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The contribution of decentralized water systems on water quality in Maniema province, DRC

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ABSTRACT

Decentralized water systems (DWS) distribute water in remote African areas. Throughout an intervention in Maniema, Congo, the influence of a DWS performing chlorination in the community's water quality was measured. Additionally, a socio-economic and WASH practices survey was conducted in the communities. Free residual chlorine (FRC) and microbiological contamination were measured; at the borehole, treatment site, distribution points, and households's water containers. In Big Five, water was collected from unimproved sources before DWS construction. Despite that, only 16,6% of households used efficient water treatment methods, resulting in 73% of water stored unsafe for consumption. After construction, household water quality drastically improved, regardless of FRC fluctuations; 93% of samples were classified as low health risk (safe). The renovation guaranteed continuous supply through electrochlorinators in RVA, where chlorination was intermittent. Water from DWS with adequate chlorine levels prevented microbiological contamination in households for 12 hours. Although economically attractive, the system's sustainability will require future evaluation.

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Groundwater; water supply; electrochlorination; drinking water; Africa; descentralized water systems

Introduction

The Democratic Republic of the Congo (DRC) is the largest country in Sub-Saharan Africa, with 2.34 million km^2 of land and about 90 million inhabitants. Despite the potential of its rich freshwater resources, not even half of the DRC's population has access to clean drinking water. Sixteen percent of the rural population uses surface water as a drinking water source (World Bank 2017; Country Economy 2023).

Decentralized water treatment and supply systems (DWS), are found in peri-urban areas and rural towns throughout Africa due to the lack of centralized drinking water supply (Collignon and Vézina 2000). These systems can be private or community-managed where the state is unable to provide drinking water to the population (Tantoh et al. 2022). In peri-urban districts of Kinshasa, a model of professional community management, the Associations of Users of Drinking Water Networks (ASUREP), was established in 2005. The installation of these community operated water supply systems is often financed by non-profit organizations, while operating expenses are covered by water sales (Bédécarrats et al. 2019). The systems serve areas that are not covered by the public water network in DRC. The ASUREP model is now present in the whole country, including rural areas. The systems generally provide water from an improved source, but water is not systematically treated. If chlorination

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is provided, the regularity of the treatment depends on the local availability of calcium hypochlorite, logistics, and price. The lack of regular water treatment and irregular provision of residual disinfectant increases the risk of microbiological contamination in the drinking water provided.

It is estimated that 1 billion people worldwide consume drinking water fecally contaminated coming from technically "improved" water facilities (Bain et al. 2014). In the sub-rural neighborhoods of Kinshasa, DRC, the concentration of E. coli in shallow wells during the wet season increased by 2–3 orders of magnitude compared to those measured during the dry season (Kayembe et al. 2018). In rural areas, the water is often more contaminated than in urban areas, with Africa and South-East Asia suffering more than other continents (Bain et al. 2014). An additional challenge is that under hygienically challenging conditions, water often is subject to recontamination during transport and storage even if the quality of the water has been good at the point of collection (Meierhofer et al. 2018; Hounkpatin et al. 2021). In stored water, a minimum chlorine concentration of 0.2 mg/L should remain to prevent recontamination (WHO 2021). The reaction of chlorine with water depends on the conditions found in the field, such as temperature, organic matter content, exposure to ultraviolet light, and storage conditions (Garcia-Avila et al. 2020). When chlorination at the DWS is adequately practiced, it allows a dose of disinfectant at the most distant fountain that guarantees drinking water on site. However, safe water at the point of collection does not mean safe water at home (Gross et al. 2022).

In a previous pilot study, chlorination provided efficient and timely decontamination at the point of distribution. Locally produced Sodium hypochlorite was automatically injected into water tank stations in rural Benin to treat the borehole water. The concentration of free residual chlorine was 0.29 ± 0.2 mg/L at the most distant point of distribution (Nogueira et al. 2022). The current publication aim to assess the presence of free residual chlorine (FRC) and E. coli as indicator for faecal contamination throughout a larger DWS until household. Therefore, water at the borehole, the treatment site with water tanks up to 4 times bigger, various distribution points in the network, and the water container of selected households were analysed in two sites from Maniema province DRC. In addition, a socio-economic and feasibility study were performed to evaluate the adequacy of the technology implemented in both communities.

Materials and methods

An impact measurement study was conducted in Maniema province, DRC, to assess the influence of a DWS performing chlorination in the Kasuku and Mikelenge community.

Study area

Maniema is one of the 26 DRC provinces. It consists of the city of Kindu and seven territories: Punia, Pangi, Lubutu, Kibombo, Kasongo, Kailo, and Kabambare. The city of Kindu comprises the communes of Alunguli, Kasuku, and Mikelenge (ICF International 2014). The study was implemented in two water supply schemes: The RVA DWS is located in the Basoko neighborhood, Kasuku commune. In May 2022, It had 14 fountains serving around 10.500 people. The Big five DWS is located in Mikelenge commune and had 55 fountains serving over 56.000 people (Figure 1).

Study design

In March 2018, a socio-economic survey related to housing, hygiene, and sanitation; was performed in the study area.

During May and June 2022, a before-and-after intervention study on the water quality of the Big five DWS neigborhood was performed (Figure 2). This water network underwent a major renovation on the spring catchment and implementation of water network (Figure 3). The population from this area was collecting water elsewhere. Total coliform counts and residual chlorine measures were the primary sources of quantitative input to evaluate the intervention at the collection point and the water stored in

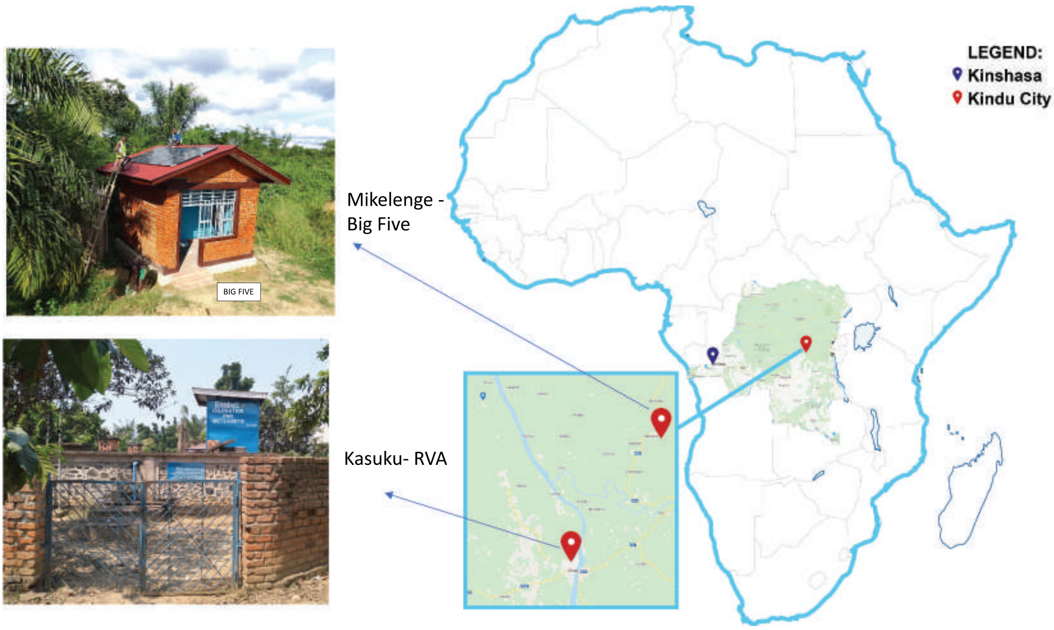


Figure 1. Water networks from Kindu city: big five and RVA.

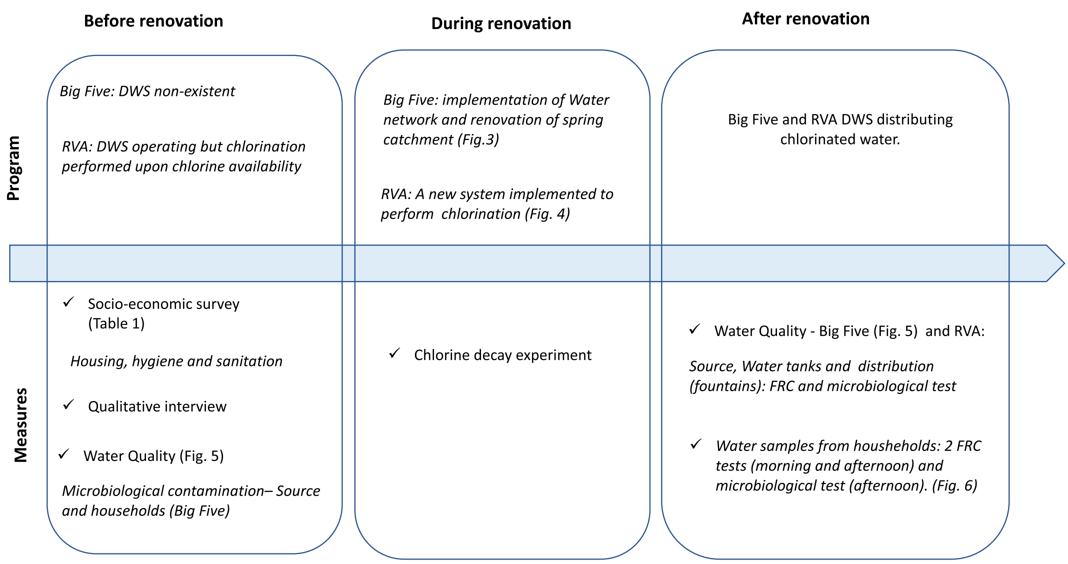


Figure 2. Study design: before, during and after intervention.

the households. The qualitative interviews at the household level were designed to draw an overview of the population using ASUREP services living in the targeted neighborhoods of the project intervention areas. Area residents willing to participate in the survey was the only inclusion criteria. The interviews were performed before the intervention. Their source of water, perceptions of drinking water quality, time employed in the collection process, storage, and if they apply any treatment to eliminate contamination were topics covered in this survey applied to residents around the RVA and the Big five DWS in May 2022.

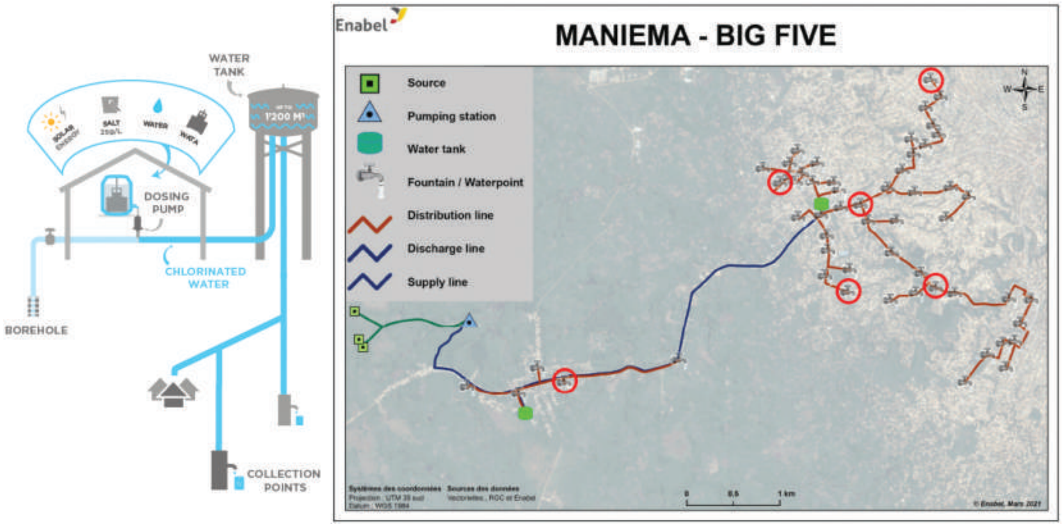


Figure 3. Water network station schema and selection of fountains from big five DWS in Kindu city, DRC.

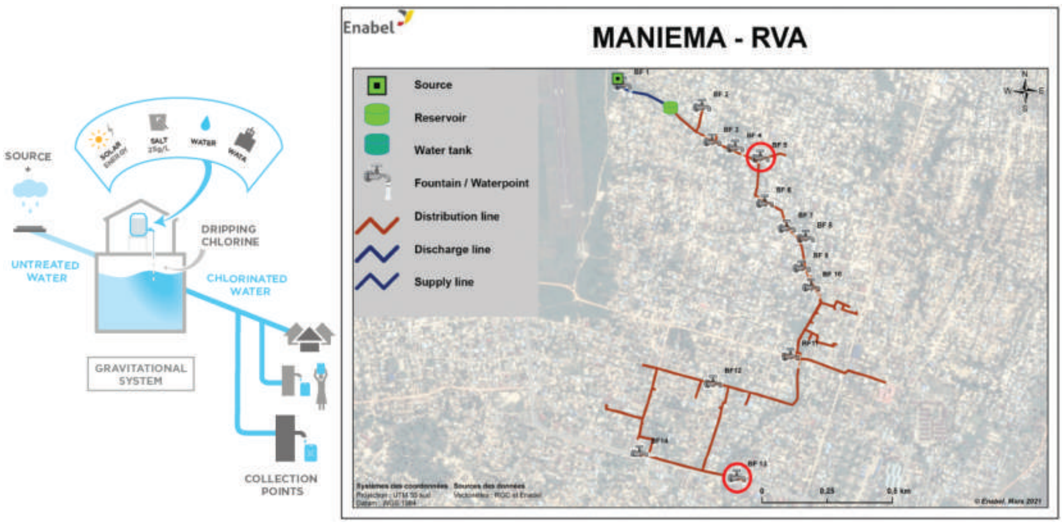


Figure 4. Water network station schema and selection of fountains from RVA DWS in Kindu city, DRC.

The RVA water network was operating before the intervention, and chlorination was performed according to chlorine availability on the market. A new system was designed to capture spring water, perform chlorination (with locally produced chlorine) and distribute it to the fountains who received two additional tapstands (Figure 4). Water quality (residual chlorine and microbiological analysis) was measured after the intervention.

Study population

Socio-economic status in 2018

The sample selection followed the binomial distribution of BERNOULLI formula ($n = t^2 * p * (1\text{-}p)/m^2$). Using the following criteria:

n: Minimum sample size to obtain significant results

t: Confidence level (confidence level of 95, therefore 1.96)
p: proportion of the population served with water by ASUREPs
m: Margin of error (set to 5)

The water networks' served and not served population was taken as variables. Therefore in 2018, 262 households using the Big five DWS and 200 homes using the RVA DWS participated in the survey.

Before intervention

A 22-question survey was applied in the water network community in May 2022, a month before installation. The intervention budget allowed a random selection of 34 households in RVA and 102 households in the Big five. A local team collected data recording geographic positioning system (GPS) using the GPS Tracks app for the iPad. Coordinates of households interviewed were matched to survey responses and water samples collected.In the Big five DWS, 17 households around the fountains: number 4, 13, 20, 25, 34, and 39 were randomly selected to participate in the survey, 102 households in total (Figure 3 right). Fountains near, mid-distant, and far from the water tank were selected to offer a comprehensive sampling of the water network. The GPS location of those fountains is described in Appendix 1.

Each household was identified by its name, telefone number and GPS address. Each one of them received a unique identification number allowing to match water samples before and after intervention. After the interview, the water stored in their house was tested in the morning and afternoon for microbiological contamination; a total of 204 samples. Water quality from the Big five source was also tested: 2 sources, 3 times a day for 4 days; 24 samples. Because there was no piped system (DWS) in place before the intervention in Big five, the water source tested was the source where housholds collected water. In RVA, there was no water test before the intervention. Only the qualitative interview was conducted (Figure 2).

Intervention

The electro chlorinators that produce liquid chlorine coupled into the dosing pump tank were field-tested in Benin. The on-site electrochlorination system is composed of two main parts: chlorine liquid production with water, salt, electricity, and electrolyzer (acquired from WATA^{TM}) and chlorine dosing and injection station with a proportional dosing pump and an injection connected to the main water pipe (Nogueira et al. 2022).

In the Big Five water network (Figure 3), the water pumped from the borehole is chlorinated with locally produced sodium hypochlorite. While in Benin the water tanks have 20–30 m^3 water capacity, in Congo there are two water tanks 4 times this size and 55 fountains where the population collects water. Therefore, a considerably larger scale.

In the RVA water network, 17 households collecting water from fountain 5 (close to the water tank) and 17 collecting water from fountain 13 (distant to the water tank) were randomly selected for the survey (Figure 4 right). The GPS location of those fountains is described in Appendix 1.

On a spring catchment like in the RVA's water source with continuous supply, chlorinating in the tank only once per day is not satisfactory as noted in previous essays. Therefore, it is necessary to continuously chlorinate in accordance with the catchment's flow rate during ASUREP's opening hours. For this purpose, a drip device was developed allowing continuous injection without pressure and complex automation. It consists of a small tank filled with chlorine solution where the flow is regulated by a simple tap, with a flexible hose attached to the supply pipe (Figure 4). The correct chlorine flow is adjusted empirically by adding successive doses until the desired FRC level is achieved.

After intervention

After the intervention in the Big Five DWS, a water control procedure in the same 102 houses visited before intervention was performed. The procedure consisted of FRC tests in the morning and afternoon with the water collected from the fountain. A microbiological contamination test was performed with the water stored in the container in the afternoon (102 samples). Therefore, the quality of stored water during the day was measured through: 2 FRC tests (morning and afternoon––204 samples) and one microbiological test (afternoon—102 samples). The time difference between water collected from the fountain and measurement in the household is estimated to be about 2–4 h in morning and 10–12 h in the afternoon. In addition, the water from the renovated borehole and fountains was tested.

The same procedure used in the Big five DWS to collect water samples was applied in RVA community (description below). But, in this case, there were 2 fountains selected. In total, 34 houses were monitored yelding a 2 FRC tests (morning and afternoon––68 samples) and one microbiological test (afternoon—43 samples). In addition, the water from the borehole and two fountains was tested.

Determination of chlorine demand

To determine the chlorine demand of the two water sources in the project and adjust dosage to a FRC value of 0.2 mg/L, Water from the borehole was chlorinated in different concentrations and stored in clean and covered containers. During 34 h, water samples were collected every 6–8 hours and FRC concentration measured.

Measurement of E.Coli

A 100-mL water sample was collected for a Compartment Bag Test (CBT) (Aquagenx, Chapel Hill, NC, USA) to determine the most probable number (MPN) of *E. coli* through a simple colour comparison following 2 days of incubation of the sample. The Aquagenx CBT is a rapid field test that can be conducted onsite at the water supply with minimal training and human capacity. In summary, the hands were washed using water and soap or hydroalcoholic gel. Following that, water was collected either from the tap (if available) or using an intermediate clean container. The CBTs were processed immediately according to the manufacturer's instructions. According to the manufacturer's table, water was quantified with an upper 95% confidence level/100 mL and classified as Low risk/safe (0 MPN/100 mL), intermediate risk/probably safe (1–3.7 MPN/100 mL), intermediate risk/possibly safe (3.1–9.6), high risk/possibly unsafe (13.6–17.1 MPN/100 mL), high risk/probably unsafe (32.6–48.3 MPN/100 mL) and unsafe (over 100 MPN/100 mL). A priority assessment classification based on the observed E. coli concentration (MPN counts/100 mL): Low Risk [0,1); Intermediate Risk [1,10); High Risk [10,100); and Very High Risk [100,þ∞) (WHO and UNICEF 2017) allowed a more descriptive water quality results across different sources.

Measurement of chlorine

Residual chlorine was measured using 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. The average of FRC and standard deviation were calculated for each data set.

Economic calculations

Although not officially available in the Kindu region, HTH (calcium Hypochlorite powder) can be purchased sometimes in the dark market. The costs of producing chlorine locally (with electro-chlorinators) versus chlorine production with HTH were calculated using the following assumptions:

(1) Chlorine needs estimation per site based on 0.2 mg/L of free residual chlorine at water point collection. An equivalent amount of HTH to ensure the same chlorine concentration and production of chlorine with WATA devices was calculated.
(2) The chlorine production costs with HTH, including purchasing HTH powder and human resources for preparing chlorine solution. For chlorine production with WATA devices, salt costs, human resources costs, and amortization of investment needed in the first year were included.
(3) The estimated product life of WATA devices is 9 years. The kind of devices used is different between the two sites as it is a WATA-Plus for RVA network and a Maxi-WATA for Big five network.

Ethical considerations

Ethical clearance was obtained from the school of public health of Kinshasa University and Eawag in Switzerland. Community consent was obtained from the respective community leaders. Oral consent was given by participants and they were informed to have the full right not to participate.

Results

Socio-economic survey and WASH practices of the study population

In 2018, a survey on socio-economic status was applied to 262 households collecting water from the Big five and 200 households using RVA water networks located in Kindu city. The community surrounding RVA was found to be more economically favored than the community surrounding Big five regarding housing structure, sanitation, and education level. When asked about water treatment methods, only 38,8% (90/232) of households in the Big five (Mikelenge) and 52,5% (105/200) of households in RVA reported knowing about it (Table 1).

Table 1. Socio-economic status of households using RVA and big five water networks. The percentages are calculated based on the total number of households reported in the brackets.

The households	Mikelenge (Big Five) $N = 262$	Kasuku (RVA) $N = 200$
Average number of people living in the same house	9.7	8.8
Primary income		
Informal sector (Agriculture, hunting, fishing)	61.5% (161)	50% (100)
State agents (teachers, health professionals)	27.1% (71)	32.5% (65)
Other	11.4% (30)	17.5% (35)
The highest level of education		
Unable to read and write	2.3% (6)	2.5% (5)
Primary school (able to read and write)	7.3% (19)	6.5% (13)
Secondary humanities	23.7% (62)	15% (30)
State diploma	40.1% (105)	26.5% (53)
University degree	26.7% (70)	49.5% (99)
Possession of a telephone	86.6% (227)	92% (184)
The quality of housing (type of walls)		
Durable (Bricks, cement blocks)	36.3% (95)	55.5% (111)
Semi-durable (Adobe)	56.5% (148)	36.5% (73)
Non-durable (cob, rammed earth, plank, mat, metal sheet)	7.3% (19)	8% (16)
Type and nature of toilets		
Wet pit latrines (mechanical/manual water)	5.3% (14)	14.5% (29)
Dry pit latrines (waterless, ventilated pit)	1.5% (4)	6.5% (13)
Traditional latrines with covered hole	50.4% (132)	47.5% (95)
Traditional latrine with uncovered hole	38.5% (101)	26.5% (53)
No toilet/bush/field	4.2% (11)	5% (10)
How hands are washed		
In a container, same water is used for several people	55.3% (145)	32.5% (65)
With a flow for each individual	44.7% (117)	67.5% (135)

The average number of people living in the same houses surrounding RVA (8,8) and the Big five (9,7) exceeds the national average of 5.3 (ICF International 2014); those are among the country's poorest communities.

In May 2022, a survey applied before the installation assessed the habits of households surrounding the randomly selected Fountains of RVA and Big Five. All households (34/34) around RVA fountains reported using ASUREP water as their primary source of drinking water. When inquired about other sources, 73,5% (25/34) reported collecting water only from ASUREP for drinking; while 26,5% (9/34), reported also using wells, bottled water, and private connection. Only two households, 5,8%, reported drinking water from the river as an alternative source. In the Big five community, where there was no access to piped supply, (15,7%) 16/102 households reported that their primary source of drinking water came from the river, and 8,8% (9/102) exclusively use this source for drinking purposes. For 63,7% of households (65/102), the main source was a nearby well (known as Miloba), and for 20,6% (21/102), a mixture of other unimproved sources. These wells, like Muloba, are single holes generally 3–6 m deep into which a bucket pulled by rope is lowered. The yarn is always left on the ground. The well is sometimes closed by a wooden hatch, its circumference 80 cm to 1 m maximum. In almost 30% (30/102) of households, water collected from the river was an alternative source of drinking water.

Treatment was not performed in 91,2% (31/34) of households from RVA, perhaps because drinking water taste was rated as very good 82,3% (28/34) and good 17,6% (6/34). In the Big five network, however, water taste was rated a "little bad" by 14,7% of households (15/102), good by 52% (53/102), and very good by 33,3% (34/102), and 45% (46/102) of households reported treating their drinking water. Sadly, only 16,6% (17/102) used efficient methods like chlorination (15/102) and boiling (2/102). What was mostly used, 76% (78/102), as a treatment was letting the water stand. This is particularly problematic because drinking water is stored for less than 24 h in 41,2% (14/34) of RVA households and 13,7% (14/102) of Big Five households. Both communities have households storing their water for more than 24 h (23,5% (8/34) RVA; 46,1% (47/102) Big Five) and even more than 2 days (35,3% (12/34) RVA; 40,2% (41/102) Big Five).

The intervention

Chlorine decay experiment

The chlorine decay experiment revealed that water should be at 0,53 mg/L FRC at the point of collection to maintain a concentration of at least 0,2 mg/L FRC after 24 h (+10 h additional) when correctly stored in a container at home. Therefore, 0,53 mg/L FRC was set as the target concentration at the point of collection.

Water quality

In Big Five, the water from the borehole before the renovation was not free from contamination. The water quality was classified as low risk in 63% (15/24) of samples collected, intermediate risk in 29% (7/24), and very high risk in 8% 2 samples collected from the source (Figure 5 A left).

Before the intervention, the average water quality in households surrounding the 6 selected fountains from the Big Five DWS was critical. Among the 204 water samples collected in 102 houses (morning and afternoon), 63% (129/204) were classified as a very high health risk, 10% (20/204) as high risk, and 9% (19/204) intermediate risk. Only 18% (36/204) had a low health risk, i.e. suitable for consumption (Figure 5 B). As reported in the survey, households collected

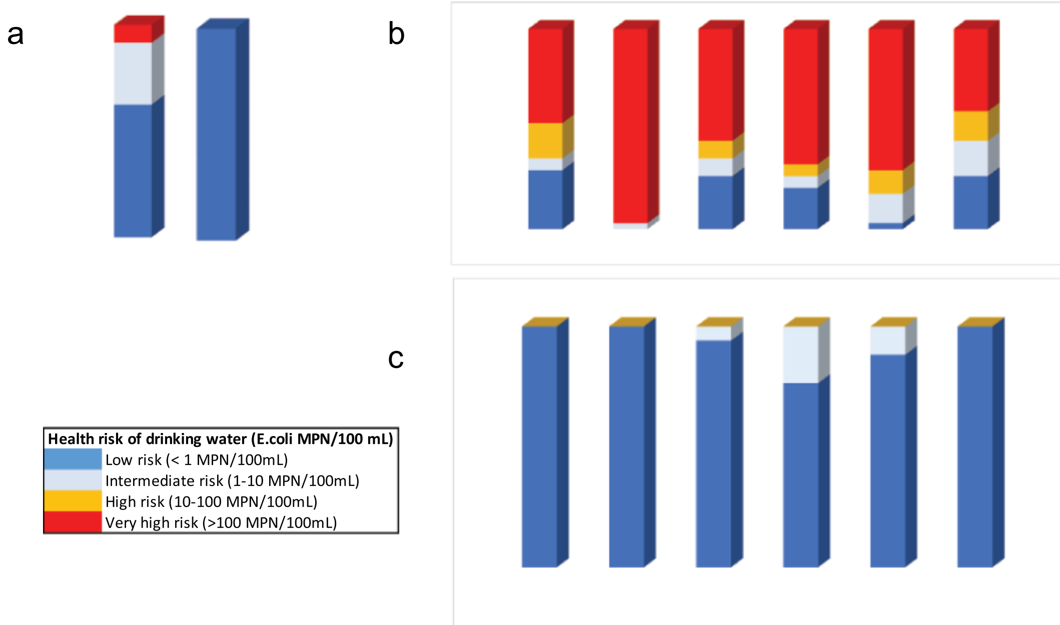


Figure 5. Risk levels for water quality. a) risk level for water quality in the source used in the households before (left) and after (right) the intervention. b) health risk level for water stored in households before (top) and c) after the intervention.

their water elsewhere because the DWS was out of order. Therefore, the main water source from the Big Five community was unimproved.

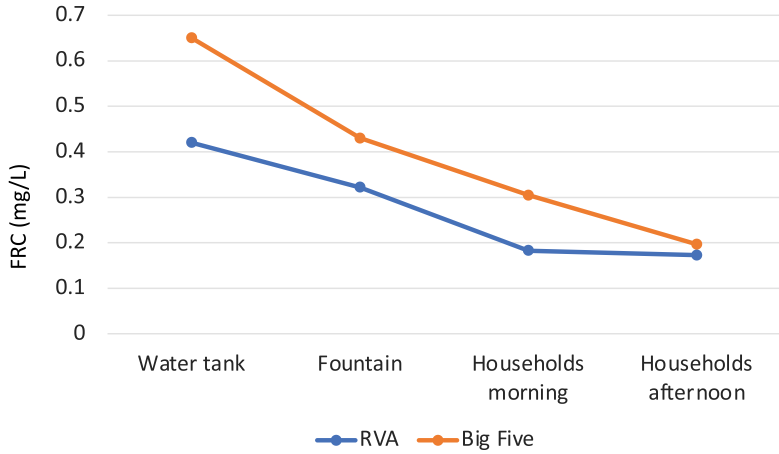
After the intervention, households from the more economically favored community (RVA) with better sanitation, housing, and education had stored drinking water of better quality. E. coli was not detected in any of the households—data not shown––despite the lower FRC level (Figure 6 A). The chlorine level within fountains in the Big five DWS fluctuated (Figure 6 B) despite the elevated average level of FRC measured in the water leaving both water tanks, which was 0.77 ± 0.09 and 0,54 ± 0,12 mg/L. A network with 55 fountains is challenging, and the ones distant from the water tank might get a lower FRC level. Some houses had a level of chlorine below 0,2 mg/L even if the fountain they collected water from had a high FRC level. Probably, they mixed the water collected with the one from the previous day or with water from a different source. However, water quality drastically improved in the Big Five community. After the intervention, 93% (95/102) of water samples collected after 12 h storage (in the afternoon) were classified as low risk and 7% (2/102) as intermediate risk. All samples collected from the source were free from contamination (Figure 5 C).

RVA DWS chlorinated their water upon product availability prior to WATA. FRC and E.coli measures validated the drip device and electro-chlorinator system installed. Even with FRC measures below the Big Five, no contamination from E.coli was found in the samples collected (Figure 6 A).

Social and economic considerations

An economic study was conducted to compare locally production of chlorine using electro-chlorinator devices versus chlorine production with HTH (calcium Hypochlorite powder). Although investment for local production is considerable ($20.052 in Big Five and $11.476 in RVA), yearly amortization is higher when chlorine needs are higher. Therefore, in Big Five yearly amortization is $1.000 higher than in RVA; yielding a higher yearly saving (Table 2).

a



b

	BF4	BF13	BF20	BF25	BF34	BF39
Fountain	0.75 ±0.08	0.52 ±0.06	0.31 ±0.14	0.53 ±0.09	0.21 ±0.05	0.25 ±0.24
Households morning (17)	0.48 ±0.19	0.5 ±0.05	0.21 ±0.07	0.17 ±0.10	0.14 ±0.10	0.33 ±0.20
Households afternoon (17)	0.27 ±0.15	0.27 ±0.04	0.17 ±0.07	0.13 ±0.07	0.13 ±0.05	0.20 ±0.11

Figure 6. Average FRC levels at different sampling points in the RVA Big five DWS (a). For Big five water network: b) average and standard deviation of FRC (mg/L) in the water from the fountains and stored in nearby households (*N* = 17).

Discussion

The results are a snapshot of two communities surrounding a DWS in Maniema province, Congo. A DWS providing residual chlorination until the point of consumption was designed for each one of the communities. Their economic status and WASH practices were assessed through a survey in 2018, and the influence of a DWS performing chlorination in the community's water quality as well as water source, perceptions of drinking water quality by the community was measured in 2022.

Our findings align with the literature, which reports that more than 75% of the DRC population cannot access in-home piped water (WHO and UNICEF 2017). Therefore, they need to rely on self-supply from multiple sources as reported in many low-income countries (Howard et al. 2002; Foster and

Table 2. The costs of producing chlorine locally (with electro-chlorinators) versus chlorine production with HTH.

	Big Five	RVA
Estimated chlorine needs per year (Kg)		
Production with WATA devices	156	84,24
HTH at 70% of active chlorine	202,8	109,5
Investment for local production with electro-chlorinators($)	20.052,0	11.476
Yearly amortization ($)	2.228	1.275
Production costs per year ($)		
Salt	*780*	*350*
HTH	*9.126*	*4.928*
Human resources	*1.029*	*780*
Using electro-chlorinators (+ amortization)	4.037	2.406
Using HTH	10.155	5.708
Yearly savings when chlorine is locally produced versus HTH acquisition ($)	**6.118**	**3.301**

Willetts 2018). As observed before the intervention, in the Big Five community, the lack of improved water sources in the sourroundings, pushes the population to collect water in "milobas" and any other available source with poor water quality. Consequently, 86% (88/102) of households stored their water for more than 24 h, with many inhabitants per household which facilitates microbiological contamination. Sanitation and hygiene were not appropriate with wet pit latrine possession very low (5,3%) and hand washing with water used for several people (55,3%), as observed in households from rural Africa (Tumwine et al. 2003). This might also have played a role in water quality found. Previous research shows increased waterborne diarrheal disease as the distance from water sources increases (Wang and Hunter 2010). Schools near water sources refill storage containers more often, avoiding contamination during transport and extended storage periods (Morgan et al. 2021). Even when 45% of households reported treating their water, microbiological contamination was detected. Indeed, before DWS installation, only 18% of water stored in the households was considered safe. A lack of education on the implications of inadequate water storage and factors related to poverty (long working hours, poor sanitation at the household level) may be the root causes of the water quality found in Big Five households. On the other hand, when the water is perceived as "good" and coming from an improved source, the population tends to neglect water treatment. This pattern was observed in over 90% of households from RVA community who just did not perform any treatment. Despite the good water quality at the source, without residual chlorine, the water can easily be contaminated during transport and storage. In RVA, almost 60% (20/34) of houses store water for more than 24 h, contributing to microbiological contamination.

Altogether, the situation described in Big Five and RVA communities represents the challenges faced in low-income countries: water collection from unimproved sources with poor water quality (during DWS intermittent service) or improved sources without residual chlorine necessary for protection. Although water from improved sources is safer than surface water, it often does not meet international standards for safety (Onda et al. 2013). In rural Benin, 60% of groundwater collected from 31 DWS stations presented microbiological contamination (Nogueira et al. 2022). As reported in this paper and in previous studies, even a covered borehole might have microbiologically contaminated water, and untreated groundwater can be a source of enteric diseases (Murphy et al. 2017). It is a fact that Drinking water quality is low across the DRC and responsible for negative health outcomes (World Bank 2017). Information collected at the General Hospital indicates that Kindu is regularly affected by cholera epidemics. The disease has struck the city several times in recent years (August – November 2015), July 2016, and July 2017-February 2018 (internal report, Enabel).

There are several small-scale water treatment technologies reported in the literature but they are mostly focused on pathogen removal (Letcher 2022). In the present study, both water treatment systems provided locally produced chlorine sufficient to inactivate *E. coli* at the point of collection regardless of the FRC fluctuation observed. FRC plays a crucial role in preventing microbiological contamination that can occur during the transportation and storage process (Meierhofer et al. 2018). This is a step forward from the previous research (Nogueira et al. 2022), considering the large size of the Big Five network and limited educational level of operators. In addition, the innovations in drip device in RVA to provide constant chlorine flow indicate how versatile electro-chlorinators can be. This seems to be a promising technology to eliminate microbiological contamination and improve drinking water quality at the source and at home depending on how long water is stored. But, although it has proved efficient and economically attractive, with cost recovery in less than 4 years, this is not a straightforward process. Usually, local communities and authorities are unable to provide the upfront payment without NGO support, as reported in many other countries (Scanlon et al. 2016) and observed recently in Madagascar (Duvernay et al. 2023). Depending on logistics and price fluctuations, HTH acquisition remains the leading practice. Furthermore, it is imperative to establish guidelines for defining and assessing community water interventions across diverse settings (Bonsor et al. 2018). Nevertheless, the use of electrochlorinators is observed by independent groups, as reported in Mali, where a decrease in surface contamination in the hospital was observed due to chlorine availability (Traoré et al. 2020).

Study limitations

The findings of our intervention should be interpreted in light of certain limitations. First, due to budget constraints, it was not possible to conduct pre- and post-program assessments of E. coli and chlorine levels. Instead, all parameters of RVA DWS were evaluated only after the intervention and the chlorine levels for Big Five DWS as well. This decision was taken because RVA practiced chlorination upon the availability of disinfectant, and the primary objective was to investigate the efficiency of the new system (electro-chlorinators and drip device). Big five DWS was built from scratch, and surrounding households collected water from an unimproved source without practicing chlorination. Therefore, no need to test chlorine levels before intervention. This allowed saving money, but is not a classical assessment. Second, chlorine levels and microbiological contamination were measured only up to 12 hours of storage. Therefore, households collecting water once per day may still consume contaminated water from their storage containers. Third, attention must be paid when comparing WASH programs implemented in disparate geographic locations. Challenges associated with procuring supplies may exert a substantial influence on the intervention, as recently observed in Madagascar where costs were prohibitively high and even basic supplies necessary for the borehole renovation were inaccessible (Duvernay et al. 2023).

Conclusions

Economically viable and technically suitable systems that require minimal behavior change can provide safe water access to low-income communities. Our findings show that the technology was operationally feasible even in large water networks, with operators adopting it, and proper chlorine levels effectively preventing microbiological contamination in households for 12 hours. However, the long-term sustainability of the system should be assessed and would require new measures to do so.

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Appendix 1 – GPS Location of fountains

Location	Fountain Number	GPS location	
		Latitude	Longitude
Mikelenge (Big Five)	4	−2.97026167	25.870023
	13	−2.96112827	25.907547
	20	−2.95880333	25.898368
	25	−2.95438670	25.901147
	34	−2.95239667	25.893402
	39	−2.94209210	25.907868
Kasuku (RVA)	5	−2.92724833	25.922318
	13	−2.93783833	25.922375