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Practical Paper

Decreasing diarrhea cases through on-site sodium hypochlorite production in Madagascar

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ABSTRACT

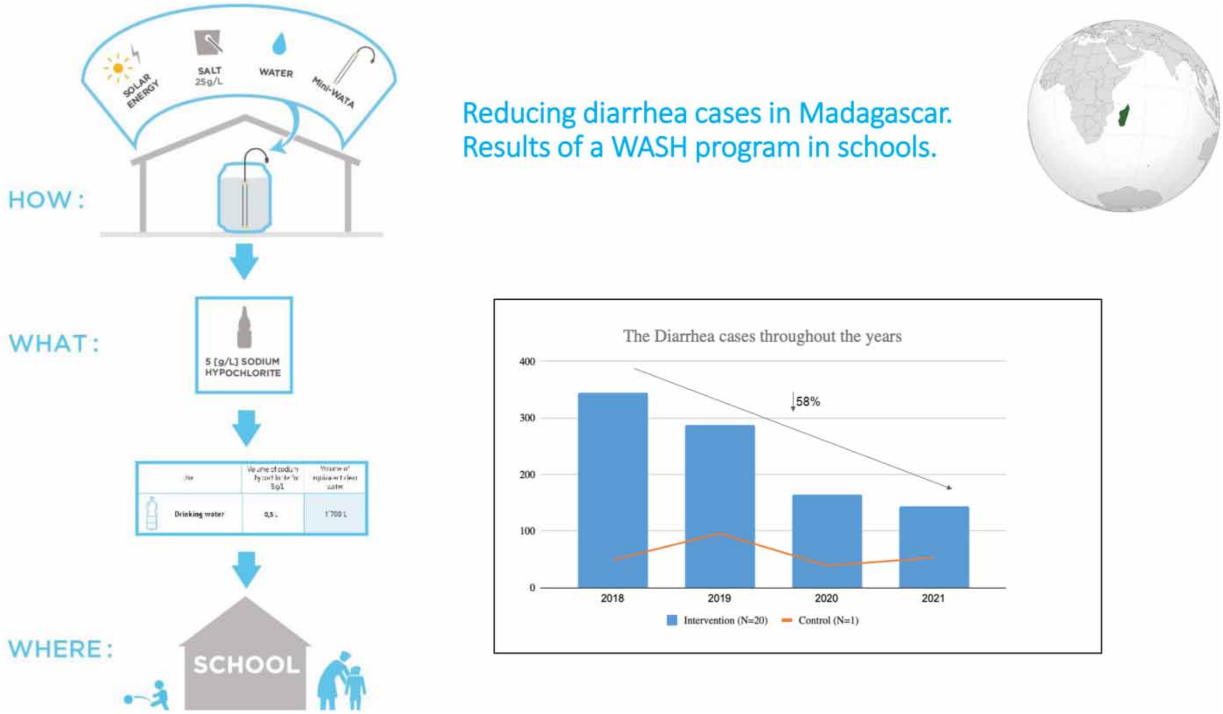
Schools from Sainte-Marie Island, off the east coast of Madagascar, participated in water, sanitation, and hygiene (WASH) programs. We report an association between the program, the sustainable access to water treatment (WT) in 20 schools, and the impact on diarrhea incidence in the region. We performed a quasi-experimental longitudinal study on the program's sustainability by accessing the continuation of point-of-use (POU) water chlorination, safe water storage (SWS), and handwashing practices on the diarrhea cases of children. Patient files from 10 health centers near the schools were consulted. Sodium hypochlorite was locally produced by the students for WT and the program's sustainability was accessed between 2016 and 2021. After the intervention, 40% of water sources were entirely replaced and 60% received improvements. A student's water club, guided by teachers, was responsible for all activities related to WT. The health centers around the schools participating in the program saw diarrhea cases drop by 58% between 2018 and 2021. There appears to be an association between a decrease in diarrhea cases and the program's implementation. The strategy used can be replicated. Nevertheless, the program's success is multifactorial, depending on community engagement, adapted technology, funding, and governmental support to ensure sustainability.

Key words: chlorine, education, HWTS, Madagascar, water

HIGHLIGHTS

- Before the project, none of the schools practiced WT and 35% did not have handwashing facilities.
- A partnership among NGOs, local authorities, and schools made the program sustainable.
- There appears to be a strong association between diarrhea cases drop by 58% and the program's implementation.

GRAPHICAL ABSTRACT



1. INTRODUCTION

This paper is about how to use electro-chlorinator devices to implement an inexpensive and successful WASH (water, sanitation, and hygiene) program in a rural part of Madagascar.

Children from Madagascar have one of the world's highest rates of stunting prevalence: 42% of its children are experiencing stunted growth (Vonaesch *et al.* 2021), which is worrisome because higher mortality is observed in stunted children (Victora *et al.* 2021); they also have a more significant risk of developing cognitive impairments later in life (Prendergast & Humphrey 2014). Globally, stunting prevalence among children younger than 5 years was estimated to be 21.9% in 2017. Africa accounts for 30% of stunted children, with significant differences between countries and socio-economic inequalities within a country (Victora *et al.* 2021).

A study on the nutritional, family, household, and socio-economic factors associated with stunting children in Madagascar pointed out that not having constant access to soap was associated with an 80% increase in stunted child growth in the capital, Antananarivo (Vonaesch *et al.* 2021). Vonaesch and collaborators suggest hand hygiene as the easiest and most effective WASH intervention to be implemented. In addition, co-morbidities such as diarrhea and dermatitis were found to be risk factors, while the higher education of the mother was a protective factor against stunting. Those findings reflect the multifactorial nature of stunting, which requires interventions in different sectors such as hand hygiene, education, and nutrition to curb this condition (Argaw *et al.* 2019; Hawkes *et al.* 2020).

Electro-chlorinator devices transform salty water into sodium hypochlorite (NaClO) through electrolysis. Local disinfectant production can overcome water treatment (WT) and disinfection barriers in rural Africa, such as logistics, price fluctuations, and quality. Community water network stations in Benin (Nogueira *et al.* 2022), hospitals (Duvernay *et al.* 2020; Nogueira *et al.* 2021), and schools in Burkina Faso (Duvernay *et al.* 2022) benefited from water quality improvement after incorporating sodium hypochlorite production. *In situ* chlorination can provide decontamination, thus decreasing waterborne diseases, as reported in a refugee settlement in Sudan (Salih & Alam-Elhuda 2019) and avoiding water recontamination during storage, which is sadly frequently observed in areas with hygienically critical conditions (Meierhofer *et al.* 2018).

Our underlying hypothesis was that point-of-use (POU) water quality interventions using safe water storage (SWS), WT through chlorination, and education through school programs would guarantee the consistent practice of WASH behaviors. As reported in the literature, WASH improvements prevent diarrhea (Migele *et al.* 2007; Dreibelbis *et al.* 2014; McMichael 2019). Therefore, 20 schools from Sainte-Marie Island, Madagascar, were studied before and after a WASH program. The data on diarrhea incidence collected from health centers and lessons learned are presented, hoping to assist government authorities, non-governmental organizations (NGOs), local communities, and anyone planning WASH programs in the education sector.

2. MATERIALS AND METHODS

2.1. Study area and population

Sainte-Marie is an island located 30 km northeast of the east coast of Madagascar, covering an area of 222 km^2 with an estimated population of 30,000 inhabitants. It is located in the province of Tamatave and the region of Analanjirofo. The program targeted 20 schools with a total of 4,547 students aged 2–14 years old, distributed throughout the island. Ten health centers located in the school's vicinity were identified to monitor the incidence of diarrhea cases (Figure 1). The health centers were between 0.1 and 8 km from the nearest school. Information on baseline conditions regarding handwashing facilities, water sources, and overall water quality was collected before the intervention (Table 1).

2.2. The intervention – Rano Madio

The ultimate goal of the Rano Madio program was to design a reliable water system that provides sufficient water for handwashing and safe drinking water, adapted to the conditions in the field. With a pre-requisite's water turbidity inferior to 5 NTUs (Nephelometric Turbidity Units), the target of active chlorine was 1.5 mg/L, for an expected residual chlorine level between 0.5 and 1 ppm (parts per million). A quasi-experimental longitudinal study design allowed for data collection and outcome interpretation.

2.2.1. The pilot study

From November 2016 to November 2018, eight schools successfully enrolled in a program called 'Rano Madio 1'. This program provided a centralized sodium hypochlorite production, distributed in schools by the operator in charge of the WT,

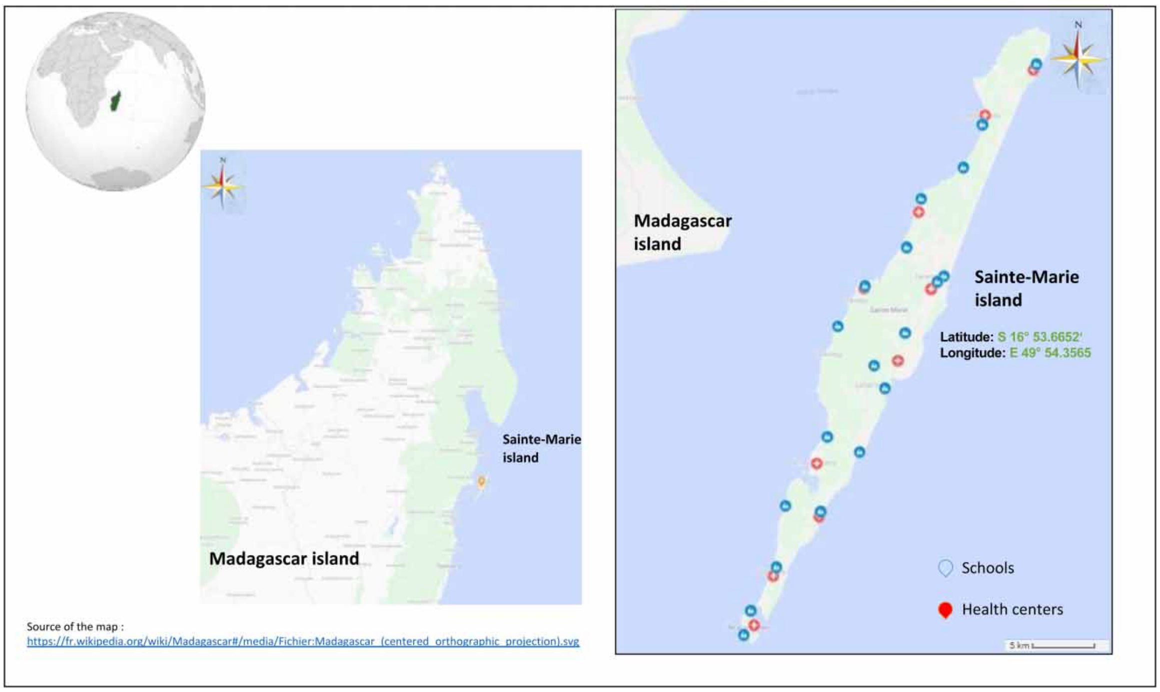


Figure 1 | Location of schools and health centers in Sainte-Marie Island.

Table 1 | Schools at baseline and after the program

Schools at baseline ($N = 20$)		Schools after the program ($N = 20$)	
Main handwashing facilities			
Not present	5	Tippy-tap	11
Faucets non-operational	2	Faucets fully operating	3
Faucets fully operating	3	Tap buckets	6
Tippy-tap	4		
Tap buckets	6		
Source of water			
Uncovered water well	10	Improved wells	5
Hills	5	Hills	2
Rain water	7	2,500 L water tank	13
River/stream	4		

allowing drinking WT every 48 h. The schools were located mainly in the southern region. A rainwater collection system was installed in each school and the operator performed the treatment of 2–3 barrels of 215 L each, depending on the school's size. Pedagogical programs that created awareness of WT and hand hygiene were introduced in the schools with the help of the local educational department (CISCO) (School District of Sainte-Marie). The study also observed that students accepted the taste of their drinking water after chlorination.

2.2.2. The intervention

From March 2019 to December 2021, 12 new schools and the 8 schools that participated in the pilot were enrolled in the 'Rano Madio 2' program. This program provided a decentralized sodium hypochlorite production system with the installation of one electro-chlorinator in each school. The school teachers who volunteered to participate ensured the output during the first 2 weeks. They were previously trained in WT, chlorine production, and the construction of tippy-taps. Afterward, students created 'water clubs', under the supervision of their teachers and these water clubs carried out the daily tasks for the program.

The activities of the water clubs throughout the year consisted of the daily production of chlorine, the injection of chlorine into the class fountains, the control of residual chlorine in the class fountains, the cleanliness of the materials (bowls, cups, transport cans, and the support table), the maintenance, and the handwashing facility (availability of soap and water). The role of the water clubs was also to raise awareness among all students and the community about WT, the need to drink clean water, and respect for hygiene rules. The recovery of water from roofs and its storage in 2,500 L tanks, as well as the rehabilitation, and the rearrangement of existing freshwater wells have been implemented. Fountains with 50 L of chlorinated water per day, with a tap for easy and safe distribution, were also made available to pupils in each classroom.

A teacher's manual, developed by the Antenna Foundation's School Unit and previously used in Burkina Faso (Duvernay *et al.* 2022) was adapted to the Malagasy context by CISCO, the local structure of the Ministry of National Education of Madagascar. Paper copies were distributed and an online version was available to download. It contained technical sheets, teaching material, and instructions on:

- The explanation of the household water treatment and safe storage (HWTS), including its components and benefits;
- The teaching of the features, operation, and maintenance of the Mini-WATA and Standard-WATA devices (the chlorination devices used in this program);
- The explanation of the practical work on chlorine production and water purification in the classroom using the Mini-WATA and the Standard-WATA devices;
- The teaching of good practices in setting up and maintaining the necessary equipment for the HWTS in a school;
- The promotion of behavioral changes in hygiene and sanitation.

The installation of 'tippy-taps' enabled handwashing by using the foot to tilt the container without needing to touch the tap. This low-cost, locally made device helps avoid contamination. Soap is hung on a string next to the container (Figure 2). A high

Figure 2 | Tippy-tap schema. Credit: UNICEF.

level commitment of CISCO, the school system, the Ministry of Health and the creation of student water clubs allowed for the smooth implementation of the program. In addition, a competition organized by the water clubs and supervised by the local project manager resulted in 527 tippy-taps being built in the community by 35% (527/1500) of the households involved in the project. The strong commitment of Sainte-Marie's Head of the School District and his collaborators, the support of the Ministry of Health, and the involvement of the pupils through the water clubs enabled the gradual and lasting appropriation of the program's content and its success.

In December 2021, a 3-year agreement was signed between Cetamada (a Malagasy Association), GHIMAO (a French association) and Antenna Foundation. This agreement guarantees the program's sustainability by transferring to CISCO the daily operations of chlorination and maintenance of the installations.

During COVID, schools were closed for 3 months (April–June 2020) and the inhabitants were forbidden to meet in groups above 50. Masks were adopted in public places. In the beginning, a mobile handwashing facility was installed by UNICEF in three schools. Inhabitants returned to an almost everyday life toward the end of 2020, adopting the masks in public spaces.

2.3. Sodium hypochlorite production

The centralized sodium hypochlorite production in the Rano Madio 1 program was performed with a WATA-Standard™ device (developed by the Antenna Foundation, commercialized by Watalux SA). In 2 h, using 2 L of water, 50 g of salt, and access to a 220 V power grid, it produced a 2 L solution of sodium hypochlorite at a concentration of 5 g/L, allowing the potabilization of up to 6,800 L of water. The sodium hypochlorite solution was distributed among the schools participating in the pilot study. An external operator performed the production during the pilot study phase.

The decentralized production of sodium hypochlorite in each of the 20 schools in the Rano Madio 2 program was performed with Mini-WATA™ devices (as mentioned above, also developed by the Antenna Foundation, commercialized by Watalux SA). In 2 h, using 0.5 L of water, 12.5 g of salt, and electricity, the devices produce 0.5 L of sodium hypochlorite, allowing the potabilization of 1,700 L of water. The solar kit from the device or 220 V solar installation already in place was used in 85% (17/20) of schools. Only 15% (3/20) of schools had access to the national electricity network. The water club performed the production during the intervention period.

2.3.1 Quality measurements

WataTest™ was applied to test the chlorine concentration after production and WataBlue™ was used to check chlorine residual.

Water potabilization was calculated to be 1.5 mg of active chlorine per liter with 0.5–1 ppm residual chlorine. This concentration indicates that the bacteria have been correctly killed or inactivated after 30 min.

2.4. Data collection and calculations

The baseline data were collected in each school before the start of the program, the 8 pilot schools from 2016 to 2018 and the other 12 schools from March 2019 to January 2021. The number of schools during the pilot phase and at the later stage is related to the total budget available for this operation. The incidence of diarrhea cases was acquired at the health centers, from historical patient files, during March–April 2022. Two district health officers supervised the operation and the data were verified by the information and management system's manager of the Sainte-Marie Health Service.

A three-point estimate based on historical data were used to calculate the device's longevity in years, directly linked to the program's continuity. Then, a yearly cost per pupil based on upfront payments for installation and program maintenance was calculated, considering the expected years of the device's longevity. That is, how long could schools enjoy the facilities implemented without needing to replace any part/instrument used in the processes of water collection, storage, and chlorination? Direct family savings were calculated based on the average amount spent when a child has a diarrhea episode. Calculations of the government's savings through the program on medical consultations were based on historical data collected from healthcare centers and an estimation based on the last year of the program until the device's expected longevity.

3. RESULTS

The intervention to improve the water quality was based on the school's previous conditions. Water sources that provided water with turbidity ≤ 5 NTU were kept and improved if necessary. The water storage conditions and handwashing facilities were adapted to the school size and necessity. The lectures and pedagogical programs were tailored to age groups.

At the baseline, before the program's start, the water from 70% (7/10) of the well source was mostly muddy or brackish, and all wells were non-covered. The well was dry in three schools during November–December. This happens when the well's depth is limited by a layer of hard rock that requires special equipment to be removed. So, they had to collect water in a river or stream nearby. In 35% (7/20) of schools, there was no handwashing facility before the program; in five schools, no facility was in place, and in two, they were non-operational.

WT and handwashing were not performed in any of the 20 schools before the program. It was also not encouraged in the schools with a handwashing system operating (Table 1).

After evaluation, 5 out of 10 wells received improvements or rehabilitations like excavation to increase depth, cleaning, disinfection, and proper coverage. The wells in five schools were not retained as a water source because the water was salty. In those cases, installing a 2,500 L tank with concrete support allowed the rainwater harvested from the roofs of school buildings to be stored. The systems that collected water from the hills were non-functional in three schools; rainwater harvesting tanks have replaced them. The functioning systems were cleaned and water storage tanks were replaced where needed. Most of the existing rainwater harvesting systems, 5/7, were replaced by new ones as the preexisting infrastructure had problems and did not allow water to be stored for long or were fragile. The water collected from the river/stream was not clear and, in most cases, was used for drinking purposes only during the dry season. This source of water was kept, but the 2,500 L tank became the primary water supply source. Therefore, 40% of the water supply source from schools was wholly replaced so that a safer and more sustainable flow could be ensured. In addition, 60% of water sources received improvements in their wells, storage capacity, and in some cases, an additional water source. 50 L chlorinated water fountains (drinking water) were installed in classes. Tippy-taps were installed in all schools and made available to students for daily handwashing. The students who make up the water clubs and teachers received training on WT and maintaining the system installed. They also participated in constructing tippy-taps so they could replace them when needed.

In 2018, the number of diarrhea cases in children from 1 to 14 years old in the health centers surrounding the 20 schools enrolled in the Rano Madio program was 344. Children are enrolled in school after they reach 1 year old. In 2019, diarrhea cases in the same health centers were 287 and the number kept decreasing from 2020 (164 patients) until the end of 2021 (144 patients), resulting in a 58% decrease in the number of cases in 2021 when compared to 2018. The same trend was not observed in the private health center used as control, situated more than 10 km away from 75% (15/20) of schools and assisting a population more economically privileged (Figure 3).

The overall cost of the program was around 90,000 dollars. The operating cost is minimal, as only kitchen salt is required for sodium hypochlorite production. The students' water clubs are responsible for and involved in the whole process and daily tasks, from the production of sodium hypochlorite to the injection of chlorine into the classroom fountains. The reagents used to control chlorine concentration after production and residual chlorine in the water of the classroom fountains are generally used during the project implementation and until the learning curve is well established. After this learning period, production conformity control is performed by visual inspection (presence of bubbles during the electrolysis process) and chlorine odor. Using a three-point estimate based on historical data, we calculated 8.3 years of device longevity, serving 4,547 pupils resulting in 2.4 dollars (US Dollar, USD) per pupil yearly. Family direct savings every year on the purchase of medication are estimated on average at 1.16 USD as expenses can range from 0.32 to 2 USD depending on the severity of diarrhea, which is 60% of an average daily income. During the 8.3 years of continuity and before CISCO needs to make any significant investment in installations, the government is expected to save 1,796 USD on consultations, which is 8 months of a nurse's earnings in a health center. Although financially attractive, the goal is not an accounting amortization but the fulfillment of Objective 6 of the UN Charter: 'ensure access to water and sanitation for all'.

4. DISCUSSION

A recent systematic review identified a lack of published information about WASH programs in schools compared with WASH programs aimed at communities (McGinnis *et al.* 2017). There are even fewer studies on long-term sustainable actions to guarantee the WT. In this paper, we investigated WASH interventions in 20 schools in a low-income country, Madagascar, where access to safe drinking water, handwashing facilities, and hygiene education were provided in partnership with local authorities. A water system tailored to each school allowed the pupils to drink safe and sufficient water. Handwashing facilities provided minimum hygiene and helped to reduce various waterborne diseases. An electro-chlorinator device operated by the student water club produced sodium hypochlorite locally, which was used for WT. The rate of diarrhea cases dropped by 58% between 2018 and 2021. The program is a good example of a successful partnership between NGOs, schools, and local authorities aiming to ensure sustainable access to safe water.

The commitment from local governments to the WASH program was essential for ensuring the success and sustainability of the projects. A self-financed and easy-to-operate system can ensure continuity (Cord *et al.* 2022). It is crucial, however, to understand the impacts of different types of WASH programs on health outcomes. We found that the extent to which students operate as change agents dictates the school's engagement and ensures sustainable and universal access to WASH adapted to

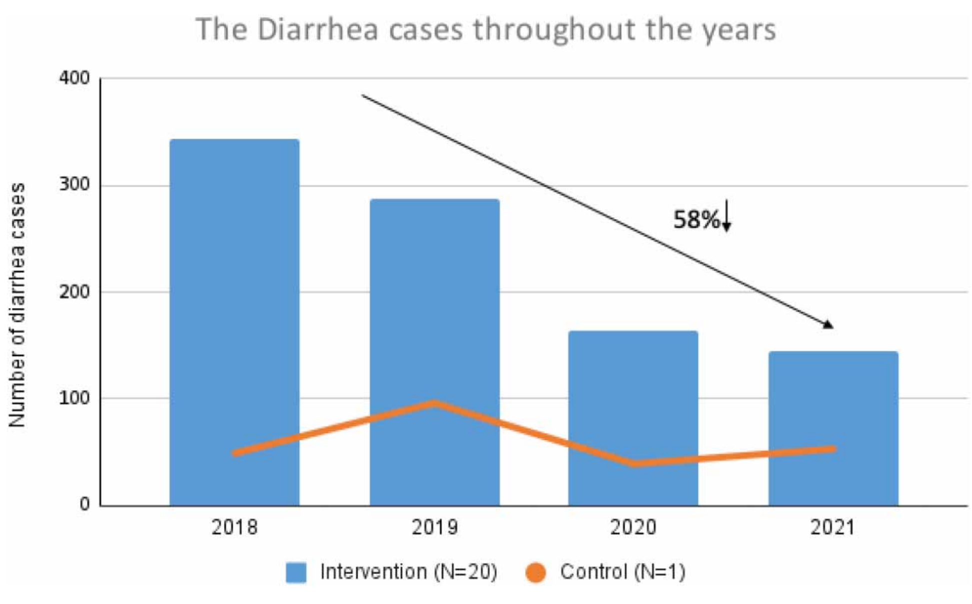


Figure 3 | The diarrhea cases throughout the years.

their socio-economic setting. Our findings are aligned with a study published on the student's willingness to use chlorine tablets as a new treatment method after a school program in Tanzania (Felix *et al.* 2022). The authors observed a significant increase ($p < 0.05$) in their attitude toward WT (100%), water quality (78%), and water consumption (67%). In addition, more than 90% of the students were willing to buy chlorine tablets if they are made available (Felix *et al.* 2022). These studies indicate the importance of empowering students, which is what was done in this publication's program by creating water clubs.

The program was designed in two parts so we could implement the lessons learned from the pilot phase on a larger scale during an intervention. During the pilot phase, an operator's decentralized production of sodium hypochlorite and distribution to each school were costly and unsustainable in the long run. Nevertheless, this phase was essential to understand the following points:

1. The pilot phase shed light on the threshold of chlorinated water acceptance, as communities not used to drinking chlorinated water may associate it with poor taste (Pickering *et al.* 2019). Furthermore, as it is the primary determinant affecting the adherence to a given water source, the pilot study was an attempt to observe if children would drink chlorinated water at the concentration practiced in the schools.
2. The pilot phase also helped us understand the missing details during WT and storage in the schools. Therefore, leading to changes in the size of storage containers to ensure water availability to all students and setting a production schedule to guarantee the daily availability of disinfectant.
3. The pilot phase allowed the community to incorporate the technology, the operation of electro-chlorinators, and the treatment of water, thus ensuring consistent delivery of WASH intervention. Indeed, it is not uncommon in this kind of program that the chosen technology is unsuitable for the local conditions, making operation and monitoring difficult. During the pilot study, it was possible to understand the local needs. The student's water club, teacher's manual, and the training provided in each school were an adaptation to create community engagement in the changing process and adoption of the new technology.
4. Finally, the local authorities' engagement contributed largely to the program's success. The local health center staff and local education authorities, CISCO, were essential to the program's success. The pilot phase was a liaison process.

Borehole water is considered to be of better quality than water from other sources, like rainwater or surface water (Johnson *et al.* 2016); however, in this program, preference was given to recovery tanks (rainwater collection) to mitigate the salinity of groundwater infiltrated by the proximity of the ocean. Because of the school's closeness to the sea, the water in the wells was brackish. The cost of a drilling rig (5,000 euros for drilling with installation) is superior to that of a rainwater collector (800 euros). The rig must be transported from Tamatave to Sainte-Marie by boat and fuel is required. Therefore, digging a well over 20 m was logistically impossible.

One must be cautious when interpreting the results of decrease in diarrhea through the years. A COVID outbreak happened during the program and results could have been impacted by other programs, even if the schools reported that it was not the case as they did not participate in any other program during this period. That said, awareness regarding handwashing to block virus transmission might have encouraged this habit in the community. Interestingly, the trend was not observed in the 'control' health center, located over 10 km away from 75% of schools in the WASH program and assisting a population with better financial means. Migele *et al.* (2007) used a similar approach to ours in Kenyan schools, collecting reports in nearby clinics. These authors observed a 46% drop in diarrhea cases among children after 1 year. In that Kenyan study, the yearly costs per pupil, of USD 4.80 were higher than what was spent in our Madagascar program, because chlorine is not locally produced and their program requires operating support (Migele *et al.* 2007). A relatively recent meta-analysis of the costing and financing of WASH in schools underlines the difficulties in budgeting and its vast variation by geographic area, local context, and project needs (McGinnis *et al.* 2017). The calculation of the cost per pupil does not favor small schools like the ones found on Sainte-Marie Island. Some of the expenses for an immense establishment are the same as the ones needed for a small one. Attention must be made when comparing WASH programs in different geographic locations. Difficulties in acquiring the equipment necessary for the chlorination process might play a significant role in the program's execution, as observed while working on an island where everything was costly and out of reach. Financing is crucial. Usually, local communities and authorities would not have the possibility of providing the upfront payment without NGO support, as reported in many other countries (Scanlon *et al.* 2016). However, in our case study, the design and operation were jointly conceived between CISCO and the local authorities. Most importantly, the program was incorporated by CISCO into the school curriculum after implementation and we believe this improves the likelihood of sustainability.

Although our study was not blinded and potentially open to some form of reporting bias, diarrhea incidence rates extracted from a hospital file should not be at risk of reporting bias, as is the case with self-reported diarrhea (Najnin *et al.* 2019).

The program's exit strategy is that the population who will not have access to the chlorinated water network is ready to buy chlorine tablets already available in small shops, as observed in other programs (Felix *et al.* 2022). At the community level, the Island's Leading Urban Water Distributor (JIRAMA), three rural water supply networks, and five health centers will be equipped with electro-chlorinators to produce chlorine for WT and disinfection needs. The challenges and adaptations of this implementation will be the subject of a further impact study.

5. LIMITATIONS OF THE STUDY

The implementing NGO took into consideration the available funds and the island's specific geography to better tailor the program. This took place incrementally and therefore the program was not uniformly launched, which caused some difficulties in the analysis. The COVID outbreak could have influenced behavior and access to sanitation, leading to health changes beyond our control.

6. CONCLUSIONS AND IMPLICATIONS FOR THE FUTURE

There appears to be an association between a decrease in diarrhea cases and the program's implementation. The formulae used in the schools – local sodium hypochlorite production alongside training on WT and hand hygiene – can be replicated. On-site chlorination may be a valuable interim solution for reducing the incidence of diarrheal diseases until potable water is made accessible to the community. Nevertheless, the program's success is multifactorial, depending on community engagement after an educational program, adapted technology with proper funding, and governmental support to ensure sustainability.

FUNDING

This program was jointly financed by the commune of Bernex and the Antenna Foundation, Switzerland; the Association GHIMAO, France. Madagascar's Ministries of Education and Health have made their staff and infrastructure available.

ETHICAL APPROVAL

Not applicable. Diarrhea incidence was collected in the health centers as part of the District Health Service Statistics Department.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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