontamination of the supplied water pumped from the ground into tanks and later distributed to the public (Salih & Alam-Elhuda 2019).

We designed a before-and-after comparison study to evaluate an adapted low-cost technology in rural Benin (West Africa) that locally produces chlorine (sodium hypochlorite) and then injects it into the system. Thirty-one water tanks from community-managed decentralized water systems were assessed, the quality of their water analyzed, and the feasibility of implanting this technology was evaluated. In the present article, essential elements vital to ensuring consistent and sustainable use of this type of intervention are discussed.

METHODS

Study setting and period

In Benin, 31 water tanks were selected by the German Cooperation and Development Agency (GIZ) and local authorities to receive the implementation during November–December 2020 of a novel technology conceptualized and prototyped in collaboration between WATALUX and Burex-3eA (Figure 1).

System

The technology was field-tested in Benin (four locations) and adapted according to GIZ's and local operators' feedback. We found that only the taps 10 m from the chlorination room still had the residual chlorine following the WHO standard during

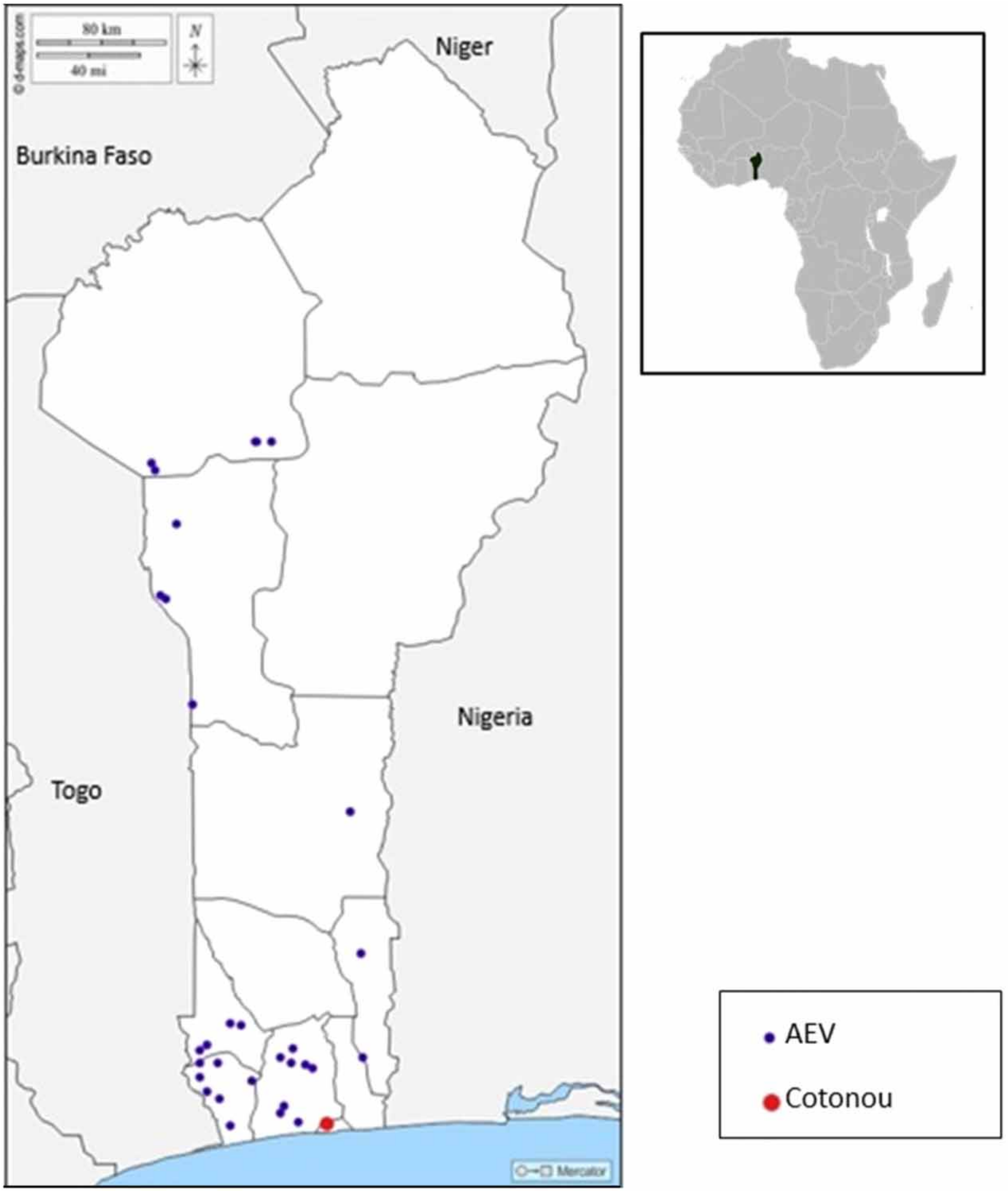


Figure 1 | Map of locations where the electro-chlorinator devices were installed. AEV (adduction d'eau villageoise), village water supply.

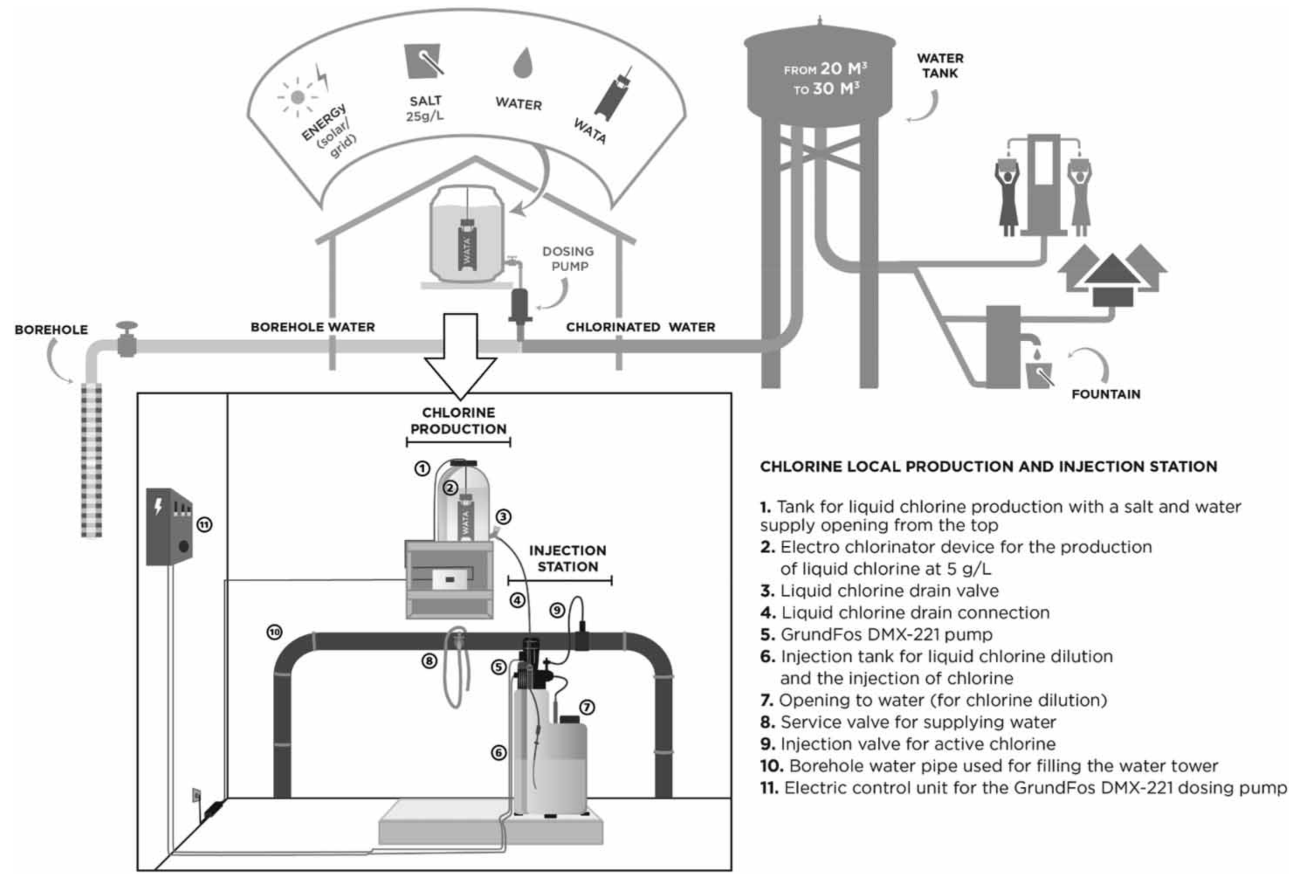


Figure 2 | Novel technology using electro-chlorinator devices (WATA™) that produce liquid chlorine to be coupled into the dosing pump tank.

this exploratory phase. The faucets at 1 and 2 km from the chlorination room did not comply with the drinking water quality standards. The chlorine injected into the chlorination room was entirely absorbed on the delivery circuit (before the water tank) but was absent in the distribution circuit (after the water tank). The amount of active chlorine injected by the dosing pump into the network was insufficient for the treatment in the sites accessed. Therefore, the system later installed was adapted so that residual chlorine could be detected in all taps following the country's specifications.

The 31 water tanks were fitted with a GRUNDFOS dosing pump. So, in parallel, the electro-chlorinators, WATA™, that produce liquid chlorine were coupled into the dosing pump tank. The on-site electrochlorination system (Figure 2) is composed of two main parts: chlorine liquid production with water, salt, electricity, and WATA electrolyzer (2) in a tank (1) and chlorine dosing and injection station with an electrical dosing pump (5), a storage tank for chlorine solution and an injection valve (9) connected to the main water pipe. First, 8 L of salt water at 25 g/L is prepared in the tank (1). The WATA-Standard (2) was then operated by switching on the power supply. After 6 h, a concentrated chlorine solution was produced in the tank (1). This chlorine solution is transferred by gravity to the storage and injection tank (6). Chlorine is then available 24/24 h for water treatment. The dosing pump (5) is settled to take the exact amount of chlorine needed and inject it into the water. The devices installed were all WATA-standard models. They produce 2 L of sodium hypochlorite with a concentration of 5 g/L in 2 h, thus producing about 8 L of disinfectant daily. This amount is sufficient to treat up to 25,000 L of water with residual chlorine of 1.5 mg/L.

Data collection

The baseline survey and water test (microbiology), installation, and water control (microbiology and residual chlorine) happened in November–December 2020. A follow-up visit occurred 6 months later, in May 2021.

Baseline

The project used a data management platform called mWater to collect data (mWater 2021). Before implementing the new technology, a questionnaire was applied to assess the challenges that operators faced regarding chlorine availability. Before installation, a water sample from the raw borehole was collected to investigate the presence of microbiological contamination. This procedure was performed in all water stations, 31 sites in total. The samples were collected with a sterile recipient and immediately tested using the portable test described below. Ethics review was not required as we collected routine data amid an ongoing water supply intervention.

After installation

The installation was performed throughout the day; two water samples were collected using the procedure described above for analysis at the point furthest from the chlorination room. We tested the microbiological contamination and quantified the residual chlorine. This procedure was performed in all water tank stations after installation.

Six months after installation

Thirty-one water tank stations were visited during the follow-up visit. Water samples from three different locations, where the raw borehole was positive for microbiological contamination, were sent to a laboratory in the capital city, Cotonou, to be analyzed. A satisfaction survey was also performed in those stations to evaluate if they were performant and if the technology implemented was satisfying expectations.

Analysis performed

Portable microbiological test (self-test)

A portable test developed by the GIZ in the field allows visual determination of water quality (GIZ 2016). The kit was acquired at the Food and Water Quality Control Laboratory (LCQEA), located within the Departmental Directorate of Health (DDS) of the Littoral in Placodji (Republic of Benin), and samples were collected and incubated for 3 days, according to the manufacturer's manual. After incubation, results were classified as positive or negative for microbiological contamination.

Residual chlorine control test

Residual chlorine was measured with a Pocket Colorimeter (Hanna checker HI701, Hanna Instruments, France). This pocket colorimeter measures free and total chlorine between 0.00 and 2.5 ppm with an accuracy of ± 0.03 mg/L. It also uses an Environmental Protection Agency (EPA)-approved N,N-diethyl-p-phenylenediamine (DPD) method. It has a large, easy-to-read LCD display and is extremely simple.

Laboratory microbiological test

The water samples were collected in a 500 mL whirl-pak® sampling bag (Thermo fisher) for microbiological analysis. The water samples were stored at a cold temperature (in a cooler) and then taken to the laboratory. The analyses were carried out at the Food and Water Quality Control Laboratory (LCQEA), located within the DDS of the Littoral in Placodji (Republic of Benin). According to the accredited laboratory source, the techniques applied for the water analysis were as follows: *Escherichia coli* and *Thermotolerant coliforms* (CFU/100 mL): NFV-08-05. Rapid-*E. coli* Agar (24 h at 44 °C); Suspected Coliforms (CFU/100 mL): NFV-08-05. Rapid-*E. coli* Agar (24 h at 37 °C); Salmonella and Shigella (CFU/100 mL): ISO 19250: 2010. Salmonella and Shigella Agar (24–48 h at 37 °C) and Fecal enterococci (CFU/100 mL): NFT 90416 – SLANETZ and BARTLEY Agar (24 h at 37 °C).

RESULTS

The 31 water tanks were distributed in 19 villages located in seven different departments (Alibori, Atacora, Atlantique, Couffo, Donga, Mono, and Plateau). The volume of each water tank was between 20 and 30 m^3. Around 130,000 people used these facilities regularly in 2020.

Before the electro-chlorinator devices (WATA™) coupled into the dosing pump were installed, the water provided was not always chlorinated, and 16 out of 31 (52%) tanks lacked access to chlorine powder, which was one of the biggest challenges in disinfecting water. Our survey shows that this is traditionally mainly because of logistics (81%) and cost issues (19%). One water tank did not use chlorine, and 14 reported not having problems acquiring chlorine powder.

Table 1 | Microbiological analysis results for samples collected at the borehole

Analysis performed	Water before chlorination (borehole) Site 1	Site 2	Site 3
Common germs per 1 mL of CFU	65	70	40
Suspected coliforms (CFU/100 mL)	25	10	8
Thermotolerant coliforms (CFU/100 mL)	22	7	7
E. coli (CFU/100 mL)	0	0	0
Fecal enterococci (CFU/100 mL)	0	3	0
Salmonella (CFU/100 mL)	0	0	0

After installation, among the sites using the novel technology, 30% (9/31) of them had infrastructural problems like lack of water (2), faulty dosing pump (6), and lack of electricity (1) that prevented the system from performing. Furthermore, the portable test revealed that (18/30) 60% of groundwater samples collected from the borehole before chlorination were positive for microbiological contamination. The laboratory analysis confirmed the contamination of three samples from groundwater collected from the Atlantique department (Pahou and Houegbo communities) and the Mono department (community of Athiémé) with high levels of common germs but also with *thermotolerant coliforms* (Table 1). The other sites were too far from the laboratory, so the water samples from the borehole (baseline) and after chlorination were tested for microbiological contamination with the portable test.

After the installation of the WATA™ technology, all samples collected from functioning systems were negative for microbiological contamination. The samples from systems presenting infrastructural problems maintained the microbial contamination as chlorination was impossible. Therefore, the water from six tanks presenting infrastructural problems continued to be distributed to the population despite testing positive for microbial contamination. The lack of electricity and faulty dosing pump prevented the production and distribution of sodium hypochlorite even if the WATA™ device was in complete working condition. Residual chlorine was analyzed in water samples from performant facilities, i.e., 22 water tanks. The average residual chlorine level analyzed at the most distant terminal fountain was 0.29 ± 0.2 mg/L, which is within the country's reference level 0.1–0.8 mg/L. Chlorine residual values varied between 0.11 and 0.78 mg/L.

Six months after installation, we conducted a follow-up visit to all 31 sites, and only 15 out of 31 systems were perfectly performing. Among the nine sites with infrastructure problems during the installation, only one was fully performant during the follow-up because the previous problem was a lack of water. The main reason was a faulty dosing pump.

DISCUSSION

Our findings suggest that community-based chlorination interventions that provide locally produced chlorine at the collection point could be an effective and scalable strategy in low-income settings. All samples collected from functioning systems were negative for microbiological contamination and had chlorine residual values within the country's reference level. Systems that require minimal behavior change for users and are economically viable can be great alternatives to achieving global progress towards Sustainable Development Goal 6.1. But, automation of the system was only possible if there was robust infrastructure and dedicated staff on site.

The fact that roughly half of the tanks faced a lack of access to chlorine powder and that 60% of water samples collected before chlorination were positive for microbiological contamination is in accordance with what is found in the literature. It is estimated that 1 billion people accessing improved water sources receive water that does not meet international standards for safety (Onda *et al.* 2012). In Benin, this is even more worrisome because almost all households do not use any means to treat water (INSAE 2018). Approximately 11% of primary roads in Benin are paved, and they are mostly in the southern region and the main towns. Muddy roads often become impassable during the rainy season, which explains the main issue, logistics, to acquire chlorine in rural areas.

The long distances and challenging road conditions often prevented us from reaching a laboratory within 24 h from the water tanks' locations, which is why only three borehole water samples were tested in the laboratory accredited by the government. The substantial germ pollution found in our samples follows what was reported in a water quality study in artesian boreholes in Dogbo Ahomey in the district of Tota, municipality of Dogbo in Benin. Their hypothesis for the high rate of microbial contamination in the various sites investigated was poor protection of these boreholes (Hounkpatin *et al.* 2021). Although the borehole water quality is found to be better than the water from other sources like drilling, rainwater, and surface water, as described in a study on the microbiological quality of drinking water in the Ahomadégbé district (Johnson *et al.* 2016), it might still not be compliant with WHO standards with the presence of presumed *coliforms* and *thermotolerant coliforms* as observed in our samples.

Households in rural areas living in hygienically critical conditions often introduce fecal contamination into drinking water during transportation and storage (Meierhofer *et al.* 2018; Hounkpatin *et al.* 2021). That is why residual chlorine is vital in water at the community level to avoid water recontamination following the immersion of unclean fingers or storage in a dirty container. Furthermore, a recent meta-analysis examining many possible links between climate change, water, sanitation, and hygiene (WASH) factors, and cholera transmission found that chlorination showed lower odds of cholera transmission (odds ratio (OR) 0.47; 95% confidence interval (CI) 0.23–0.98). Instead, drinking untreated water was shown to have higher odds of cholera transmission (OR 2.8; 95% CI 1.82–4.29) (Jones *et al.* 2020). This indicates that relationships between climate change dynamics, WASH factors, and cholera transmission must be considered soon. Nevertheless, attention must be paid when introducing new habits, and poor product acceptance by local populations may be challenging to overcome. In a recent study conducted in urban Bangladesh, it was reported that a low chlorine residual ($<$0.5 ppm) in treated water increased the taste acceptability of chlorinated drinking water while still reducing the risk of diarrhea (Pickering *et al.* 2019). After installing the electro-chlorinator devices, the average residual chlorine level analyzed at the most distant terminal fountains, 0.29 ± 0.2 mg/L, is below this value.

Limitations of the study

30% (9/31) of the sites from our study presented infrastructure problems, which was a severe limitation. Non-functional rural water supplies are a significant obstacle in low-income countries, thus preventing safe water for all Sustainable Development Goal achievements. In a recent review of statistics for hand pump water supplies in sub-Saharan Africa, it was found that approximately one in four hand pumps is non-functional, which in 2015 was broadly equivalent to 175,000 water points in a state of disrepair (Foster *et al.* 2019). The data collection and analysis happened in November–December 2020, the dry season in Burkina Faso. If data collection was performed in the wet season, perhaps we would identify a percentage higher than 60% of microbial contamination from the water collected in the borehole.

CONCLUSION

In the water tank sites that we studied in remote communities of Benin, the significant challenges to water treatment were (1) the cost and logistics of acquiring chlorine tablets and (2) infrastructure problems. The installation of water-chlorinator devices (WATA™) to produce chlorine locally to be dispensed into the system can effectively eliminate many traditional setbacks and produce water without microbiological contamination and with chlorine levels within WHO's recommended values. The system installed might be an alternative decentralized water treatment method with good acceptability by the local population. However, the success of the technology tested depends on the infrastructure of the water facility.

FUNDING

The German Cooperation and Development Agency (GIZ) funded the project.

ETHICAL APPROVAL

Not applicable. This article does not contain any studies with human or animal subjects.

CONFLICT OF INTEREST STATEMENT

This research was conceptualized and analyzed by Antenna Foundation (a non-profit organization, in Switzerland, that aims to disseminate innovations that improve the essential needs of the world's most vulnerable populations) in partnership with Watalux SA (a private company also based in Switzerland that manufactures and distributes electro-chlorinators).

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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