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Performance of passive chlorination in rural Kenya

Master's thesis

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Abstract

In rural and low-income settings in the developing world, unsafe drinking water represents a significant burden on human health. Additionally, recontamination of drinking water during transport and storage is a serious problem. Chlorine can provide a residual protection to water to reduce the risk of recontamination. Many technologies have been developed to chlorinate water at point of collection, passively and without using electricity. The aim of this Master thesis was to assess the performance, from construction to operation, of three different passive chlorinators in a rural setting. The chlorinators were installed at six small water supply schemes (automated and non-automated) in the countryside of Kenya. Local suitability of fabrication, assemblage, installation, fine-tuning, and operation of the devices was assessed considering time consumption and complexity. Robustness was evaluated using the number and the type of repairs needed. Campaigns of FRC measurements at the tap were carried out to evaluate the stability of chlorine levels provided at the tap. Finally, FRC and faecal contamination in clean and unclean jerrycans were analysed after 30 min and 24 h storage to investigate the difference in chlorine decay for various jerrycans. Jerrycans were classified via biofilm colonisation. The AkvoTur and the T-chlorinator were best suited to the rural context of Kenya. They were fabricated with locally available material; they were robust and easy to operate. Between the two, the T-chlorinator showed the best robustness, whereas the AkvoTur was faster and easier to both build and put into operation. The BlueTap chlorinator was less appropriate for the local context as it was fabricated with components imported from overseas and its operation required a big effort both for the kiosk operators (doser refill) and for the service provider team (chlorine production and transport, many repairs). A consistent dosage was achieved when the FRC readings at the tap were in the interval $\text{mean}_{FRCreadings} \pm 0.5$ mg/l, which was specific to each site. Dosage consistency (DC) was defined as the probability of achieving a consistent dosage. The BlueTap chlorinator had the best performance (DC = 88%), followed by the AkvoTur (DC = 69%), and the T-chlorinator (DC = 63%). After 24 h storage in jerrycans, water with low turbidity (< 10 NTU) and initial FRC ≥ 1.5 mg/l was protected from *E. coli* recontamination 50% of the time. Protection decreased with higher water turbidity and lower FRC dosage. In addition, an FRC residual ≥ 0.2 mg/l after 24 h storage protected the jerrycans from recontamination 50% of the time. These outcomes suggest that both adequate chlorine dosage and sufficient FRC residual after 24 h reduce the risk of faecal contamination in water stored in jerrycans. Yet, it is not a guarantee to comply with the WHO guidelines which aim at water free from *E. coli*. In fact, the water analysed was generally turbid and we found that 33% of the jerrycans with concentration ≥ 0.5 mg/l after 24 h storage still contained *E. coli*. Therefore, water quality improvement interventions such as turbidity treatment were suggested to both decrease chlorine demand of water and increase chlorination effectiveness. The findings of the study showed that the installation of inline chlorinators could help broaden access to safer water in the studied area. However, a major challenge for the two highlighted chlorinators (T-chlorinator and AkvoTur) is the local supply of TCCA tablets that will eventually affect the scale up of the technologies.

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Acronyms

CFU Colony forming unit

CHF Swiss Franc

DC Dosage consistency

EC *Escherichia coli*

FRC Free residual chlorine

GI Galvanized iron

KES Kenyan Shilling

LDCs Least developed countries

MF Membrane filtration

NTU Nephelometric turbidity units

ORP Oxidation-reduction potential

POC Point-of-collection

POU Point-of-use

SD Standard deviation

SDGs Sustainable Development Goals

TC Total coliforms

TCCA Trichloroisocyanuric acid

UN United Nations

USAID United States Agency for International Development

USD United States Dollar

WHO World Health Organisation

WQOs Water Quality Officers

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I Introduction

This introductory chapter first presents an overview of access to safe water in Least developed countries (LDCs), focusing on rural settings. Then, it describes water disinfection with chlorine.

i Background and context

In 2020, one in four people lacked safely managed drinking water. This equates to two billion people without access to water services on-site, on-demand, and free from contamination (World Health Organization, 2021). Contaminated water causes waterborne diseases, such as cholera, diarrhoea, dysentery, hepatitis A, typhoid, and polio. The World Health Organisation (WHO) estimates that 829 000 people die each year from diarrhoea, and more than half of the deaths, 485 000, are due to contaminated drinking water. Those with the greatest risk of getting sick are infants and children (World Health Organization, 2019). Unsafe drinking water still constitutes a significant burden on human health.

The 2030 Agenda for Sustainable Development adopted by the United Nations (UN) in 2015 aims to achieve 17 Sustainable Development Goals (SDGs) that address critical issues for humanity and the planet, considering the present and the future. SDG 6 focuses on clean water and sanitation, with target 6.1 addressing safely managed drinking water services to all. Unfortunately, the current rate of progress does not allow to meet the target by 2030. In fact, in five years (2015-2020), the percentage of the population with access to safe water increased from 70% to only 74%. To reach the target on time, a four-fold acceleration in the rate of progress would be necessary. LDCs need to make the biggest strides, and the greatest challenge remains reaching rural areas and poor and vulnerable populations (World Health Organization, 2021). In addition, in the context of the COVID-19 pandemic, countries have focused more on the direct health response, putting aside other commitments, as the ones regarding water. Thus, achieving the 2030 goal appears to be even harder (Ndaw, 2020). As revealed in the study conducted in 2020 by the United States Agency for International Development (USAID), in six African countries, including Kenya, about one in four people found it harder to access drinking water. The water access problem was once again higher in rural areas than in urban areas (World Health Organization, 2021). Access to safe water for all is fundamental, especially in this pandemic crises, where "COVID-19 reinforces the need for access to clean water for health" (Food and Agriculture Organization (FAO), n.d.).

Rural communities in the LDCs often don't have access to conventional centralised water facilities and extensive piping systems. This is mainly due to installation, operation, and maintenance costs which are unaffordable (Whittington et al., 2008). On-site water supply and storage at community scales are deployed to provide drinking water, as better suited for this context (Crider et al., 2018). In fact, rural and urban systems differ in terms of size, demand, institutions, and finance (Hope et al., 2020). In rural areas households choose between different water source depending on the season and the usage; they may use dug wells, handpumps, ponds, kiosks, bottled water, rainwater, or private taps (Hope et al., 2020). Still, water safety is not always guaranteed: even if water is safe for consumption at the Point-of-collection (POC), it may get recontaminated during transport and storage (Harris et al., 2013; Meierhofer et al., 2019; Opryszko et al., 2013; Wright et al., 2004). Water disinfection can help improve water quality and reduce waterborne diseases, nevertheless a suitable treatment should be selected considering the context (Whittington et al., 2008). Chlorination is the most commonly method used to disinfect drinking water, as it is inexpensive and relatively safe to use. Moreover, it consists of an effective way that provides a residual chemical disinfectant to the water and reduces the risk of pathogen regrowth (World Health Organization, 2017a). Thus, it perfectly suits rural and low-income settings, where recontamination of drinking water during transport and storage is a main problem (Harris et al., 2013; Meierhofer et al., 2019; Opryszko et al., 2013; Wright et al., 2004).

Water disinfection can occur both at community level and at household level; in other words it can be performed at POC or at Point-of-use (POU), respectively. Household water treatment requires substantial behaviour changes and its implementation turns out being challenging (Figueroa & Kincaid, 2010; Luby et al., 2008; Luoto et al., 2011; Shaheed et al., 2018). In fact, people do not easily change and adopt new habits concerning water treatment due to many reasons ranging from emotional, to practical; such as beliefs, perceived risks, knowledge, time allocation, or affordability (Figueroa & Kincaid, 2010). Thus, POC disinfection may be more suitable for rural communities in low-income settings. In fact, when water disinfection is performed at community level it does not rely on single household behaviour, thereby changing the user daily water habits isn't necessary. In addition, as the treatment serves more households at the same time, it ends up being more affordable in the long term (Pickering et al., 2015). Hence, many technologies have been developed and tested for water disinfection at POC, in particular by chlorinating water passively without electricity (Dössegger et al., 2021; Ngo & Peterson, 2018; Pickering et al., 2015; Pickering et al., 2019; Voth-Gaeddert & Schranck, 2021). It consists of a water treatment solution at community scale which, by using chlorine as disinfectant, can provide a residual protection to water from recontamination.

ii Drinking water disinfection: chlorination

Drinking water disinfection aims at deactivating or eliminating pathogens responsible of waterborne diseases. It can be a physical process, with the use of UV light or heat, or a chemical process, with the use of chlorine or ozone, for instance. As mentioned in section I.i, the convenience and performance of chlorination make it the most widely used disinfection method. Chlorine can be added to water in gaseous form as chlorine (Cl_2), in liquid form as hypochlorous acid (HOCl), or in solid form as calcium hypochlorite ($Ca(OCl)_2$), sodium dichloroisocyanurate (NaDCC) (World Health Organization, 2017a), or trichloroisocyanuric acid (TCCA). However, in low-income settings the solid and liquid form are preferred for practical reasons.

Chlorine is an oxidizing agent. Prior water disinfection, it reacts with organic and inorganic matter, metals, and other compounds present in the water forming disinfection byproducts. The most common byproducts in the case of chlorination are trihalomethanes (THMs) and haloacetic acids (HAAs), that have no disinfecting activity and may pose health risks. Nevertheless, the

WHO states that "the risks to health from these byproducts are extremely small in comparison with the risks associated with inadequate disinfection", thus, "disinfection should not be compromised in attempting to control disinfection byproducts" (World Health Organization, 2017a).

The raw water quality directly affects the chlorine dosage needed to oxidise the interfering compounds and to ensure a sufficient residual to deactivate pathogens. In fact, the more interfering compounds are present, the more chlorine will be consumed to oxidise them. The chlorine required to oxidise these impurities is known as chlorine demand. The chlorine left after chlorine demand of water has been met is called total chlorine residual which is the sum of Free residual chlorine (FRC) and combined chlorine (Figure 1).

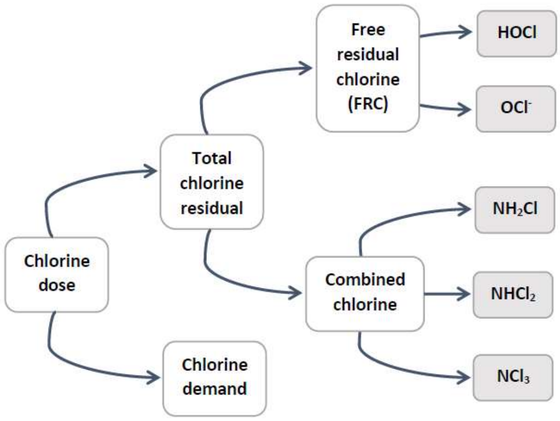

Figure 1: *Chlorine classification diagram.*

FRC is mainly responsible for water disinfection. With a sufficient dose and contact time, it is effective in killing bacteria and most of the viruses, but less effective with protozoa inactivation (World Health Organization, 2019). FRC consists of two disinfecting agents formed when chlorine gets in contact with water: hypochlorous acid (HOCl) and hypochlorite ions (OCl^-). Chlorine speciation in the two forms depends on pH and less considerably on temperature. At 20°C and pH 7.6 the two species are equally present; at a lower pH values hypochlorite ions dominate, whereas at a higher pH values hypochlorous acid is the most present. Considering that hypochlorous acid is a more powerful bactericide, as it has a higher oxidation potential, it is important to keep the water pH around 7 or lower (Brandt et al., 2017; Crittenden et al., 2012).

In addition to FRC, **combined chlorine** also participates in water disinfection, nonetheless it is less effective given its lower oxidation potential. Combined chlorine is produced through the reaction of chlorine with ammonia. The species formed are called chloramines and can be composed of one, two, or three chlorine elements, known as monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3), respectively.

For chlorine dosage, chlorine demand of the water, of the transport and storage container, and chlorine residual should be considered. The latter is key to allow water disinfection during transport and storage. The WHO recommends to dose FRC at 2 mg/l at the tap for clear water (Nephelometric turbidity units (NTU) < 10). For turbid water (NTU > 10), dosage should be doubled. This, should allow a FRC concentration in the range of 0.2 to 0.5 mg/l as a residual at the POU (World Health Organization, 2017a). However, dosage is dependent on the local context. For example, Gärtner et al., 2021 suggest that 2 mg/l dosage at POC is insufficient to prevent *E. coli* recontamination in uncleaned jerrycans after 24 h storage. Chlorination effectiveness depends also on the contact time with water. For water temperatures above 18°C a contact time of at least 30 min is needed. For colder water, contact time should be increased (World Health Organization, 2017a).

As previously described, chlorination has the great advantage to allow water disinfection in a simple and affordable way. Nevertheless, it has also some drawbacks. The most relevant one is represented by the community acceptability due to odour and taste change. Health-based guideline value for chlorine is 5 mg/l which is much higher compared to the taste threshold recorded by the WHO (World Health Organization, 2017a). In fact, levels as low as 0.3 mg/l of chlorine can be perceived by individuals (World Health Organization, 2017a). It is therefore necessary to find a good balance for chlorine dosage that on one hand, is effective in killing pathogens, but on the other hand does not prevent people from drinking the treated water due to its unpleasant taste and smell (Crider et al., 2018; Mitro et al., 2019; Smith et al., 2021). Moreover, if biofilm and algal growth are present in the water containers, chlorine is not effective at reducing algal odours, on the contrary, it may make the smell and taste even worse (Crittenden et al., 2012). Other disadvantages of chlorine are its relatively low protection against protozoa, lower effectiveness in turbid waters, and potential long-terms effects due to chlorination by-products (Centers for Disease Control and Prevention, 2019).

II Aims and objectives

The Swiss Federal Institute of Aquatic Science and Technology (Eawag) in collaboration with Oxford University and the Kenyan partner organisation FundiFix were conducting a study on passive chlorination in rural Kenya. The study aimed to monitor three different chlorinators installed in water supply systems for at least one year. The goal was to capture implications of seasonality, intermittent supply and varying user patterns over the course of the study.

For this Master's thesis, I was involved in the preliminary phase of the project: construct, install and fine tune the chlorinators, and collect data to monitor the performance of the devices as well as the water quality improvement in water storage containers.

i Research questions

The research questions tackled address the technical performance of the three different passive chlorinators under "real world" conditions. They are listed below.

a. How well are the fabrication, assemblage, installation, and operation of the different passive chlorinators adapted to the local context?

b. How robust are the different passive chlorinators to resist the conditions in rural settings?

c. How consistent is the chlorine dosing of the different passive chlorinators in supply schemes with intermittent operation?

d. Does the residual chlorine protect water stored for 24 h in cleaned or uncleaned jerrycans from recontamination?

III Materials and methods

This section presents details of the materials and methods employed for the study. First, passive chlorinators and chlorine types are described. Then, the study setting and selected sites are introduced. Next, the considered parameters, instruments, and techniques are outlined. Finally, the fieldwork organisation and data analysis are presented.

i Chlorine dispensers and chlorine

i.i Passive chlorinators

Three types of chlorination devices were studied. All of them were passive water-powered chlorinators. This means that chlorine was dispensed automatically (passively) driven by the moving water and not by electricity, for instance. Each type of chlorinator was tested in double, at two distinct sites. In total, six chlorinators were installed at six different sites: two AkvoTur, two T-chlorinators, and two BlueTap chlorinators.

- T-chlorinator

The T-chlorinator, an airtight device adapted from Orner et al., 2017, consisted of an upside down T-piece in which a chlorine containing cylinder was placed (Figure 2). The cylinder could not rotate and had holes in the direction of flow so that water could pass through the cylinder and erode the chlorine tablets. Depending on the number, arrangement, and dimension of holes, as well as the number of tablets in the cylinder, chlorine dosage could be adjusted. The device was made of PVC pipes and PVC fittings and was installed inline, inside the kiosks. The chlorinator worked with slowly dissolving chlorine tablets.

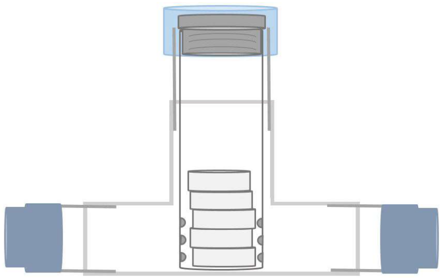

Figure 2: *T-chlorinator.*

The construction and dosage manual is provided in Appendix I.

- AkvoTur

The AkvoTur consisted of a closable, non-airtight vessel in which a PVC cylinder was placed vertically on a PVC plate (Figure 3). The cylinder had two vertical and opposite slits allowing the water to erode the chlorine tablets sitting inside the cylinder. The dosage could be adjusted by turning the cylinder: highest dosage occurred with the slits in the direction of flow while lowest dosage occurred with the slits at 90° to the flow direction. Dosage could also be adjusted by varying the number of

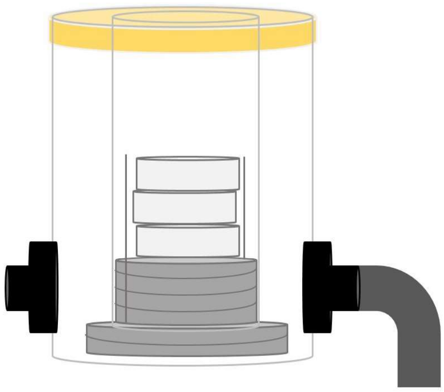

Figure 3: *AkvoTur chlorinator.*

chlorine tablets in the cylinder. The device was made of PVC pipes, PVC fittings, and a PVC vessel. It was installed endline, attached to the tap. The chlorinator worked with slowly dissolving chlorine tablets.

The construction and dosage manual is provided in Appendix II.

- BlueTap chlorinator

The BlueTap chlorinator was developed by the British start-up and social enterprise BlueTap. Liquid chlorine was dosed according to the Venturi effect. As the water passed through a pipe constriction, its velocity increased and its static pressure decreased. This under-pressure allowed the chlorine solution to be suctioned into the water stream from the chlorine reservoir.

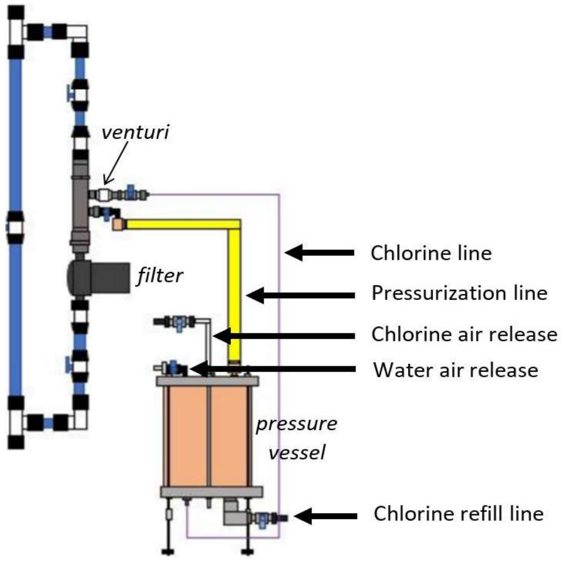

Figure 4: *BlueTap chlorinator.*

Figure 4 shows a scheme of the BlueTap chlorinator installed on a bypass. The pressure vessel had two chambers: a flexible chlorine-containing bag placed in the centre, and an outside part which filled up with water. When the bypass was on, water passed through the pressurisation line and filled the outside part of the cylinder squeezing the chlorine containing bag. Chlorine came out from the bottom of the cylinder through a microtubing (chlorine line). When passing through the pipe constriction of the venturi, chlorine was suctioned into the water stream. The chlorine refill line on the bottom of the pressure vessel allowed the chlorine bag to be refilled with the chlorine solution. Whereas the two valves on the top of the vessel (chlorine air release and water air release) were both for releasing air when it got trapped. To fine-tune the doser, the microtubing length and the chlorine stock concentration could be adjusted. The general rule was that, for the same chlorine stock concentration, in order to increase the dose by 10%, the microtubing should be cut of half a meter. Whereas to decrease the dose, the microtubing should be completely replaced; each half meter extra decreased the dose by around 10%. If a dramatically lower dose was needed, a microtubing with a lower diameter should be used.

The chlorinator was installed inline outside the kiosk, on the water pipe to the tank. Thus, 30 min chlorine disinfection contact time was ensured and this allowed to directly consume water at the tap. In principle, the device could also have been installed inside the kiosk.

The assemblage manual is provided in Appendix III and the refill and dosage manual in Appendix IV.

i.ii Type of chlorine

The AkvoTur and T-chlorinator used 1 inch (1") slowly dissolving chlorine tablets (Trichloroisocyanuric acid (TCCA) 90% tablets) suitable for drinking water. The tablets were available in

Nairobi early 2021, unfortunately they went out of stock during the first weeks of the field study (September 2021). Some trials were performed using calcium hypochlorite ($Ca(OCl)_2$) tablets instead, which unluckily lead to unpromising results, as later discussed. Eventually, Water Mission Kenya, a nonprofit organisation also working with passive chlorinators, was able to provide us with 3 inches (3") TCCA 90% tablets. The size of the tablets was later adjusted to fit the chlorine cylinder.

The BlueTap chlorinator dosed liquid chlorine, i.e. sodium hypochlorite (NaOCl). The Wata® technology was used to produce chlorine in situ.

- Trichloroisocyanuric acid (TCCA, $C_3Cl_3N_3O_3$) 90%

Trichloroisocyanuric acid (TCCA, $C_3Cl_3N_3O_3$) is a stable source of chlorine to disinfect water (World Health Organization, 2017a) and can be found in the form of white crystalline powder or tablet. When in contact with water it liberates free chlorine and cyanuric acid ($C_3H_3N_3O_3$), as shown by the following equation. Cyanuric acid is the carrier allowing chlorine to be in a solid and stable form (Clasen & Edmondson, 2006) and that eventually helps release chlorine gradually.

$$C_3Cl_3N_3O_3 + 3\,H_2O \longrightarrow 3\,HOCl + C_3H_3N_3O_3$$

The tablets used (ACL® 90 Plus by the company OxyChem) had high chlorine content, i.e. 90%, and were certified by the U.S. Environmental Protection Agency for use in drinking water (Occidental Chemical Corporation, 2012).

- Calcium hypochlorite ($Ca(OCl)_2$)

Calcium hypochlorite is found in solid form, as granules or tablets with different chlorine concentration. It readily dissolves into water producing a cloudy water (Occidental Chemical Corporation, 2012). When in contact with water it liberates free chlorine as shown by the following reaction.

$$Ca(OCl)_2 + 2\,H_2O \longrightarrow 2\,HOCl + Ca^{2+} + 2\,OH^-$$

- Sodium hypochlorite (NaOCl)

Sodium hypochlorite (NaOCl) is a liquid form of chlorine commonly known as bleach.

During fieldwork, sodium hypochlorite was produced in the lab using the Wata® machine. The Wata® technology allowed liquid chlorine to be produced locally by only using salt, water, and electricity (Wata™, n.d.-c). Chlorine was generated via electrolysis of a saline solution. When direct current passes through a sodium chloride solution, chlorine (Cl_2) and hydrogen (H_2) are produced at the anode and at the cathode, respectively. In a fully mixed cell, sodium hypochlorite (Na^+OCl^-) is eventually formed, as showed by the following reactions (Brandt et al., 2017).

$$\textit{At the anode}: \quad 2\,Cl^- \longrightarrow Cl_2 + 2\,e^-$$
$$\textit{At the cathode}: \quad 2\,H_2O + 2\,e^- \longrightarrow 2\,OH^- + H_2$$
$$\textit{On mixing}: \quad 2\,Na^+ + 2\,OH^- + Cl_2 \longrightarrow Na^+OCl^- + Na^+Cl + H_2O$$

A 25 g/l sodium chloride solution was prepared with clear water (turbidity < 5 NTU). The Wata® device was immersed in the solution and connected to an adequate electricity source. Two devices were used: WATA-Plus® and Maxi-WATA®. In around 4 h they were able to produce 15 l and 60 l of a 5 g/l chlorine solution, respectively. By adjusting the current through the solution and the time the machine was on, the chlorine concentration could be modified. Bicarbonate was used to increase the pH of the sodium hypochlorite solution and stabilise it.

ii Study site: water supply systems in Mwingi North Sub-County, Kitui County, Kenya

ii.i Study context

The study was conducted during October, November, and December 2021 in a rural area of Kenya, Mwingi North Sub-County, in Kitui county (Figure 5). The Sub-County had a semi-arid climate experiencing increasingly severe dry periods and extremely variable rainfall (Hope et al., 2015). Rainy season usually started early October and it could last until the end of December. During fieldwork, it only started late November and ended late December. Poverty in the region was high: two out of three households were classified as poor (Hope et al., 2015). The population lived mainly on agro-pastoralism and rain-fed agriculture. More than half of the population (54%) used unimproved water sources such as dams and shallow wells (Hope et al., 2014). Improved water sources were available. However, to shorten the journey to and from the water point, to avoid paying the water fee, or due to high water salinity, people still switched to unimproved alternatives (dug wells) when possible, for instance during rainy season (REACH, 2015; Nyaga, 2019; FundiFix Water Quality Officers (WQOs), personal communication, December 2021).

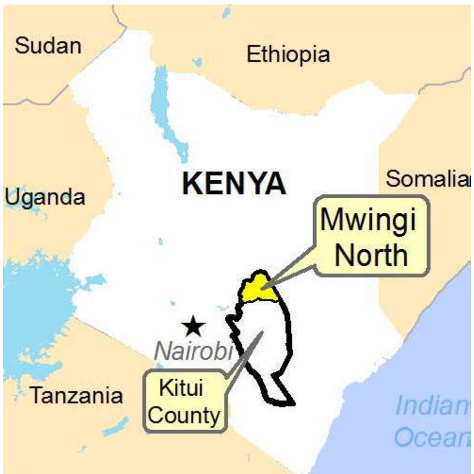

Figure 5: *Map of Kenya showing Kitui County and Mwingi North Sub-County (Nyaga, 2019).*

ii.ii FundiFix Limited

The study team partnered with FundiFix, a Kenyan-owned and registered social enterprise based in two counties: Kitui and Kwale. FundiFix supported "rural communities, schools, health facilities, institutions and governments at large in sustainably maintaining water supply infrastructure through offering professional installations, preventative maintenance services, high quality spares and repairs of rural water supply systems" (FundiFix, n.d.). In Kitui county, it operated in Mwingi North sub-county (Figure 5), one of the eight sub-counties, and was based in Kyuso. It provided services to approximately 60 sites of which about one half were small piped water systems whereas the other half were handpumps. For piped systems, water users collected water at community scale water kiosks which could be equipped with automated water dispensing systems, also called water ATMs, or were managed by an operators (non-automated kiosks).

To sustainably manage its water supply infrastructures, FundiFix had a Public-Privat Partnership model based on four pillars (REACH, 2019). First, functionality of the schemes was smartly monitored by sensors, cloud computing, and a user interface. Second, the enterprise was local and professional ensuring maintenance and repair services within three to five days after a breakdown alert. Third, to assure financial sustainability of the service, funds not only came from communities, but also from grants based on performance and obtained through proposal writing (P. Mugo, personal communication, December 2021). In fact, in the rural context, full cost recovery from communities turned out being an unrealistic scenario (Rusca and Schwartz, 2018; P. Mugo, personal communication, December 2021). And fourth, a coordination plan with institutions and all actors in the government water sector was established.

FundiFix had primarily focused on providing water access for communities. Improving water quality for communities was the company's next goal, which would also help them further expand their network and target additional funding.

ii.iii Community approval and awareness

Approval and consent of the communities to install the chlorinators was obtained by the FundiFix team. The team discussed with the different communities' chairmen and kiosk operators. People's reaction on water disinfection was generally positive (FundiFix WQOs, personal communication, October 2021).

Later, throughout the installation and testing period, the WQOs continued to inform and raise community awareness of water quality by interacting with the water users at the kiosk. In particular, they explained what the installed devices were for and shared recommendations on chlorinated water consumption. Specifically, community members were asked not to drink the water directly from the tap, but to wait 30 min to allow disinfection and reduction of chlorine taste. This, especially at the first and last flush, which were more chlorinated than the rest of the water. The kiosk operators were also asked to help further share the recommendations. Beside that, a diagram explaining chlorination was posted on the kiosks (Appendix VI).

ii.iv Site selection

Around ten supply schemes were inspected to determine which ones were suitable candidates to install the six chlorinators. The study sites were selected according to the chlorinators requirements, the water demand, the water contamination levels, and the distance from the FundiFix office in Kyuso.

Dössegger et al., 2021 found that a flow rate < 12 l/min at the tap was necessary to ensure compatibility with the AkvoTur device and avoid overflow. The two schemes with the lowest flow rate at the tap were selected for this device, i.e. Kitumbini and Mitamisyi.

The T-chlorinator was suitable for all conditions. FundiFix wanted to chlorinate the surface water of the Kyuso rock catchment, since previous analyses of the REACH program showed that the water was contaminated with faecal bacteria. The only running kiosk of the Kyuso rock catchment at the time of installation (October 2021), as well as one of the only water source in town, was the Mikwa kiosk. However, the flow rate at the kiosk could reach 80 l/min when the tank was full and turbidity could be an issue given it was surface water. On one hand, in terms of flow rate, it was an opportunity to test the performance of the T-chlorinator for higher flow rates than the ones tested by Dössegger et al., 2021. In lab trials, Dössegger et al., 2021 met a constant dosage up to 20 l/min. However, other flow rates were not tested. On the other hand, to reduce water turbidity, it was planned to install a filter. The second site for the T-chlorinator was selected based on water demand, thus water disinfection could benefit a large number of people. The Kivui kiosk was chosen.

As for the BlueTap chlorinator, the sites were primarily selected according to water demand, presence of a kiosk operator and distance from the office. The frequency of chlorine refilling by the kiosk operator and the transport distance of the chlorine solution wanted to be minimised. Hence, kiosks with low water demand and near the office were targeted. Moreover, the following technical requirements for the chlorinator were considered: minimum flow rate of 10-15 l/min and minimum pressure head of 2 m in the system. The Mumo wa Ikaaie (Mumo) and Ivonangya sites were selected as they were fulfilling the requirements, especially in terms of low water demand, compared to the other candidate sites.

Water contamination at POC was only problematic for one water supply system: the Kyuso rock catchment. Faecal contamination for the other sites was not a major problem, as previous REACH program analyses have highlighted. Overall, efforts were made to find a suitable site for all chlorinators among the ten sites visited, verifying to meet minimum chlorine device requirements and at times making some compromises.

ii.v Study sites

The T-chlorinators were installed inline, inside the kiosk at the Kyuso rock catchment and in Kivui. The AkvoTur chlorinators were installed tap-attached in Mitamisyi and Kitumbini. And the BlueTap chlorinators were installed before the tank in Mumo and Ivonyanga. A summary table with the sites characteristics is provided in Appendix V.

- Kyuso rock catchment, Mikwa kiosk - T-chlorinator

Figure 6: *Kathinge reservoir, Kyuso rock catchment.*

The Kyuso rock catchment scheme consisted of three reservoirs providing water to two kiosks and four households, the latter through private connections. The largest reservoir, Kathinge (Figure 6), could supply both kiosks (Mikwa and Mbuani) while the other two reservoirs, Kaiweti and Matingani, only supplied the Mbuani kiosk. None of the kiosks had any animal drinking trough, nevertheless, there was an earth dam near the Mbuani kiosk used only for animals. Water usually flowed from the reservoirs to the kiosks by gravity. However, for the Kathinge reservoir, if the water level was too low to reach the reservoir outlet, water needed to be pumped up to a tank (black tank on the right in Figure 6) by means of a generator. A kiosk operator was responsible to turn the pump on and off. When the Mbuani kiosk was closed, Mikwa was the nearest kiosk to Kyuso town. During dry season, the kiosk was operational from around 4am to 7pm and jerrycans were filled one after the other without interruption, except when the water was pumped.

Figure 7: *Mikwa kiosk, Kyuso rock catchment.*

At the time the chlorine devices were installed, Mikwa was the only operational kiosk, as the Kaiweti and Matingani reservoirs were drained. Thus, the T-chlorinator was installed at the Mikwa kiosk (Figure 7). Further, as the water level in the reservoir was too low (Appendix VII) for the water to flow by gravity, it was first pumped to the tank. Water turbidity at the tap was very high, reaching up to 600 NTU. Turbidity was primarily generated by resuspension of fine sediments from the bottom of the reservoir during pumping. To improve water turbidity, two

130 microns filters were installed before the chlorinator (filters are black in Figure 33). After filtration, turbidity ranged between 100 and 300 NTU. When the water was not pumped and it only flowed by gravity to the kiosk (last week of fieldwork), turbidity was around 50 NTU. Overall, turbidity fluctuations at the tap were frequent.

- Kivui, main kiosk - T-chlorinator

The scheme in Kivui consisted of a borehole serving two kiosks and a standpipe. The water was pumped to a main tank and flowed by gravity to the kiosks. The pump was solar powered and switched itself on in the morning. At around 1pm, when the tank was full, the kiosk operator switched it off. The main kiosk, where the chlorinator was installed, had one tap to fill the jerrycans and 5 m away there was a cattle trough (Figure 9). It was a water ATM powered by a solar panel installed on the kiosk roof. People used a reloadable magnetic token to fetch water. They placed it on the water ATM and their "water balance" decreased according to the amount of water collected. The kiosk operator was also responsible for loading credit on people's token using an app on the smartphone.

Figure 8: *Water ATM, Kivui.*

Figure 9: *Drinking trough, Kivui.*

- Mitamisyi - AkvoTur chlorinator

The scheme in Mitamisyi consisted of a borehole serving a single water ATM. Water was pumped into a tank located on top of the kiosk. The pump was solar powered and situated around 200 m away. The kiosk (Figure 10) had two taps: one to fill jerrycans and the other to fill the cattle drinking trough. The kiosk operator was responsible for turning the pump on and off and was on site two days a week to load credit on people's tokens.

The AkvoTur chlorinator (Figure 11) was installed before the jerrycan tap and a cage was placed around it to avoid tempering (Figure 12). The kiosk operator was responsible for refilling the chlorinator with chlorine tablets.

Figure 10: *Water kiosk without chlorinator, Mitamisyi.*

Figure 11: *AkvoTur chlorinator, Mitamisyi.*

Figure 12: *Cage for chlorinator, Mitamisyi.*

- Kitumbini - AkvoTur chlorinator

The scheme in Kitumbini consisted of a borehole serving a kiosk (Figure 13) located right next to it. The water pump and the water ATM were solar powered. Two taps were present: one at the kiosk to fill jerrycans and another one at the cattle trough which was located 20 m away. The site was guarded by a night watchman and the water users tokens were loaded by the same kiosk operator as in Kivui. The kiosk operator was in charge of being at the Mitamisyi kiosk two days a week so that the water users could reload their token. Kitumbini was around 15 min away from Kivui by motorbike.

The AkvoTur chlorinator was installed before the tap (Figure 14) and a cage was placed around it to avoid tempering. The kiosk operator was responsible for refilling the chlorinator with chlorine tablets.

Figure 13: *Water kiosk, Kitumbini.*

Figure 14: *AkvoTur chlorinator with cage, Kitumbini.*

- Mumo wa Ikaaie - BlueTap chlorinator

The scheme in Mumo wa Ikaaie, commonly called Mumo, consisted of a borehole serving a kiosk (Figure 15) located next to it. The kiosk had four taps; one of them fed a small mobile water trough via a plastic tube. The water pump was powered by a generator. The kiosk operator turned the pump on in 15 min cycles. In fact, the subsurface replenishment was very slow and it was necessary to alternate pumping cycles and pause cycles to allow the subsurface to replenish.

The BlueTap chlorinator was installed on a bypass (Figure 16) on the water line going to the tank. Figure 15 does not show the device yet; the device was later installed on the left of the kiosk on the pipe going from the ground up to the tank. In addition, a cage was installed to avoid tempering. Further, a 130 microns filter was put on the bypass just before chlorination took place (black plastic filter on the lower part of the bypass in Figure 16). The kiosk operator was responsible for refilling the chlorine doser.

Initially, just after the water was pumped in the tank, turbidity at the tap was very high (> 600 NTU). This was the result of particulate matter resuspension inside the tank. In fact, the tank was open on the top allowing the dust to enter and increase water turbidity. A deep cleaning of the tank took place few weeks after installing the device to reduce its chlorine demand. It was emptied, sediments were removed and liquid chlorine was used to disinfect the inside walls; a lid was also put to cover the tank. After the above measures, turbidity dropped drastically reaching levels around 20 NTU.

Figure 15: *Water kiosk, Mumo wa Ikaaie.*

Figure 16: *BlueTap chlorinator, Mumo wa Ikaaie.*

- Ivonyanga - BlueTap chlorinator

The Ivonyanga scheme consisted of a borehole serving a single water kiosk. The borehole was located 100 m away from the kiosk and it was solar powered. The chairman was responsible for turning on and off the pump according to the water level in the tank. The community members contacted him when needed; for instance, when there was no water in the tank anymore, or when the tank was full and it overflowed. The kiosk (Figure 17) was a water ATM with a tap for jerrycans, and a tap at the drinking trough located opposite to the kiosk. The water users loaded money on the token using mobile money (M-PESA).

The chlorinator was installed on the lower part of the pipe going to the tank. A cage was also constructed to protect the device from tempering. Having Ivonyanga a water ATM, no physical person was present on site. The chairman was asked to refill the doser. BlueTap paid him 100 Kenyan Shilling (KES) (around 0.80 Swiss Franc (CHF)) per refill.

Figure 17: *Water kiosk and tank, Ivonyanga.*

iii Parameters, instruments and techniques

Water quality was monitored by analysing FRC, Oxidation-reduction potential (ORP), pH, conductivity, turbidity and parameters for microbiological contamination *Escherichia coli* (EC)/Total coliforms (TC).

iii.i FRC

As explained in section I.ii, FRC represents the disinfection potential of water with chlorine.

FRC was measured with the *LaMotte* DC1500 Chlorine colorimeter using the *LaMotte*'s chlorine DPD #1 IG RAPID TesTabs® tablets, and with the *planetpool* pooltester using the *Water-i.d.* DPD #1 tablets. The *LaMotte* device was calibrated using three calibration samples according to the expected FRC readings; the readings of the calibration samples were around 0.2, 1, 2.5 mg/l.

For sampling, water at the tap was left running for 10 sec, a plastic cup was rinsed three times and then filled. Water from the cup was used to measure FRC, ORP, conductivity, and pH.

The FRC measurement with the *LaMotte* colorimeter was taken as follows (LaMotte, 2022). A 10 ml *LaMotte* tube was rinsed three times and then filled to the 10 ml line with the sample. The tube was wiped dry and inserted into the colorimeter chamber. A blank measure was taken. Then, without touching it, a DPD1 tablet was put into the sample tube. The latter was gently shaken for 10 s by inverting it slowly five times. The chlorine present in the water reacted with the tablet by making the water pink. The tube was wiped dry, inserted into the colorimeter chamber, and the FRC measure was taken. The analysis was performed after sample collection and in the shade, to avoid photolysis of chlorine.

The FRC measurement with the pooltester was taken as follows (PlanetPool, 2022). The pooltester was opened, rinsed three times, and filled up to the top. Then, without touching it, a DPD1 tablet was added into the chlorine compartment. The pooltester was closed and shaken vigorously until tablet dissolution. Finally, the water colour was directly compared with the scales present on the pooltester to determine the FRC concentration.

iii.ii ORP

ORP is the measure of the oxidation potential of a solution in millivolt (mV), namely of the tendency of water components to lose or gain electrons. In drinking water it is mainly governed by the presence of iron (Fe), chlorine (Cl_2), and oxygen (O_2), and in general it depends on pH and temperature as well (Copeland & Lytle, 2014). ORP can be an indicator for metallic pollution in water and it can reflect a water disinfection ability. The latter since chemical water disinfection occurs through oxidation and reduction reactions due to the presence of oxidising and reducing agents. Thus, as chlorination works through oxidation, ORP could reflect the FRC concentration in water. Nevertheless, ORP measurements are not yet widely used to monitor water quality primarily due to the absence of regulatory references (Copeland & Lytle, 2014).

ORP measurements were performed using the Redox Meter *PCE-PHD* 1-R which was calibrated by the company (PCE Instruments UK Ltd) in September.

To take the measurement, the ORP probe was rinsed three times with the sample water and placed inside the plastic cup. The measure was read once the value had stabilised.

iii.iii Conductivity and pH

Conductivity refers to the ability of water to conduct current. It is determined by the presence or absence of dissolved salts and other inorganic materials. The higher the salinity or the dissolved solids concentration, the higher the conductivity. In addition, conductivity increases with temperature since ions move more easily. Conductivity is not directly linked to health issues, but is rather a parameter indicating change. In fact, water bodies tend to have relatively stable conductivity values that can be used as term of comparison. For example, a rapid increase in conductivity may be a result of water pollution. A higher value of conductivity is expected after chlorination, as chlorine ions participate to current conduction (US EPA, 2013).

pH measures how basic/acidic a water is and it is determined by the concentration of H^+ ions. It's important to monitor water pH as it affects chlorination efficiency. A more efficient water disinfection takes place at low pH, as the proportion of hypochlorous acid (HOCl) is higher. In fact, hypochlorous acid is a stronger disinfectant compared to hypochlorite ions (OCl^-) (Crittenden et al., 2012).

Conductivity and pH measurement were performed using the *HannaInstruments* HI9813-6 Multiparameter pH/EC/TDS/°C. The device was calibrated monthly. The multiprobe was rinsed three times with the sample water and placed inside the plastic cup to take the measurement. The measure was read once the value had stabilised.

iii.iv Turbidity

Turbidity refers to the cloudiness of a water caused by suspended particles, such as clay, silts, plant debris and organisms. It is expressed as nephelometric turbidity units (NTU). Water turbidity $\geq$ 4 NTU is visible and can have aesthetic implications by affecting the acceptability of drinking water (World Health Organization, 2017b). Turbid water can also indicate the presence of pathogens as they can be attached to particles and hide, hindering water disinfection. In addition, turbidity increases the chlorine demand of the water (World Health Organization, 2017b).

ORP measurements were performed using the *HannaInstruments* HI-93703 Portable Turbidity Meter.

To take the measurement, a 10 ml *HannaInstruments* tube was rinsed three times and then filled to the 10 ml line with the sample. The tube was wiped dry and inserted into the turbidimeter chamber to take the measurement.

iii.v *E. coli* (EC) / Total coliform (TC)

EC and TC are used as indicator to assess microbial water quality. TCs are a large group of related bacteria commonly found in human or animal waste, soil and vegetation. Faecal coliforms are a subgroup of TC and are found in the intestinal flora of animals and humans. EC represents the major specie of faecal bacteria. As it is the only species of the group not being able to grow and reproduce in the environment, it appears to be the best indicator of faecal pollution and eventual presence of pathogens (New York State Department of Health, 2017).

The sampling was performed as follows. Sterile Whirl-Pak® Thio-Bags containing a sodium thiosulfate tablet were used. Sodium thiosulfate neutralises chlorine allowing to freeze the number of bacteria at the time of collection. At the study site, the tap outlet was sterilised using a cotton with ethanol. Water was left running for 10 s and sampling bags were filled up to 100 ml directly from the tap. The sample bags were shaken to dissolve the thiosulfate tablet and then put in a coolbox with ice packs. Once back to the office, the samples bags were put in the lab fridge. Samples were analysed within 7 h. In the lab, the water contained in the jerrycans was carefully poured into the sampling bags, put in the fridge, and directly analysed for EC/TC. Before sample collection, hands were disinfected. Samples were processed using the

Membrane filtration (MF) technique (Meierhofer and Sherestha, 2020). A filtration equipment was sterilised using methanol and a flame. A sterile 45 μ filter was placed on the filtration unit, 100 ml of the sample were passed through the filter using a small hand pump. For water with turbidity between 50 and 100 NTU, 50 ml of the sample were processed; for more turbid water (> 100 NTU), only 10 ml of the sample were processed. In fact, filtering turbid water (> 50 NTU) could easily clog the filter, making sample processing time consuming. The agar plate was hydrated with 1 ml of water which was previously boiled (L. Bouman, personal communication, November 2021). The filter was then carefully put on the agar plate with a sterilised forceps. Finally, the samples were placed into an incubator for 24 $\pm$ 2 h and the incubator temperature was set at 35 $\pm$ 0.5 °C ("Compact Dry EC (en)", n.d.). Colonies were counted after incubation. Visible colonies were counted as bacterial Colony forming unit (CFU) and expressed as CFUs per 100 ml. Blue colonies corresponded to EC, purple colonies to Coliforms. Total number of coliform bacteria (TC) were obtained by summing the purple colonies with the blue ones.

For quality check, a lab blank of water previously boiled and a duplicate sample were analysed daily, approximately every ten samples.

iv Study design

Fieldwork in Kyuso lasted 11 weeks. The following on-site activities were carried out: (A) fabrication, assemblage, installation, and fine-tuning of chlorinators, (B) monitoring of microbiological quality of source water (before and after chlorination) and of water in jerrycans (FRC and *E. coli*), (C) intensive, and (D) extensive FRC monitoring at the tap. The initial timetable (Table 1 above) could not be respected as installation of the chlorinators took longer than expected due to unavailability of slowly dissolving chlorine tablets. The schedule was adjusted as shown in Table 1 below. An additional two weeks were required to install the devices, thus monitoring intensity was reduced to two campaigns instead of four. Moreover, two additional series of water quality monitoring in jerrycans were conducted during the two weeks of extensive FRC monitoring at the tap so as to have a larger data sample.

	12-16.10	18-23.10	25.10-29.11	1-6.11	8-13.11	15-19.11	22-26.11	29.11-3.12	6-11.12	13-17.12
A										
B										
C					1st camp.			2nd camp.		
D						1st camp.	2nd camp.		3rd camp.	4th camp.

A										
B										
C							1st camp.		2nd camp.	
D								1st camp.		2nd camp.

Table 1: *Fieldwork schedule. Initial schedule (above) and actual schedule (below).*

iv.i Fabrication, assemblage, and installation of chlorinators

The AkvoTur and T-chlorinators were assembled with locally available material. They were fabricated in PVC using pipes of different dimensions, various types of fittings, and PVC cement. The BlueTap chlorinator components were brought from the UK by the chief operating officer of BlueTap, who helped with the assemblage, installation and fine tuning of the BlueTap chlorinators.

Installation required the help of plumbers and welders since pipes needed to be cut, rearranged, removed from the wall and cemented back in, metal cages needed to be built, etc.

The fabrication manuals for the three chlorinators are provided in Appendix I (T-chlorinator), II (AkvoTur), and III (BlueTap).

iv.ii Fine tuning of chlorinators

The chlorine dose fine-tuning was carried out once the devices were installed and there were no leakages anymore. For the T-chlorinator and the AkvoTur, FRC was measured at the tap. To analyse chlorine dosage at different moments, FRC measures were taken at three different instants: immediately after opening of the tap, during a period of water left running, and just before the tap was closed. In addition, FRC was as well measured in jerrycans filled with the first water flow after valve opening, and in jerrycans filled when the tank was getting empty. This, to determine the effect of any residual chlorinated water in the devices, and the effect of the reduced flow rate on the FRC concentration in the jerrycan, respectively. For the BlueTap chlorinator, FRC was measured directly after chlorination, i.e. at a tap installed still on the bypass, to assess the dose entering the water stream, and at the tap.

The target chlorine concentration at the tap was between 1 and 2 mg/l, aiming namely for 1.5 mg/l. However, dosing was adjusted based on community complaints and peak chlorine concentration in the jerrycans (for T-chlorinator and AkvoTur), as summarised in Appendix V.

iv.iii Monitoring of water quality at the source

Three chlorinators, one of each type, were selected for monitoring water quality at the source and in jerrycans based on distance from Kyuso. The monitoring sites were the Kyuso rock catchment for the T-chlorinator, Mitamisyi for the AkvoTur, and Mumo for the BlueTap chlorinator.

Water was monitored before and after chlorination measuring pH, conductivity, ORP, turbidity, and EC/TC. The following microbial samples were collected for each site: before and after chlorination, a double to test different dilutions (1 ml and 100 ml), and a duplicate.

iv.iv Monitoring of water quality in jerrycans

Some preliminary experiments with used jerrycans were conducted to determine the FRC decay in the jerrycans for the water coming from the different sites. The used jerrycans were filled with chlorinated water and stored for 24 h in the lab, lid closed. The goal was to define a chlorine dosage for the point of distribution for each site. Yet, the FRC measurements were conducted using some DPD1 tablets (*LaMotte* DPD #1 BF RD) which gave inconsistent concentration values.

In particular, the FRC readings of deionised water were around 0.2 mg/l, although they were expected to be 0 mg/l. Some FRC readings performed with these DPD1 tablets were compared with readings performed with other tablets, the DPD #1 IG: the readings for the two tablets were discrepant. No pattern and no systematic error were highlighted. The results of the preliminary jerrycan experiments were thus discarded. The tablets which were eventually used for the rest of the study were the DPD #1 IG which had consistent readings for deionised water and chlorine solutions. Subsequent communication with the *LaMotte* sales team confirmed the compatibility of the tablets with the *LaMotte* device by emphasising the fact that the tablets had to be really well crushed before using them (Sale LaMotte Europe, personal communication, January 2021). Potentially, the tablets were not crushed well enough.

In the different sites the duration of water storage in the jerrycans was also investigated; approximately twenty households were consulted. Water users stated that they stored their jerrycans between one to two days.

In addition to the monitoring of water quality at the source, faecal bacteria, FRC, and ORP decay were monitored in ten 20 l jerrycans over 24 h. Ten jerrycans were bought locally. They were empty vegetable oil canisters usually reused as water storage and transport containers. They were cleaned by the cleaning lady of FundiFix using leaves, soap, and chlorinated water to remove the oil residuals (Figure 18). Some leaves along with around 2 l of water mixed with soap were put in the jerrycans. The jerrycan were afterwords closed with the lid and shaken for around 30 s. Then, they were rinsed with water. Two rounds of washing were performed. Thereafter, I rinsed the jerrycans personally with chlorinated water by shaking them. The chlorinated water used had a chlorine concentration of around 2 mg/l, as one Aquatabs® tablet was dissolved in 20 l of water (Clasen & Edmondson, 2006). Three of the ten cleaned jerrycans were used for the experiments. The other seven were exchanged with used jerrycans obtained at the water kiosk in Kyuso. Finally, water parameters were monitored in three cleaned jerrycans and in seven used jerrycans recuperated from households. They will be referred to as "clean" and "uncleaned" jerrycans, respectively.

Figure 18: *Cleaning lady cleaning the jerrycans with green leaves, soap, and water.*

In total, five series of experiments were conducted with the same set of ten jerrycans: twice with water deriving from the Kyuso rock catchment, twice with water from Mitamisyi and once with water from Mumo. The chronological order of the experiments according to the site was as follows: Kyuso rock catchment, Mumo, Mitamisyi (all of them during the third week of November), Mitamisyi (last week of November), and Kyuso rock catchment (second week of December) (Table 1).

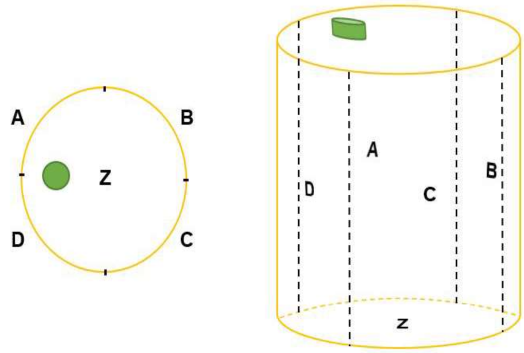

Figure 19: *Jerrycan showing the five areas for biofilm colonisation evaluation. Top view (left) and lateral view (right).*

Biofilm colonisation of the ten jerrycans was evaluated before the experiments. Biofilms are bacterial communities living attached to a surface within an extracellular matrix that provides food and protection (Wilson et al., 2017). As many studies have shown, including Gärtner et al., 2021, biofilm in uncleaned jerrycans consume FRC and can release microorganisms. The chlorine demand of the containers and the risk of water recontamination are therefore higher. Chlorine consumption and water recontamination in clean versus uncleaned jerrycans had already been investigated previously. We wanted to include the degree of cleanliness of the jerrycans in the analysis. This, to study the influence of a larger or smaller biofilm presence on chlorine decay and water quality in the jerrycans. Quantification of biofilm in jerrycans can be evaluated using more or less complex lab methods, however most of them include the destruction of the container. The literature does not present any methods that can be performed on the field in an easy way. Here, it was attempted to quantify biofilm in jerrycans evaluating the biofilm's inner surface coverage and biofilm's colour intensity. It was assumed that the greater the surface coverage of the biofilm, the greater the contact surface with water which can consume FRC and can release microorganisms. Further, biofilm colour was considered as proxy for the biofilm thickness, which is relevant in terms of microbial community presence. A thicker biofilm might accommodate more bacteria and, if, for instance, the upper layer is degraded by chlorine, other bacteria could be present in the underneath layer. The surface coverage and thickness evaluation were done visually. Five inner parts of the jerrycan were considered (Figure 19): the bottom (Z) and four longitudinal lateral zones (A, B, C, and D). A surface score and a colour score was attributed to each of these areas. The surface score indicated the biofilm surface coverage in percentage: a maximum score of 100% was attributed when the entire inner zone was covered by biofilm, while minimum score of 0% was attributed when there was no biofilm. As to the colour score, the difference between dark colour (light barely passed through the jerrycan walls), and light colour (light passed through the jerrycan walls easily) was considered. The colour score was used as weighting factor. If the biofilm was dark green, the weighting factor was set to 1. Otherwise, if the biofilm was light green, the weighting factor was set to 0.5. For all five areas a weighted surface score was calculated. By averaging these scores, a final score was attributed to the jerrycan. Finally, the jerrycans were divided into groups according to their biofilm colonisation score. Four classification approaches were considered, α, β, γ, and δ, as shown in Table 2. At the study sites, jerrycans were filled up, transported to the office and stored in the lab for the period of the experiments, lid closed. Water was tested for EC/TC, FRC, and ORP just after collection, as well as 30 min, 12 h, 24 h, and, few times, 48 h after collection.

classification	groups			
α	0 % (clean)	]0, 100] % (uncleaned)		
β	[0, 50] %	]50, 100] %		
γ	0 %	]0, 50] %	]50, 100] %	
δ	0 %	]0, 50] %	[50, 75] %	[75, 100] %

Table 2: *Classification of jerrycans into groups according to biofilm colonisation score. Four classification approaches are presented: α, β, γ, and δ.*

iv.v Intensive and extensive FRC monitoring

For the intensive FRC monitoring, chlorine dosage consistency at the tap was monitored over the course of a day. Two intensive monitoring campaigns were conducted per site. They were interspersed with a period of extensive monitoring (Table 1). Both FRC and ORP were measured. 17 measurements were taken over the course of seven hours: the first 12 measurements were taken at 30 min intervals and the remaining 5 at 15 min intervals. The initial plan was to take all 17 measurements at 30 min intervals, however, the first site visited for intensive monitoring (Kyuso rock catchment) had been closed before all samples were taken. Thus, for the last five measurements a smaller interval was considered. FRC was measured using both the *LaMotte* colorimeter and the pooltester.

For the extensive FRC monitoring, FRC and ORP were measured at the tap once a week for all six sites. Two extensive monitoring campaigns were conducted per site. FRC measurements were taken by myself using the *LaMotte* colorimeter and by the WQOs using the pooltester. In addition to this, FRC monitoring was performed once a day by the kiosk operator using the pooltester. As a reminder, a FundiFix staff called the operators, and an SMS was sent to them daily. The kiosk operators were trained on how to take the measurements. In case of need, an illustrated step-by-step explanation on how to conduct the test was provided on the pooltester box (Appendix VIII).

Dosage consistency was assessed by considering only the FRC measurements performed with the digital *LaMotte* instrument. The dosage was consistent if the reading at the tap was in the interval $mean_{FRCreadings} \pm 0.5$ mg/l.

v Data analysis

Data analysis was performed using Excel and R-studio. Central tendencies were assessed calculating descriptive statistics. Normality was tested using Shapiro-Wilk's test and checked visually with a Q-Q plot. Normality was tested for: FRC and ORP measurement at the tap, FRC concentration and *E.coli* number in jerrycans at filling and after 24 h of storage, and water 30 min and 24 h chlorine demand. None of the variables were normally distributed. Hence, non-parametric tests were performed. To investigate correlation, Spearman's test was applied. To test the difference of a variable between various groups, Wilcoxon test and Kruskal-Wallis test were carried out for two categories and more than two categories, respectively. A 5% level of significance was considered. For the Wilcoxon test, the effect sizes (r) of the differences between groups were calculated using the formula r = $Z/\sqrt{n}$, where Z is the z-value and n the sample size ((Tomczak & Tomczak, 2014)). For the Kruskal-Wallis test, it was calculated using the formula r = (H - k + 1)/(n - k), where H is the value obtained in the Kruskal-Wallis test, k is the number of groups, and n is the total number of observations ((Tomczak & Tomczak, 2014)). Dosage consistency (DC) was defined as the relative frequency of consistent dosage. To allow logarithmic transformation zero *E. coli* counts were considered as 0.5.

IV Results and discussion

In this chapter the results of the performance of the three passive chlorinators installed in Kenya are presented and discussed. First, chlorine measurement instruments and proxy are evaluated. Then, preparation of the different chlorine type is described. Next, an overview on each chlorine device is presented. In particular, the challenges encountered during fabrication, assemblage, installation, and fine-tuning are assessed, the operational feasibility is discussed, and the dosage consistency and device robustness are evaluated. After that, chlorine decay and microbial quality of water in jerrycans are presented and discussed. Subsequently, the handover of the devices is described focusing on operation and maintenance, chlorine supply, and FRC monitoring. Finally, the limitations of the study and the recommendations are outlined.

i Chlorine measurement instruments and proxy

This section first assesses the performance of a visual compared to a manual instrument to measure FRC. Then, it discusses the viability of using ORP measurements as FRC proxy.

i.i Digital versus visual instrument

For the FRC monitoring campaigns at the tap, chlorine was measured using both the digital *LaMotte* colorimeter and the pooltester. The latter allowed to determine the FRC concentration visually. The aim was to assess if a manual and easy to use colorimeter could sufficiently inform about chlorine concentration in water. In particular, to capture a potential chlorine overdosing so as to prevent dissatisfaction of water users and eventual health issues.

During fieldwork, the Water Quality Officers (WQOs) and kiosk operators were trained on how to use the pooltester (Figure 20). At first, they all found it tricky to interpret the results since it was necessary to visually compare the colour of the water sample, in which a DPD1 tablet was dissolved, with a colour scale. After some practice they understood the proceedings and were more comfortable with reading the results. The pooltester box provided a step-by-step explanation on how to take the measurement (Appendix VIII). The kiosk operators used it to make sure they were taking the reading correctly.

Figure 20: *Kiosk operator taking a FRC measurement using the pooltester, Mitamisyi.*

FRC readings taken with the *LaMotte* colorimeter and pooltester were significantly correlated (*rho* = 0.9, p = 0.000). Three out of four times the pooltester readings were higher than the *LaMotte* colorimeter readings (n = 147). The average deviation of the overestimated and underestimated readings of the pooltester compared to the digital readings were 0.4 mg/l (n = 110) and 0.2 mg/l (n = 37), respectively. Overall, the use of the pooltester to measure FRC gave a safety factor with respect to the measurements performed with the digital colorimeter. And despite the subjective assessment of colour, the pooltester readings were representative of the most accurate readings taken with the analytical instrument *LaMotte*.

i.ii ORP as FRC proxy

Correlation between FRC concentrations and ORP values was explored to assess the feasibility of directly using ORP sensors to monitor FRC. In fact, FRC sensors are expensive and need regular maintenance, whereas ORP sensors would be more suitable for field application (L. Bouman, personal communication, January 2021). Looking at the plotted variables in Figure 21, samples with FRC readings < 1.2 mg/l had ORP values spread over the entire ORP range. Whereas samples with FRC > 1.2 mg/l had only higher ORP values (> 550 mV). ORP measurements could be used to check for low chlorine concentration (no data in the lower right part in Figure 21). Moreover, a logarithmic model was fitted to explain the data (trendline: ORP [mV] = -693.48 + 102.37 log(FRC [mg/l]), R^2 = 0.81) and we found that the model was significant (p = 0.000). The trendline is consistent with Kim and Hensley, 1997. Nevertheless, to better understand the relationship between the two variables and find a better model, additional parameters should be as well considered, such as the presence of other oxidants, which also contribute to ORP, and the pH. The latter affects the speciation of components which may contribute more or less to the redox potential of water (Kim & Hensley, 1997).

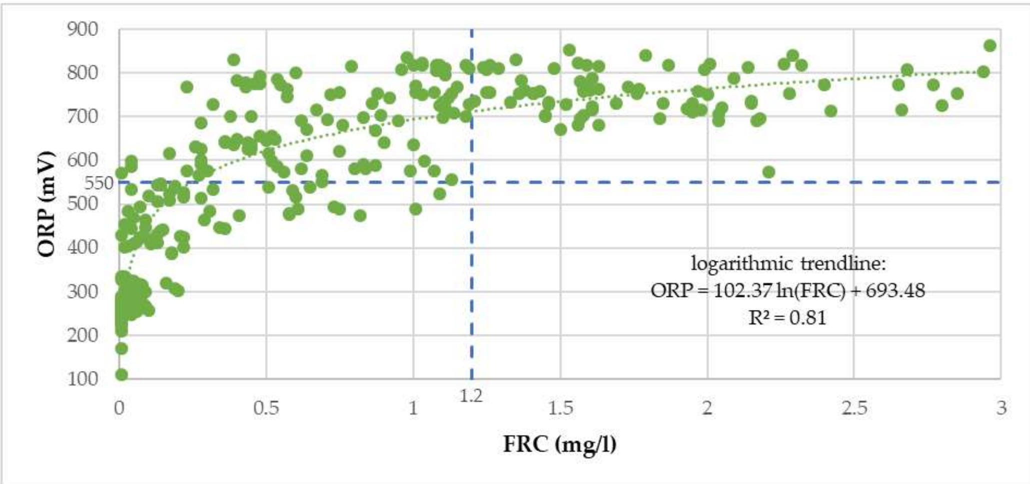

Figure 21: *Graph of FRC and ORP measurements. Dashed line: logarithmic trend line.*

ii Chlorine preparation

This section presents the challenges encountered during the preparation of the chlorine tablets and the chlorine solution.

ii.i Downsize chlorine tablets

Figure 22: *Attempt to cut 1" TCCA tablets.*

To ensure the performance of the T-chlorinator and AkvoTur chlorinator, slowly dissolving tablets were needed, as highlighted by unsuccessful trials with calcium hypochlorite tablets (section IV.iii.i). TCCA tablets were difficult to find in Kenya. The Water Mission organisation could provide these tablets, nevertheless they were 3" in diameter, meaning they could not fit into the chlorine cylinders. Thus, the size of the tablets needed to be adapted. First, it was planned to use a hole saw to obtain 1" cylindrical tablets. However, due to the friability of the tablets that was not possible (Figure 22). To avoid excessive production of chlorine dust, the tablets were resized into more or less regular shapes that fit the cylinder using a 3 mm drill bit. A couple of holes were drilled into the tablets and they were subsequently broken up by hand.

In general, it was very challenging to have tablets with the same shape. Moreover, drilling the tablets was unpleasant as it produced a lot of chlorine dust. Its smell was pungent and could be perceived even through the face mask. Having the tablets of the right size would avoid spending time in resizing the 3" tablets and prevent the contact with the irritating chlorine powder. Nevertheless, it turned out that resizing these tablets was at the time the best solution to be able to operate the chlorinators.

ii.ii On-site chlorine production.

For the BlueTap chlorinator, chlorine was produced in the lab using the Wata® machine. According to Wata™, n.d.-a, the main advantages using this technology to produce chlorine locally are (Wata™, n.d.-a): a lower supply time as the consumables (salt and water) and electricity are present on site, no need of chlorine transport, a personalised production (concentration and amount), and a lower chlorine cost (0.08 United States Dollar (USD)/l, around 0.08 CHF/l), i.e. more than eight times cheaper compared to a bleach solution with same concentration. The biggest challenge in producing chlorine during fieldwork was access to water. The FundiFix office did not have any water connection, hence, water had to be fetched from one of the kiosks around Kyuso using jerrycans. Furthermore, the Wata® machine required water with low turbidity (< 5 NTU) which was not always easy to find. If the water fetched was too turbid, it was diluted with water filtered through ceramic filters that were available in the office. It also occurred that bottled water needed to be bought from the store since no other water with low turbidity was available. In addition to water, electricity was also an issue. Since blackouts were an everyday occurrence, FundiFix had a backup battery powered by a solar panel. However, the battery could not provide the necessary power supply to the machine. Thus, chlorine production sometimes had to be delayed until the return of electricity.

iii Chlorinators

This section gives an overview from fabrication to operation of the three chlorinators. Fabrication, assembly, installation, and fine-tuning are outlined focusing on the problems encountered, the adjustments undertaken as well as the final settings. Then, the operational feasibility is discussed, and the dosage consistency and device robustness are assessed. The section is organised by chlorinator type. Finally, a comparison between devices is presented.

iii.i T-chlorinator

Fabrication and assemblage. The T-chlorinator was constructed from scratch following a prototype fabricated in the Eawag labs. Locally available materials were used. Given that some components were not obtainable, as it was the case for the PVC plates, they had to be specifically manufactured. The plate fabrication involved several steps. PVC pipes were cut (Figure 23) and, after setting a fire, heated enough to make them flexible. They were remodelled (Figure 24), reshaped into a disk form and finally glued together with PVC cement (Figure 25). Overall, due to the multiple steps it was worth preparing more disks in a batch. Another challenging part was threading the pipe to screw the lid on and make the chlorinator airtight (Figure 26). A metal threader was used since it was the only threader available. Soft PVC pipe was a better choice compared to hard PVC pipe. In fact, it was easier to start the threading process for soft PVC pipes. Nevertheless, the threads made were not deep enough for the lid to screw on. Thus, a knife and a file were carefully used to deepen the threads and be able to close the lid. The final challenge was the curved bottom of the chlorine containing cylinder (Figure 29). The curved shape was necessary to prevent the cylinder to rotate inside the upside down T-piece. The bottom part (Figure 27) had to be filed so that it fitted perfectly the cylinder (Figure 28). This required precision and patience as it consisted of an iterative process of filing and checking.

Figure 23: *Pipe pieces to remodel.*

Figure 24: *Heated pipe remodelling using a hammer.*

Figure 25: *Gluing PVC disks together to fabricate a plate.*

Figure 26: *T-chlorinator cylinder with threads (without lid), Kivui.*

Figure 27: *Bottom lid of chlorine containing cylinder, T-chlorinator.*

Figure 28: *Chlorine containing cylinder without lid, T-chlorinator.*

Figure 29: *Assembled chlorine containing cylinder, T-chlorinator.*

Installation. Two main challenges were encountered during the installation of the T-chlorinators. First, leakages at the various fittings and valves, which could require several hours to repair. Second, chlorine tablets in contact with water when water did not flow, which could lead to chlorine overdose. Figure 30 shows a diagram of the water supply scheme in Kivui after the installation of the chlorinator. From the ATM, water could flow either to the drinking trough or to the chlorination system. The water user could choose which tap to use by opening and closing the desired valve outside the kiosk. The valve for the jerrycan tap was placed before the entire chlorination system to prevent water from remaining in the chlorinator when it was not fetched or when the drinking trough was in use. In addition, the chlorinator system was placed at a slight slope to allow water to flow to the tap by gravity after the valve was closed (Figure 32). Furthermore, the chlorinator was installed on a bypass to isolate it in case of a problem and to allow chlorine to be refilled without interfering with water collection. Figure 31 shows the chlorination system inside the kiosk; water flowed to the ATM using the vertical pipe on the left of the figure. At the Kyuso rock catchment, the kiosk operators were responsible for preventing the water from stagnating inside the chlorinator by draining the system, namely by closing the bypass inlet and outlet valves (valve B1 and B2, Figure 33) and opening the tap (valve T3, Figure 33). This was preferred over closing the bypass and removing the chlorine cylinder as less chlorine handling was required.

Fine-tuning. Fine-tuning was first carried out using calcium hypochlorite 65% tablets while waiting for the TCCA 90% tablets to be delivered. Calcium hypochlorite tablets were used to evaluate the chlorinators performance with another type of chlorine tablet which were easily available in Nairobi. The tablets were 3" in diameter; their size was adapted using a drilling machine with a 1 ½" hole saw to fit the cylinder. During the field trials, the tablets became flaky in contact with water and a very thick whitish paste formed in the cylinder thereby clogging it. This led to a reduction in flow rate and triggered several interventions to unblock the cylinder. In general, chlorine dosage at the tap was very irregular and unpredictable resulting to several FRC readings that were > 4 mg/l. Conversely, TCCA tablets did not crumble in contact with water and no cylinder blockage occurred.

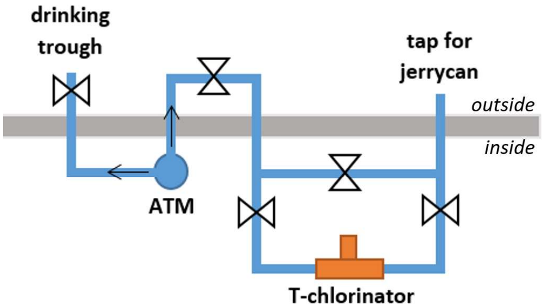

Figure 30: *Diagram of water scheme (top view), Kivui.*

Figure 31: *Chlorination system inside the kiosk, Kivui.*

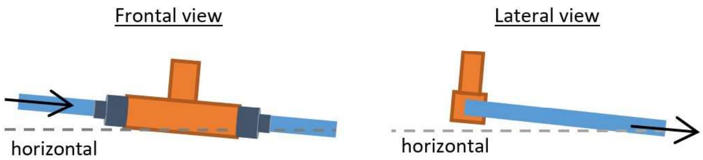

Figure 32: *Diagram depicting the chlorination system inclination, Kivui. Chlorinator frontal view (left) and lateral view on the side of the water outlet (right).*

In Kivui, the first water flush after opening the tap was always highly chlorinated (FRC > 4 mg/l). The reason could be the presence of residual chlorinated water in the chlorinator system. After closing the valve used to fill jerrycans (Figure 30), the water still inside the chlorine cylinder would gradually exit through the holes and sit, for instance, just before the reducer connection between the chlorinator and the scheme pipes (Figure 32). As the water exited the cylinder more slowly, the contact time with the tablets was longer and more chlorine could be dissolved. This was also explained by the last drops coming out from the tap having FRC readings > 4 mg/l. We wanted to avoid overdosing of chlorine in jerrycans. Thus, the dosage of chlorine at the tap was adapted so that the FRC concentration in the first jerrycan filled after opening the tap was < 4 mg/l, more preferable around 3 mg/l, twice the target dose. Throwing away the first flush to avoid a higher dosage was an unrealistic scenario (Kiosk operator of Kivui and Kitumbini, personal communication, November 2021; FundiFix WQOs, personal communication, November 2021) which would also lead to water waste. In fact, water users would have need to pay the thrown away water. Moreover, the kiosk operator was not permanently on site to checked whether the first flush would have been discarded as the kiosk was automated. The jerrycan filled with the last water flush before closing the tap had a chlorine concentration < 3 mg/l, showing that chlorine concentration was only too high in the first jerrycan filled and not in the last one. The target dosage at the tap was 1.3 mg/l.

Figure 33 shows the chlorination system installed in Kyuso, the T-chlorinator is placed next to valve B2. When the kiosk was in operation, the bypass was open (valve B1 and B2 open) to chlorinate the water. The valve on the main line (valve M1) was closed so that all the water could be chlorinated. When the flow rate at the two taps started to reduce, the kiosk operators would close one of the tap valves (valve T1 or T2) to enhance the flow at the tap. At the same moment they would also close the bypass (valve B1 and B2) and open the main line (valve M1) to avoid overdosing of chlorine in jerrycans. This implied that the last few jerrycans were filled with non chlorinated water. For a flow rate at the tap $\leq$ 4 l/min, FRC was > 4 mg/l

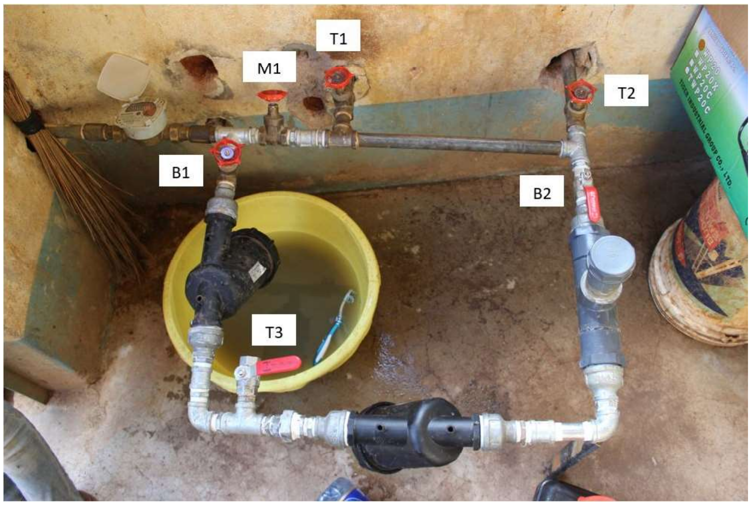

Figure 33: *Chlorination system, Kyuso rock catchment. The names of the valves are indicated.*

The dose adjustment was performed by changing the number, dimension and disposition of the holes in the chlorine containing cylinder. For Kyuso, 13 3 mm holes and 17 1 mm holes were drilled above the disk where the tablets were placed, and one 3 mm and three 1 mm below. The target dosage at the tap was 1.3 mg/l so that also the last jerrycans filled before the bypass was closed were protected from chlorine overdosage (< 4 mg/l). A disk was placed inside the cylinder to elevate the tablets, thereby preventing them being in contact with residual water present in the bottom part of the cylinder. The holes below the disk were necessary to allow any remaining water to flow out the cylinder bottom. First, 1 mm holes were drilled on the cylinder centre (facing the flow direction) one on top of the other every 4 mm. Then, they were progressively enlarged to 3 mm and other holes were drilled 5 mm on the right and 5 mm on the left, starting from the bottom. The steps undertaken for the chlorine cylinder of Kyuso are depicted in Appendix X. The fine-tuning process showed that a higher increase in dosage occurred when the holes were drilled in the lower part of the cylinder rather than in the upper part. Compared to the study of Alan Tournefier, 2020, many holes were drilled to achieve a similar chlorine dosage. Alan Tournefier, 2020 achieved a dosage of 1.32 $\pm$ 0.16 mg/l (flow rate > 4 l/min) by drilling 4 holes of 2 mm one on the top of the other over 3 cm. In fact, the cylinder design was different. In our

Figure 34: *Chlorine containing cylinder, Kyuso. The dashed plate represents the disk where the tablets were placed.*

cylinder some of the water could pass below the disk without being chlorinated, thus, mixing of chlorinated and non-chlorinated water occurred. Moreover, the plate where the chlorine tablets were placed was located at a higher level compared to Alan Tournefier, 2020's cylinder; 2.8 cm height with respect to the cylinder bottom and 2 cm height, respectively. This could also explain the need of more holes as we found that the biggest increase in chlorine dosage took place when the holes were added on the bottom part of the cylinder. The shape and number of chlorine tablets could play a role as well.

Operation. To operate the chlorinator, the kiosk operator in Kivui should check and refill the cylinder with tablets twice a week. In Kyuso, the kiosk operators should check and refill the cylinder and clean the filters at least once a day. Additionally, they should drain the chlorinator. During dry season, the chlorinator draining was only necessary in the evening before closing the kiosk, since water was fetched continuously. During rainy season, draining was also required a couple of times a day when water was not collected for more than 15 min.

Device robustness. Once installed, the T-chlorinator did not have any breakdowns.

Dosage consistency. The average dose at the tap during intense monitoring was 1.3 mg/l (SD = 0.7 mg/l, n = 32) in Kivui and 0.6 mg/l (SD = 0.3 mg/l, n = 27) in Kyuso. For Kyuso, the dose recorded during monitoring was lower than the one selected during fine-tuning (1.3 mg/l). The reason could be due to a difference in the water contact surface of the tablets. Namely, during fine-tuning the tablets used could have a higher contact surface with respect to the tablets used during the monitoring period. In fact, while fine-tuning, the cylinder was newly filled, whereas during monitoring, which started late morning, the kiosk was already operational for several hours and the tablets partially eroded.

The overall DC for the T-chlorinator was 63% (n = 59), which was lower than measured by Dössegger et al., 2021. However, the DC differed from site to site. The Kyuso chlorinator had a DC of 89% (n = 27), which is consistent with Dössegger et al., 2021's results. This shows that the T-chlorinator is also well suited to higher flow rates. On the other hand, the T-chlorinator installed at Kivui had a DC of only 41% (n = 32). The discrepancy in DC could be explained by the different operation modes of the kiosks. In Kyuso, water was fetched continuously, which kept the water flowing through the chlorinator and the tablets wet, whereas in Kivui the operation was intermittent. In fact, for an intermittent regime, more variables could possibly affect the consistency of the dosage. Such as any residual chlorinated water in the system and a variable moisture content of the tablets. In particular, dry and wet tablets could release chlorine differently, hence, affecting the dose of the first water flushes passing through them.

iii.ii AkvoTur chlorinator

Fabrication and assemblage. PVC plates needed to be manufactured for the AkvoTur chlorinator as well. As for the T-chlorinator, the fabrication process of the plates implied several time-consuming steps (section IV.iii.i). Apart from that, there were not many challenges in fabricating and assembling the chlorinator. In fact, the low number of components (Figure 35) and the simple design made the AkvoTur construction straightforward.

Installation. The main challenge during installation was to make sure that the chlorinator did not overflow. Dössegger et al., 2021 recommend a flow rate < 12 l/min to avoid overflowing. One of the study sites selected for the AkvoTur chlorinator, Mitamisyi, had a flow rate of around 15 l/min at the tap which was too high for proper operation of the device. Overflow still occurred after installation of the device; the fittings setup (Figure 36) did not decrease the flowrate enough to prevent water outflow from the vessel. Thus, larger bulkheads (3/4" instead of 1/2") were used to allow water to flow in and out the vessel faster. Another issue, was the bottom plate position. To permit a good water flow, the bottom plate had to be placed in the centre of the vessel slightly shifted towards the water inlet. In fact, if the bottom plate was too near to the water outlet, water could not flow out properly leading to a rise of its level. Moreover, the chlorine cylinder would bend in the direction of the flow when water was flowing through the chlorinator. The cylinder had to be replaced by a tallest cylinder so as to touch the vessel lid and to make it more stable. Finally, the chlorine tablets should not be in contact with water when it was not flowing. Thus, the device had to be installed after the valve and the bottom plate height had to be adjusted according to the water level in the vessel when the tap was close (Figure 37).

Figure 35: *AkvoTur assemblage. From left to right: PVC vessel, PVC bottom plate, and PVC cylinder.*

Figure 36: *AkvoTur chlorinator installed after the valve.*

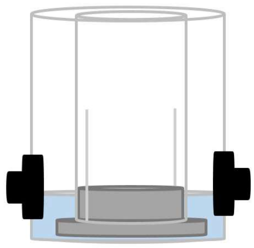

Figure 37: *Scheme of water level in AkvoTur chlorinator when tap is closed.*

Fine-tuning. As for the T-chlorinator, fine-tuning was first carried out using calcium hypochlorite 65% tablets. The chlorine dosage at the tap was as well very irregular and unpredictable. The dosage was then set and adjusted using TCCA tablets. The first water flush and the last droplets at the tap when the valve was closed were highly chlorinated (> 4 mg/l). As for the T-chlorinator, it could be due to chlorinated water in contact with the chlorine tablets slowly exiting the cylinder and stagnating at the bottom of the vessel (Figure 37). The jerrycans, both filled when the tap was opened and just before the tap was closed, had reasonable amount of chlorine (< 3 mg/l). Thus, the target dosage at the tap could be set to 1.5 mg/l. For Kitumbini, due to complaints from the community, the dosage was later reduced to 1.1 mg/l.

Operation. To operate the chlorinator, the kiosk operators should check and refill the cylinder with tablets twice a week.

Device robustness. During fieldwork, one of the AkvoTur had a minor problem twice that could be easily repaired by the WQOs: the bottom plate where the cylinder was located detached from the vessel. First, the technicians claimed they did not wait long enough for the glue to dry. So, throughout the repair they made sure to avoid the same mistake. Nevertheless after the second detachment of the plate, it was realised that the chlorine cylinder was too short. In fact, it could not touch the lid and therefore, under the flow of water, it turned out being unstable. After using a longer cylinder, the bottom plate never came off again.

Dosage consistency. The overall DC was 69% (n = 68), in agreement with Dössegger et al., 2021. As for the T-chlorinator, the DC of the device varied by site, yet not excessively: we found a DC of 59% (n = 34) for Mitamisyi and 79% (n = 34) for Kitumbini. For Mitamisyi, the DC for the first day of data collection was 71% (n = 17) and for the second day 47% (n = 17). The better performance on the first day could be explained by more continuous water collection at the kiosk, which might have kept the tablet hydrated and conferred a more stable chlorine release, as explained in section IV.iii.i.

iii.iii BlueTap chlorinator

Fabrication and assemblage. The components of the BlueTap chlorinators were brought from the United Kingdom. The doser only needed to be assembled and no pieces had to be fabricated on site. Nevertheless, the complexity of the assemblage was an issue: more than 30 different components (excluding bolts and washers) should be put together following an instruction manual (provided in Appendix III). Overall, the assemblage was successful and once the first doser was built, it was easier to build the second one.

Installation. The main challenges in installing the bypass were the leak repairs and the cutting and threading of Galvanized iron (GI) pipes. The pipes leading to the water tank were made of GI, thus, the cutting, threading and fixing processes required more effort and time with respect to PVC pipes. Further, the room to manoeuvre was generally minor. In fact, the bypass (Figure 38) had to fit the cut section of the water pipe, hence, a precise work of measuring and cutting was necessary. Due to the many fittings and components, after the first installation, several leaks occurred. The latter were repaired by using thread tape and tightening the pipes. In general, a minimum of two technicians were necessary to work on the installation. The bypass, including leak repairs and cage installation, took an entire day to be installed.

Figure 38: *BlueTap bypass without the chlorine doser, Mumo.*

Fine-tuning. Fine-tuning the BlueTap chlorinator was a lengthy process that could take more than one day. First, it involved making sure that the chlorinator was dosing by checking the FRC concentration immediately after chlorination (still in the bypass). Second, since the water was being chlorinated before the tank, it could take about one day to detect a FRC at the tap, especially if the tank previously contained non-chlorinated water. Initially, Mumo's chlorinator was not dosing. This was due to blockages: they occurred in the top microtubing adapter and a couple of times also between the microtubing adapter and the venturi (Figure 4), hence, the components had to be disassembled. Blockages were caused by the accumulation of precipitates in the system. Once the device was functioning, the chlorine in the dispenser was depleted faster than expected. After every two pumpings, the chlorine stock (10 l) was consumed and the doser needed to be refilled. Moreover, after the first dosing, the chlorinated water did not have any FRC at the tap: the high chlorine demand of the tank consumed all the disinfectant. After cleaning the tank, fine-tuning was able to continue and the FRC readings at the tap were as targeted. The stock chlorine concentration was set at 3.5 g/l and the tubing length at 8.4 m (1.6 mm ⌀) so as to have FRC readings at the tap of 1.5 mg/l (target dosage).

For Ivonyanga, the pumping was solar dependent, thus also the fine-tuning process. When solar intensity on the panels was not high enough, the water could not flow up to the tank and chlorination was not taking place; this happened most of the time after 2h30pm. Blockages were also an issue. The stock chlorine concentration was set to 4.5 g/l and the tubing length at 4.5 m (1.6 mm ⌀); the target dosage at the tap was 1.5 mg/l.

In general, the poor accuracy of the stock chlorine concentration could represent an issue for dosage adjustment. The concentration was measured using the WataTest® reagent that had an accuracy of ± 0.5 g/l (Wata™, n.d.-b). Thus, the FRC readings after dosage could be shifted by ± 0.5 mg/l from one chlorine production batch to another (considering a flow ratio *water:chlorine solution* of 1 000).

Operation. To operate the chlorinator, chlorine should be produced. The WQOs produced nine 20 l jerrycans of chlorine in the lab each week and then delivered the jerrycans to the kiosks. This could take an entire day. In Mumo, the kiosk operator should refill the doser around three times per day during dry season, wheres in Ivonyanga around three times a week. Refilling required quite an effort as several valve opening and closing steps should be carefully followed.

Device robustness. The BlueTap chlorinator had many minor and major problems to be fixed during fieldwork. The most frequent was the venturi blockage. This was due to particulate buildup in the chlorine injection line. The components between the top microtubing adapter and the venturi had to be disassembled so as to check for the presence of any blockage and this required the use of pipe wrenches and help from technicians. Blockages also occurred in the microtubing (Figure 39) where particulates entered the stream from the sediment accumulating in the microtubing adapter at the bottom of the doser (Figure 40). The blocked microtubing was replaced as it was difficult to remove the particulates due to the length of the tube (4.5 m) and its small diameter (1.6 mm ⌀); this was a minor repair. In addition, it once happened that the bottom lid of the dispenser cracked (Figure 41) and water leaked out through the crack while the pump was on. The crack could be caused by the stress buildup as a result of a too tight screwing or of an asymmetrical screwing of the surrounding threaded rod. The entire doser had to be taken back to the office to replace the lid; this was a major repair. Finally, a fitting on the chlorine refill line broke (Figure 42) and had to be replaced, which represented a minor issue.

Figure 39: *Microtubing blockage with particulates, BlueTap chlorinator.*

Figure 40: *Particulates in the bottom microtubing adapter, BlueTap chlorinator.*

Figure 41: *Bottom lid crack, BlueTap chlorinator. Bottom microtubing adaptor and microtubing are also shown.*

Figure 42: *Fitting breakage on the chlorine refill line, BlueTap chlorinator.*

Dosage consistency. When the intensive monitoring period took place, the BlueTap chlorinator at Ivonyanga was blocked and the reservoir was full of non-chlorinated water. Since rain had started, the community was no longer fetching water. Therefore, it was not possible to pump the water and to put the chlorinator into operation. For Mumo, this happened on the second monitoring campaign, therefore, only one monitoring campaign was performed. The average FRC value (mean = 0.9 mg/L, SD = 0.4 mg/l, n = 17) at the tap in Mumo was slightly outside the target range (1-2 mg/l). The result was unexpected because when the BlueTap staff was in the field, the average dosage at the tap was 1.5 mg/l (SD = 0.3 mg/l, n = 5).

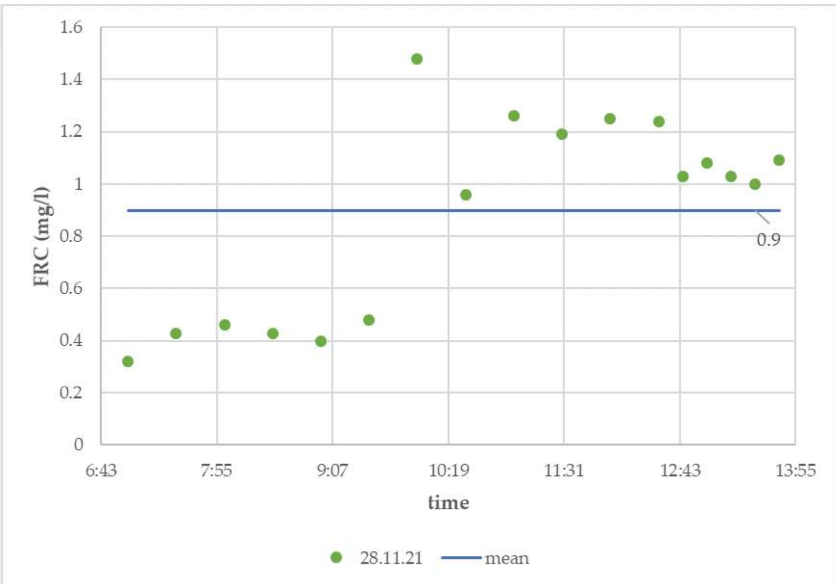

Figure 43: *Graph of FRC at the tap during intensive monitoring period, Mumo.*

Looking at the chart in Figure 43, there was a clear change in dosing throughout the day. In the morning, when the water was pumped, the readings at the tap were around 0.4 mg/l (SD = 0.1 mg/l, n = 6), while in the afternoon the readings were higher, 1.1 mg/l (SD = 0.1 mg/l, n = 11). The low concentrations in the morning could be due to a layer of water at the bottom of the tank that had a longer contact time with chlorine. In fact, chlorine decay is enhanced in warm environment (during the day air temperature could be > 30°C), such as in the black tank exposed to sunlight were chlorinated water was stored. And the jump in FRC concentration, could be explained by the depletion of the water with decayed chlorine sitting at the bottom of the tank and the collection of freshly chlorinated water. Further, the afternoon dosage still lower than the target value might be due to the low accuracy in determining the stock chlorine concentration, as explained in the section *Fine-tuning*. The DC for the BlueTap chlorinator at Mumo was 88% (n = 17).

iii.iv Comparison between chlorinators

Fabrication, assemblage, installation and fine-tuning. Table 3 shows the time consumption and complexity of construction, assemblage, installation, and fine-tuning of each type of chlorinator. Time consumption was estimated considering a person with previous experience with the devices, and neglecting any particular setbacks or challenges. Whereas the complexity was evaluated according to the instruments needed, the number of components to be construct/assemble/install, the number of technicians needed and the straightforwardness of the process. Three scores of complexity were attributed: +, ++, +++ that represent low, medium and high complexity, respectively.

		Construction	**Assemblage**	**Installation**	**Fine-tuning**	Summary
AkvoTur chlorinator	time (h)	1.5	0.5	3	0.5	5.5 h
	complexity	+	+	++	+	+
T-chlorinator	time (h)	2.5	0.5	4	1.5	8.5 h
	complexity	++	+	++	++	++
BlueTap chlorinator	time (h)	NA	1	8	24	33 h
	complexity	NA	+++	+++	+++	+++

Table 3: *Comparison between chlorinators: time consumption and complexity of construction, assemblage, installation and fine-tuning. +, ++, +++ represent respectively low, medium and high complexity.*

Comparing all three devices, the AkvoTur chlorinator was the simplest and the one needing least time to be fabricated and put into operation. Construction involved fabricating the bottom plate, which required a certain effort, but apart from that it was straightforward. Once the components were manufactured, assemblage was also uncomplicated. For installation, few pipe cuts and leakage repairs were necessary; however, a cage had to be built as the chlorinator was placed outside and a welder had to be involved. Fine-tuning was simple: the chlorine cylinder only needed to be rotated to adjust the dosage.

The T-chlorinator ranked second according to the time required to put it into operation and complexity. There were more components to be fabricated and some of them were more complicated to build, such as the inner lid and the chlorine-containing cylinder. Assembly was straightforward. Installation required the construction of a bypass, hence pipe cutting and leak repairs were necessary. To fine-tune the chlorinator, the bypass had to be closed, the chlorine containing cylinder removed, and new holes had to be drilled in the cylinder. Thus, many steps were required compared to the AkvoTur chlorinator. The T-chlorinator showed a medium complexity and a full day was needed to fabricate it and put it into operation.

The BlueTap chlorinator was the most complex chlorinator and the most time consuming to put into operation. Its assemblage involved many different components and an instruction manual had to be carefully followed. Installation was also challenging; many GI pipe cuts were required, leakage problems were frequent due in part to the many fittings in the bypass, and a cage had to be installed. For the fine-tuning, more variables could be adjusted to regulate the chlorine dose in the tank: microtubing length and diameter and chlorine stock concentration, making the process more complex. In addition, checking the chlorine concentration at the tap involved waiting a few hours to allow the water in the tank to mix. The BlueTap chlorinator showed a high complexity and required more than one day to put into operation.

Operation. Table 4 shows the minimum number of tasks per week to be performed to operate the chlorinators and the complexity of operation. Dry season was considered and any operational setbacks or challenges were neglected. The tasks were divided between kiosk operator (KO) and WQO. Whereas the complexity was evaluated according to the time consumption and the straightforwardness of the process. Three scores of complexity were attributed: +, ++, +++ that represent low, medium and high complexity, respectively.

		Operation	
AkvoTur	task/week	2 (KO)	
	complexity	+	
T-chlorinator	task/week	2 (KO) automated kiosk, Kivui	21 (KO) non-automated kiosk, Kyuso
	complexity	+	++
BlueTap chlorinator	task/week	1 (WQO) + 3 (KO) Ivonyanga	1 (WQO) + 21 (KO) Mumo
	complexity	+++	+++

Table 4: *Comparison between chlorinators: number of tasks required pro week to operate the chlorinators and complexity of operation. Tasks are divided between kiosk operator (KO) and WQO. +, ++, +++ represent respectively low, medium and high complexity.*

The easiest devices to operate and the ones that required the fewest operational tasks were the AkvoTur and the T-chlorinator installed in the automated kiosk of Kivui. Only refilling of the chlorine cylinder by the kiosk operators was needed twice a week. For the T-chlorinator installed in the non-automated kiosk of Kyuso, more tasks were involved. Refilling the cylinder and cleaning the water filter should take place daily. Moreover, the kiosk operator should ensure that the chlorine tablets were not in contact with water when no one was fetching it. Thus, chlorinator drainage was necessary at least once a day: only in the evening, for continuous water collection, or also during the day, for intermittent water collection. Finally, the BlueTap chlorinator was the most complex chlorinator to operate. Once a week, the WQOs had to produce chlorine and deliver it to the kiosks. In addition, refilling the doser was complicated and required several steps to follow. The multiple and involved tasks needed to operate the BlueTap chlorinator made its operational feasibility challenging according to the local context.

Devices robustness. The chlorinator robustness was evaluated considering the number of repairs as well as the type of repair needed during fieldwork period. The latter could be minor (m), if one of the WQOs could easily solve the problem by itself, or major (M), if the problem would be more complicated thus requiring need of a technician. Table 5 summarises the breakages of the different chlorinators that occurred during fieldwork.

		# repairs	type	description
T-chlorinator	Kyuso	0		
	Kivui	0		
AkvoTur	Mitamisyi	0		
	Kitumbini	2	m	detachment of bottom plate from vessel
BlueTap	Mumo	4	M	venturi blockage (x3) + doser bottom lid crack (x1)
		1	m	chlorine refill line fitting break
	Ivonyanga	2	M	venturi blockage
		1	m	chlorine microtube blockage

Table 5: *Chlorinators repairs during fieldwork. M and m represent major and minor repairs, respectively.*

During the fieldwork period the T-chlorinator showed the best robustness with no repairs needed. The AkvoTur also demonstrated a good robustness despite the minor issue of the bottom plate detachment. The BlueTap chlorinator required the most repairs, from minor, such as the replacement of a fitting or a tube, to major, such as the disassemblage of the bypass parts to check for the presence of any blockages. In general, the BlueTap device was also the most complex one as it was made up of many components. Thus, the probability for any of these components to brake was higher. In addition, it was the first "real" field application of the BlueTap doser. Only a field test was conducted in the UK using an NaCl solution instead of chlorine, which is cheaper and could still be monitored using an ORP sensor to investigate dosing. The blockage challenges were not expected and the BlueTap team was already working on a new design of the venturi and microtubing adapters to try to avoid them.

Chlorine dosage consistency. Table 6 shows the target concentration, central tendency (mean), dispersion (Standard deviation (SD)), DC, and sample size (n) of FRC measurements at the tap for all six sites.

Overall, DC at the tap ranged from 41% for the Kivui T-chlorinator to 89% for the Kyuso T-chlorinator. This shows that for a given device the DC could vary considerably. For the T-chlorinator for example, the DC depended on its operation, especially in terms of intermittency. For continuous kiosk operation, the T-chlorinator could achieve a constant dosage 89% of the time (Kyuso); for intermittent water collection, DC could drop to 41% (Kivui). The overall DC score for the T-chlorinator was 63%. For the AkvoTur chlorinator, on average, the dosage was in the right range 69% of the time. And for the BlueTap chlorinator 88% of the time. If the chlorinators were to be ranked in terms of DC, the BlueTap doser performed the best, followed by the AkvoTur chlorinator and finally by the T-chlorinator.

	T-chlorinator		AkvoTur		BlueTap	
	Kyuso	**Kivui**	**Mitamisy**	**Kitumbini**	**Mumo**	**Ivonyanga**
target (*mg/l*)	1.3	1.3	1.5	1.1	1.5	1.5
mean (*mg/l*)	0.6	1.3	1.5	1.1	0.9	NA
SD (*mg/l*)	0.3	0.7	0.7	0.4	0.4	NA
DC (%)	89	41	59	79	88	NA
n (-)	27	32	34	34	17	0

Table 6: *Target concentration, central tendency, dispersion, and dosage consistency of FRC at the tap for the six chlorinators installed.*

iv Chlorine decay and water quality in jerrycans

The following section presents and discusses the results obtained during the jerrycans experiments regarding chlorine decay and water quality.

iv.i Jerrycans chlorine decay

Difference between water source – Kyuso, Mitamisyi, Mumo. Chlorine decay in jerrycans was analysed for three water sources: the surface water of the Kyuso rock catchment and the groundwater of Mitamisyi and Mumo. Figure 44 shows the average 30 min, 12 h, and 24 h chlorine demand in jerrycans for the three water sources with the respective standard deviation. The exact values are provided in Appendix IX.

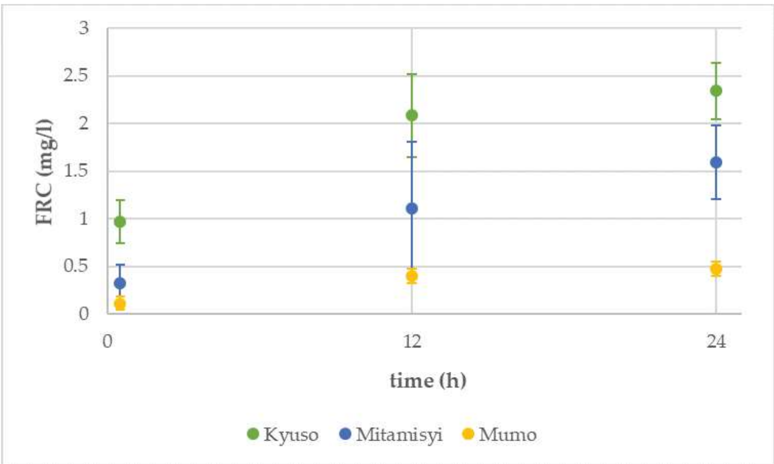

Figure 44: *Graph of average 30 min, 12 h, and 24 h chlorine demand in jerrycans for the water of Kyuso, Mitamisyi, and Mumo. The vertical bars represent the SD.*

The jerrycans filled with water from the Kyuso rock catchment had the highest chlorine demand, highlighted by the high chlorine consumption in the first 30 min (mean = 1.0 mg/l, SD = 0.2 mg/l, n = 9). The reason for that was the high turbidity ($\sim$ 200 NTU) of the surface water of

Kyuso. The 24 h chlorine demand should be interpreted with caution, as only 2 water samples (n = 20) still had a FRC after 24 h. In addition, according to Mohamed et al., 2014, a 3.75 mg/l chlorine dose for water with turbidity > 100 NTU was not sufficient to detect any FRC after 24 h of storage, which is also in line with the WHO recommendations to dose turbid water ($\geq$ 10 NTU) at 4 mg/l. The jerrycans filled in Mitamisyi had an average 30 min chlorine demand of 0.3 mg/l (SD = 0.2 mg/l, n = 20), and an average 24 h chlorine demand of 1.6 mg/l (SD = 1.6 mg/l, n = 11). The chlorine demand in jerrycans filled with the water of Mumo was the lowest. The average FRC in the jerrycans after 24 h storage was 0.07 mg/l (SD = 0.01 mg/l, n = 10), thus very close to the detection limit of the *LaMotte* colorimeter (0.05 mg/l). The average difference in the FRC between 12 h and 24 h storage was 0.05 mg/l (SD = 0.03 mg/l, n = 10). This, along with the fact that the chlorine dosage at the tap was quite low, on average 0.5 mg/l (SD = 0.1 mg/l, n = 10), suggests that the chlorine was consumed before 24 h, namely between 12 and 24 h. In addition, the BlueTap staff also performed a chlorine demand experiment with an uncleaned jerrycan with the water of Mumo. They showed that 1.7 mg/l (n = 1) of chlorine were consumed after 24 h storage. Nevertheless, this value might be overestimated. In fact, during BlueTap's experiments, the 20 l jerrycan analysed was filled only with 6 l of water and it was vigorously shaken for around 2 min to allow water mixing. This, might imply biofilm detachment and particle suspension, thus increasing the chlorine demand. The average 30 min and 24 h chlorine demand between the three water sources were significantly different (χ^2 = 24.9, p = 0.000, n = 39 and χ^2 = 15.4, p = 0.000, n = 21) and represented a medium and large effect size, respectively (r = 0.4 and r = 0.7).

Overall, in contexts where water is transported and stored in containers, it is worthwhile to conduct some jerrycan experiments to study the chlorine demand of both the water and the water containers which can differ from site to site. The aim is to fit the chlorine dosage at the tap so as to meet the chlorine demand in jerrycans, provide a residual protection, and avoid over- and under-dosing. For the three waters analysed, considering a minimum 0.2 mg/l residual suggested by the WHO for water protection at the POC (World Health Organization, 2017a), chlorine dose should be around 2.5 mg/l at Kyuso, 1.8 mg/l at Mitamisyi, and around 1.9 mg/l at Mumo, the latter according to BlueTap's experiments. In general, an eye should always be kept on water quality at the source as it can change according to the season. In addition, user acceptability should be considered as taste-related objections could cause water users to opt for other water sources which might be unimproved.

Difference between jerrycans biofilm categories. 30 min and 24 h chlorine demand were analysed in jerrycans with various degree of biofilm colonisation. This, to investigate the role of different levels of jerrycans cleanliness on chlorine demand. As presented in section III.iv.iv, each jerrycan received a biofilm surface coverage score weighted according to the colour intensity of the biofilm. Then, the jerrycans were divided into various categories. Since the previous section evidenced the difference in chlorine demand between waters, especially for Kyuso, the analysis was performed separately for the three water sources.

First, the difference for chlorine decay between clean and uncleaned jerrycans (classification α) was tested. Analysing the water sources separately, the 30 min and 24 h chlorine demand between clean and uncleaned jerrycans were not significantly different. The statistical results are provided in Appendix XI. The difference in chlorine decay was also analysed between other jerrycan groups, namely the groups of classification β, γ, and δ (section III.iv.iv). The average chlorine decay (30 min and 24 h) was not statistically different between the groups analysed, for all classification type.

Figure 45 shows the 30 min and 24 h chlorine demand in uncleaned versus clean jerrycans for the three water sources. Surprisingly, the basic assumption that FRC consumption in uncleaned jerrycans was statistically different with respect to clean jerrycans was not confirmed. This, was not in line with previous studies that showed that FRC degradation over 24 h in cleaned jerrycans was significantly less than in uncleaned jerrycans (Meierhofer et al., 2019; Gärtner et al., 2021). The reason why no difference was highlighted between the two groups of jerrycans could be the water quality fluctuation at the tap during jerrycan filling, which could affect the chlorine consumption. In particular for the water of Kyuso, where vegetable debris and sediments could accumulate at the water meter placed before the kiosk and could be released intermittently by increasing suddenly water turbidity. A further possible explanation might be that some oil residuals were still present in the clean jerrycans, thus leading to an increase in chlorine demand. In fact, the jerrycans used for the study had a narrow mouth which made their cleaning more difficult. In particular, the inner wall could not be rubbed and it could not be easily checked if there were some oil leftover after cleaning. Hence, despite the several wash steps, it could occur that the jerrycans that were supposed to be clean may not have been. Moreover, for Kyuso, the high chlorine demand of the water, could have a major effect on chlorine consumption than the jerrycan cleanliness, making irrelevant the distinction between jerrycan with biofilm and

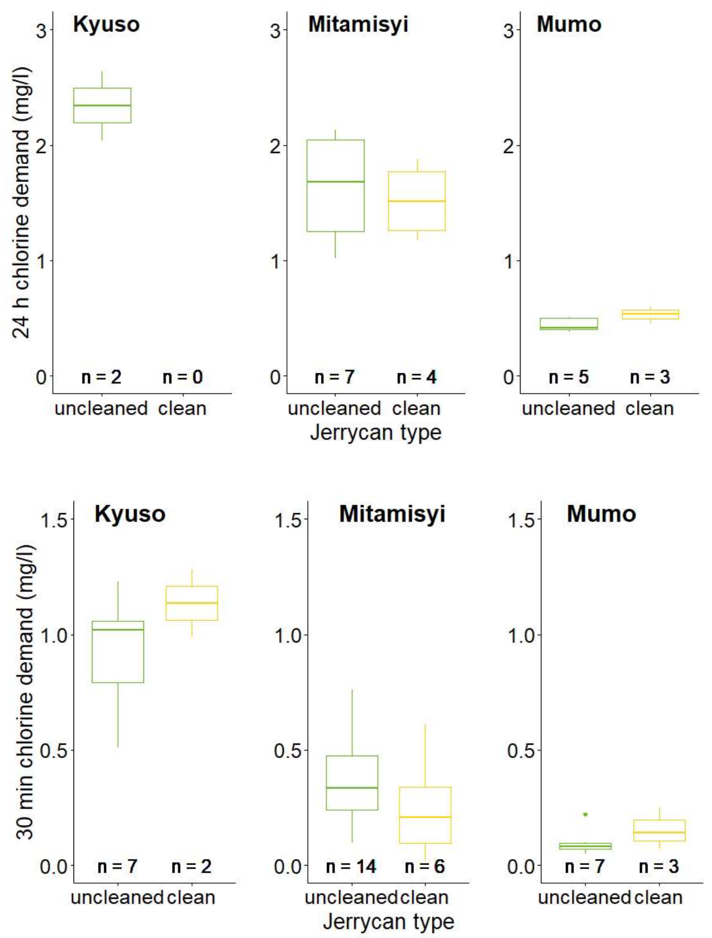

Figure 45: *Boxplot showing the 24 h (above) and 30 min (below) chlorine demand in uncleaned versus clean jerrycans for the three water sources. n represents the sample size.*

without. Finally, considering the various water separately, the sample size per group (Figure 45) could be small. For instance, while studying the 30 min chlorine decay in Kyuso, only two water samples from clean jerrycans were analysed. The sample size, was smaller when more than two groups of the same set of jerrycans were compared (classification γ and δ).

Overall, the basic assumption that led to investigate the effect of different degree of biofilm colonisation on the chlorine decay in jerrycans was not met. In fact, no difference was identified on chlorine consumption in clean versus uncleaned jerrycans, contrary to studies conducted by Meierhofer et al., 2019 and Gärtner et al., 2021, for instance. Nevertheless, an additional attempt on testing the difference in degree of biofilm colonisation on chlorine demand may be worthwhile by making sure water chlorine demand is not too high and the starting condition is fulfilled, i.e. clean jerrycans are really clean. For the cleaning of oil canisters, it may be reasonable to, for instance, use a more heavy rubbing agent, fine sand (Gärtner et al., 2021) in place of green leaves, to ensure the use enough soap, and to use a stronger chlorinated water. Additionally, a bigger sample size should be considered.

iv.ii Microbial water quality

Drinking water quality was graded according to health risk based on *E. coli* contamination (World Health Organization, 2017a): if no *E. coli* were present the guidelines were respected and the health risk was low. The risk was intermediate when water contained 1-10 *E. coli* CFU/100 ml, whereas the risk was high when it contained 11-100 *E. coli* CFU/100 ml, and very high when it contained more than 100 *E. coli* CFU/100 ml.

Before and after chlorination. Microbial contamination was assessed before chlorination and immediately after chlorination, at the tap. As expected and reported from previous REACH program researches (FundiFix WQOs, personal communication, October 2021), Kyuso's surface water was highly contaminated with *E. coli*. Our measurement revealed that water contained > 1 000 CFU/100 ml (n = 1), representing a very high health risk. After chlorination, there were 10 *E. coli* CFU/100 ml (n = 1) present in water, representing an intermediate risk. The high disinfection efficiency, two orders of magnitude, with minimal contact time, estimated to be around 5 s, should be interpreted with caution. In fact, water quality at the tap was highly variable, and the samples before and after chlorination were taken approximately 30 min apart. It is likely that the water quality within this time lapse changed. Waters from Mitamisyi and Mumo were not contaminated with *E. coli* both prior to and after chlorination. The reason for the low health risk of these waters could be the nature of the water, groundwater, which is naturally filtered through the soil. The data were only collected once (Table 7), therefore they might not be representative of the entire fieldwork period.

Water samples were also collected immediately after filling the jerrycans, so as to assess contamination origin. For Kyuso, all jerrycans (clean and uncleaned) contained *E. coli* at various concentrations with an average of 90 CFU/100 ml (SD = 105 CFU/100 ml, n = 10). For Mumo, *E. coli* bacteria were found in 33% of the clean jerrycans (mean = 0.7, SD = 0.9, n = 3) and in 42% of uncleaned jerrycans (mean = 7.9, SD = 16.5, n = 7). After filling, the clean jerrycans of Mitamisyi (n = 3) were not contaminated, whereas the uncleaned ones were contaminated 27% of the

	Kyuso		Mitamisyi		Mumo	
E. coli	**before chlorination**	**after chlorination**	**before chlorination**	**after chlorination**	**before chlorination**	**after chlorination**
mean (CFU/100 ml)	>1000	10	0	0	0	0
SD (CFU/100 ml)	0	0	0	0	0	0
n (-)	1	1	1	1	1	1

Table 7: *Summary of E. coli contamination at the source, before and after chlorination for the three water sources.*

time (mean = 1.7, SD = 7, n = 7). Statistical tests did not show any significant difference in the average *E. coli* concentration at filling between clean and uncleaned jerrycans (Kyuso: p = 0.517, W = 7, r = 0.26; Mitamisyi and Mumo merged: p = 0.416, W = 33.5, r = 0.18). Table 8 shows the central tendency and dispersion of *E. coli* contamination after filling clean and uncleaned jerrycans for the three water sources.

	Kyuso		Mitamisyi		Mumo	
E. coli			**after filling**			
jerrycan	clean	uncleaned	clean	uncleaned	clean	uncleaned
mean (CFU/100 ml)	24.7	117.9	0	1.7	0.7	7.9
SD (CFU/100 ml)	11.2	114.8	0	7	0.9	16.5
n (-)	3	7	3	7	3	7

Table 8: *Summary of E. coli contamination in clean and uncleaned jerrycans after filling for the three water sources.*

All canisters could be contaminated by handling them, such as by moving them and opening and closing their lid. In fact, water users went to the kiosk with donkeys, used to carry the jerrycans, and more generally with livestock to water them. Even though the kiosks were often fenced off, animals still entered the kiosk area and the ground was full of animal excreta (Figure 46). Thus, by placing the jerrycans on the ground and moving them, bacteria could spread very easily and *E. coli* contamination through handling of the jerrycans was very likely, even after filling. For Kyuso, contamination in jerrycans after filling mainly came from the water source. The water of Kyuso was contaminated and the mean *E. coli* concentrations after filling the jerrycans were higher compared to the other sites (Table 8). For Mitamisyi and Mumo, knowing that the water at the source was safe, contamination was more likely to originate from elsewhere. For uncleaned jerrycans it could be released from biofilm already present in the containers, especially at filling when biofilm was possibly detached from the inner walls due to water turbulence. Whereas for clean jerrycans, contamination could come from the water source or the handling.

Figure 46: *Water collection situation, Mumo.*

After 24 h storage. The presence of *E. coli* in jerrycans after 24 h storage was analysed according to the initial FRC concentration and to the turbidity level of the water. Two categories were considered for both turbidity and FRC: < 10 NTU and ≥ 10 NTU, and < 1.5 mg/l and ≥ 1.5 mg/l, respectively. 1.5 mg/l was the initial concentration aimed at the kiosks.

Figure 47 shows, for each FRC and turbidity combination, the percentage of water samples attributed to each of the WHO health risk categories after 24 h storage. Considering waters with low turbidity (< 10 NTU), jerrycans were protected from *E. coli* recontamination 50% of the time (n = 8) for initial FRC ≥ 1.5 mg/l, and 27% of the time (n = 8) for initial FRC < 1.5 mg/l. Looking at turbid water (≥ 10 NTU), jerrycans were free from *E. coli* after 24 h storage less frequently: 25% of the time (n = 8) for initial FRC concentration ≥ 1.5 mg/l and 23% of the time (n = 22) for initial FRC concentration < 1.5 mg/l. Moreover, a large proportion of samples belonged to water with high risk after 24 h storage. Samples with low turbidity were classified as high risk less frequently compared to samples with high turbidity. For turbid water, 50% of the samples showed high risk for both FRC categories. The fact that many jerrycans after 24 h storage contained > 100 *E. coli* CFU/100 ml was due to depletion of FRC after 24 h (Figure 48) and to the favourable conditions for faecal bacteria growth. In fact, in jerrycans with very high risk, the average chlorine concentration after 24 h storage was < 0.2 mg/l (mean = 0.1 mg/l, 0.2 mg/l, n = 22) and 85% of the samples had an FRC value < 0.05 mg/l (detection limit of *LaMotte* colorimeter). The plot of FRC and *E. coli* concentration after 24 h storage is provided in Figure 48. FRC concentration and the number of *E. coli* (CFU/100 ml) after 24h of water storage were significantly correlated (ρ = -0.322, p = 0.026). Furthermore, water turbidity and biofilm in the inner walls of jerrycans could provide the bacteria with food and the temperature was favourable for bacteria growth (warm climate, average water temperature in jerrycans = 27 °C, SD = 2 °C, that could increase when the jerrycans were stored on the outside).

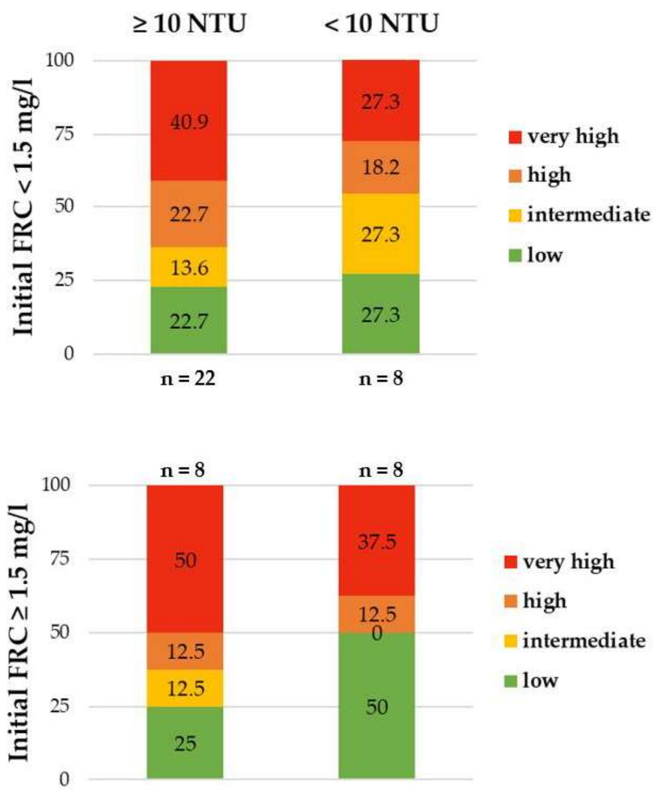

Figure 47: *Percentage of water samples attributed to the WHO health risk categories after 24 h storage, considering turbidity level and initial FRC concentration.*

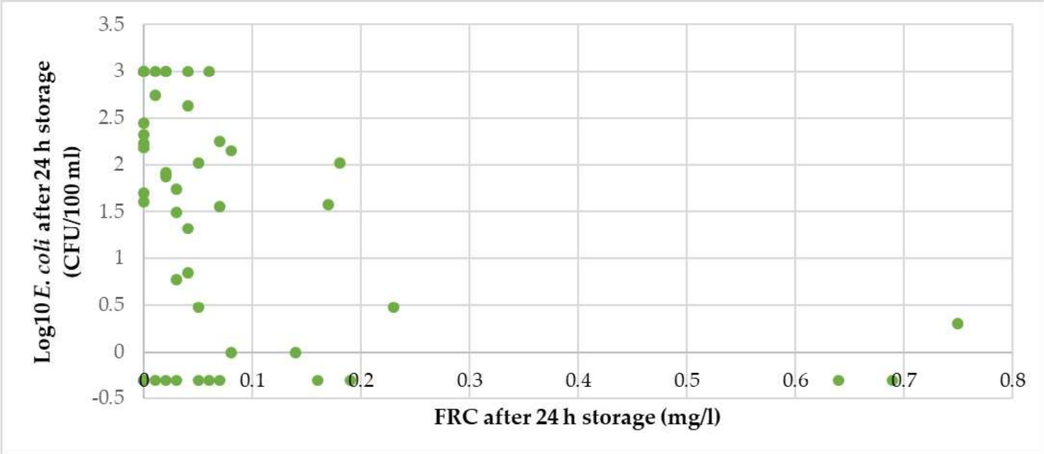

Figure 48: *FRC and E. coli concentration in jerrycans after 24 h.*

After 24 h storage four jerrycans (n = 49) had a residual FRC ≥ 0.2 mg/l. One of them had a FRC concentration in the interval recommended by the WHO, namely 0.2-0.5 mg/l (World Health Organization, 2017a), the other three had a higher concentration (≥ 0.5 mg/l). The sample with chlorine concentration between 0.2 and 0.5 mg/l was contaminated with 3 *E. coli* CFU/100 ml after 24 h storage. Moreover, one of the three water samples with FRC ≥ 0.5 mg/l was contaminated with 2 *E. coli* CFU/100 ml.

Null and Lantagne, 2012 reported that 77% (n = 73) of water containers with FRC ≥ 0.2 mg/l were free from *E. coli* after 24 h storage, and Gärtner et al., 2021 pointed out that with FRC concentration > 0.4 mg/l after 24 h storage no *E. coli* were detected in water. Here, we found that FRC ≥ 0.2 mg/l after 24 h storage protected jerrycans from recontamination only 50% of the time (n = 4). Moreover, 33% of the time jerrycans with FRC > 0.4 mg/l were still contaminated with *E. coli* (mean = 0.7 CFU/100 ml, SD = 0.9 CFU/100 ml, n = 3) after 24 h storage. Thus, water disinfection was less efficient compared to Null and Lantagne, 2012 and Gärtner et al., 2021. The reason could be water turbidity. In particular, the water sample having FRC ≥ 0.4 mg/l and contaminated with *E. coli* was collected at the Kyuso rock catchment, thus, particulate matter causing high water turbidity could have protected some bacteria from disinfection (World Health Organization, 2017b). Additionally, only 36% (n = 50) of the samples after 24 h storage had a pH < 7.6, namely the pKa of HOCl, and none of them had pH ≤ 7, desirable value suggested by Crittenden et al., 2012 to disinfect water. Thus, the bactericide efficacy of chlorine was weakened.

Full protection of jerrycans after 24 h storage occurred at most one over two times, namely for an initial chlorine dosage ≥ 1.5 mg/l and water with low turbidity (< 10 NTU). This suggests that enough FRC (≥ 1.5 mg/l) in jerrycans with low water turbidity could help protect them from recontamination, however it does not guarantee a water with low risk (free from *E. coli*). In fact, the rest of the samples belonged for the majority to the very high risk category, as shown in Figure 47. Furthermore, ≥ 0.2 mg/l residual after 24 h storage helped reducing *E. coli* number to 3 CFU/100 ml (n = 4), nonetheless, compliance with WHO guidelines for a low health risk water might not be met.

v Handover

Operation and maintenance. The chlorinator assemblage was performed with several technicians and the assembly instructions were reviewed with their help and feedback. The chlorinator fine-tuning was conducted in close collaboration with the WQOs. The latter were then able to adjust the dosage of the already installed chlorinators and fine-tune new devices. While technicians were able to fabricate new T-chlorinators and AkvoTur chlorinators, assemble the BlueTap dispensers and install all devices on site.

To refill the chlorinators with tablets, kiosk operators were instructed on when and how much to refill the chlorine cylinder. They were briefed on how to handle the tablets and what to do in case of skin or eye irritation. They were given protective gloves, a stock container of tablets, and a chlorine measuring kit (pooltester with DPD1 tablets and notebook with pen). For the Kyuso rock catchment water kiosk, operators were instructed on the daily routine regarding opening/closing valves to prevent chlorine tablets from sitting in the water. A bullet point list in English and Swahili was as well posted inside the kiosk. For the BlueTap devices, a video was created to show the step-by-step process of filling the dispenser. The video was in Swahili and was shared through Whatsapp to the operators. This allowed them to download it once and have it on their phone. Along with the gloves, safety glasses were provided as protection against any chlorine splashes. With the help of the FundiFix team, a chlorine logistics plan was also developed. This, to minimise transportation costs and manage time more efficiently. Mondays were dedicated to the production and delivery of chlorine to the kiosks. Water was taken at Mumo, and 180 l (nine jerrycans) of chlorine was produced in the lab. The chlorine was put into 20 l jerrycans and then taken to the kiosks: three jerrycans in Ivonyanga and six in Mumo. Empty chlorine jerrycans were brought back to the office where they were refilled the following week.

Monitoring. It was planned that chlorine monitoring would continue. When the rain would stop and people would start fetching water again (usually in January), kiosk operators should take a chlorine measurement with the pooltester twice a week. They should record in the notebook the FRC reading at the tap after letting the water run for 10 s. For FRC readings > 4 mg/l, they should take an extra measurement. If the measured value would still be > 4 mg/l, they should close the chlorinator bypass for the BlueTap and the T-chlorinator or remove the chlorine tablets for the AkvoTur chlorinator. They should then contact the WQOs to check the device. The same would apply for FRC readings < 0.2 mg/l. However, before calling the WQOs they should check the chlorine status of the device. Kiosk operators should also contact FundiFix in case of chlorine stock depletion or in case of any other issue. In addition, they should also record on the log the date the chlorinator was filled and, for the T chlorinator and AkvoTur, the number of tablets added. Furthermore, in case of inconsistencies when checking the data on the log, WQOs should inspect the device.

A monitoring program was tested in a different format during the extensive monitoring period. 37% of the time (n = 51), the kiosk operators did not take any FRC readings even though they should have. According to the WQOs, operators at kiosks fully managed by FundiFix (Kivui, Kitumbini, and Mitamisyi) would more likely adhere to monitoring. Whereas it would be more challenging to obtain data for community-operated kiosks (Kyuso rock catchment, Mumo, and Ivonyanga) because operators did not directly receive their salaries from FundiFix (WQOs, personal communication, December 2021). This was reflected in the data from the extensive monitoring period where 67% of the time (n = 21) operators at community-operated kiosks did not collect the FRC data compared to 17% (n = 30) at kiosks operated entirely by FundiFix. One reason for the low monitoring adherence was that they had to go to the kiosk to obtain a sample expressly each day. Nevertheless, data collection could improve as there would be more work related to the water kiosk when the rain would stop and monitoring begin, so operators would not have to go there expressly. Also, monitoring would be less intensive, twice a week instead of five.

Chlorine supply. A local solution for the supply of 1" TCCA tablets was not found. The 1" tablets were out of stock and the suppliers did not seem to be intended to restock partly due to unstable market. However, FundiFix WQOs were in contact with their chemical reagents supplier who was still investigating the feasibility of importing these tablets as long as the demand of other clients would be satisfied as well. If a local supply would not be possible, Water Mission could still supply with 3" tablets whose size should be adjusted to fit the chlorine containing cylinders; as done during fieldwork. However, if this would be the long-term solution, a permanent order with Water Mission should be further discussed.

vi Study limitations

The rural setting of Mwingi North posed some limitations during fieldwork. When the rains started, the roads often became difficult to drive on due to mud or seasonal river fill, thus, mobility was hindered. It happened several times that difficulties arose when the car got stuck in mud or sand; delays made data collection not always executable as planned. In addition, chlorinator breakage and people not fetching water during the last period of fieldwork hindered the evaluation of the BlueTap chlorinator performance. Moreover, the intensive monitoring period of FRC at the tap was conducted when rain had started and most of the time the kiosks were empty. The only moment where the tap was opened was when samples needed to be taken. Thus, the data might not be totally representative of a normal day at the kiosk during dry season, i.e. when the people frequent the kiosks. Finally, the chlorine tablets that were used during fieldwork did not have a regular shape. This influenced the amount of tablets fitting into the cylinder from time to time, and thus the water contact surface of the tablets.

More from a methodological point of view, water turbidity levels at the tap were fluctuating and turbidity measurements were not taken systematically for every water samples.More intensive monitoring of turbidity could have been useful to directly link it to chlorine decay or water quality. Negative monitoring of jerrycans filled with clean water was not performed, this would have given additional quality assurance and control. The coolbox temperature could not be properly monitored due to the breakage of the thermometer. Since the box was opened and closed several times to put the samples inside, it was possible that the temperature at which the sample bags were stored was higher than desired (> 10°C) considering the warm climate ($\sim$ 30°C). Water quality was only explored analysing *E. coli*. However, viruses and protozoa are usually more resistant than bacteria (World Health Organization, 2017a). Hence, although water free from faecal bacteria is a good result in terms of water quality, other more resistant pathogens might still be present. Finally, as the chlorine dosage was selected to avoid overdosing the jerrycans and protect the water users, and as the demand for chlorine in the jerrycans was higher than expected, FRC after 24 h was often nearly depleted. This implied a small sample size that might not be representative for the analysis on chlorine demand and faecal contamination. Further, considering the three water sources separately, the sample size for clean and uncleaned jerrycans was also small, therefore reducing the power of the statistical tests.

vii Recommendation

Turbidity. Water turbidity was a problem, especially for the surface water of the Kyuso Rock Catchment (turbidity $\sim$ 200 NTU). Turbidity can protect microorganisms from disinfection and result in significant chlorine demand, as explained in section IV.iii.iv. Therefore, water pre-treatment against turbidity would be beneficial. In Kyuso, the pumped water could be filtered before entering the tank. In fact, pipe blockages between the tank and the kiosk occurred several times a week and could prevent people from fetching water for an entire day. The pumped water entered the tank through the opening on the top of it which was never covered by its lid. A rigid sieve-like structure could be fabricated and placed into the opening and laid on its edges (Appendix VII). Then, a large cloth could be set on top to retain the particles. Since a kiosk operator was always at the tank during water pumping (check of water level in the tank, turn the generator on and off), it could also be responsible for washing the cloth. Additionally, the filter could trap inappropriate material from entering the tank, such as windblown sand. Filtering the water could translate into less frequent repairs for FundiFix and more consistent access to water for people. For the other sites, a suitable filter should be put in place before the chlorinator and washed regularly, to prevent reduction in water flow. Water storage tanks should be sealed with their lids. First, to avoid any material or animal entering the tank and deteriorating water quality. Second, at kiosks where the water was chlorinated before the tank (where the BlueTap chlorinator was installed), to limit chlorine degradation of treated water stored inside the tank. In fact, chlorine decay is enhanced in open environments exposed to sunlight. Moreover, the tanks should be systematically cleaned and disinfected at least once a year; a suitable period could be during rainy season when the kiosk is not in use.

Kyuso rock catchment. The surface water of the Kyuso rock catchment was highly turbid and contaminated with faecal bacteria. Dosage at the tap was selected to avoid chlorine overdosage in jerrycans when the flow rate was low and to avoid overloading the kiosk operators with too many instructions. The mean FRC concentration at the tap during intensive monitoring was 0.6 mg/l, a very low value considering that the average 30 min chlorine demand was 1.0 mg/l. Given that the kiosk operators would be more familiar with the chlorinator operation and the water users more familiar with the chlorine taste, the chlorine dose could be increased. During fieldwork, the bypass was closed at the same time as one of the taps. At that moment the chlorine dose was already higher ($\sim$ 4 mg/l) than the mean value at the tap, due to the lower flow rate. Thus, anticipating the bypass closure would allow to increase the chlorine dose at the tap by still protecting the jerrycans from chlorine overdosage. In practice, the kiosk operators should monitor the flow rate so as to know when to close the bypass. This would be a feasible task, as the operators had a phone to chronometer the time needed to fill a jerrycan. However, it would require commitment and diligence. Nonetheless, training the kiosk operators would be necessary to ensure the proper management of the bypass closure and avoid overdosing water with chlorine.

For the other kiosks, where the first jerrycan was more chlorinated than the others, water users awareness should continue. In particular, by sensitising about keeping the water in the first jerrycan filled for cleaning, or about storing it for longer before drinking it, so that the chlorine taste would also lessen.

Suitable chlorine dosage. To avoid as much as possible water users dissatisfaction regarding the taste and odour of chlorinated water, each water supply system should be considered as a separate case for the selection of the suitable chlorine dosage. The choice would be influenced by the chlorine demand of water and jerrycans, as well as by the water users perception. Especially when chlorination is first implemented, starting with a lower dose helps avoid rejection about the change in taste and odour while still reducing bacterial load in water (Smith et al., 2021). Hence, jerrycans experiments are important to inform about an appropriate chlorine dosage, but should always be weighted with chlorine people's acceptability, which might also change with time.

Chlorinators. Two of the three chlorinators installed in the field performed properly considering the rural setting of Mwingi North, namely the AkvoTur and the T-chlorinator. The BlueTap chlorinator was less suitable to the local context. Its operation required a lot of time and effort from both the kiosk operators and the WQOs and breakdowns were frequent. However, it showed the best dosage consistency at the tap.

Assuming that the new BlueTap prototype would be more robust, would not present challenges with blockages, and would be donated, the BlueTap chlorinator could further be installed and operated in the context of Mwingi North. Nevertheless, the following points should be considered. First of all, the kiosk operator should be an involved person and should be permanently on site to operate the kiosk. It should ensure safe doser refill and eventually produce the chlorine solution in loco. In fact, to avoid chlorine solution transport, especially for sites far away from the lab, chlorine production could take place directly at the kiosk. For instance, chlorine granules, which were easily available in Nairobi, could be used. During fieldwork, the BlueTap chlorinator was installed at no charge to FundiFix, yet the technology cost was approximately 1 000 USD, namely two orders magnitude the cost of the AkvoTur and the T-chlorinator. Thus, considering the financial aspect, and taking into account that the cost might reduce when suppliers of components would be found locally (BlueTap team, personal communication, November 2021), a more suitable setting to install the device might be a sub-county level health centre, or a private clinic. They might bear the cost of the device and the employee might be more at ease with its operation.

For future chlorinator installations at small supply schemes in Mwingi North, the choice between the AkvoTur or the T-chlorinator would depend on the characteristics of the supply scheme. The AkvoTur supported rather low water flows (we tested up to 15 l/min), considering the supply schemes operated by FundiFix. Larger fittings (3/4" bulkheads instead of 1/2") at the entrance and exist of the vessel were used so that the water had a smaller residence time in the vessel and the latter did not overflow. In terms of robustness, it should be ensured that the bottom plate where the cylinder was placed did not detach. In addition to being glued, the plate could also be fixed with a screw and some silicon could be used to avoid leakages. For kiosks with more than one tap, being the AkvoTur a tap-attached chlorinator, more devices should be installed, one at each tap. Further, a cage should be considered to protect the devices from tempering. Thus, if the flow conditions are met and there is a single tap, the AkvoTur would be the best chlorinator to install as we found it was the easiest to fabricate and operate.

The T-chlorinator was a suitable alternative to the AkvoTur, especially for higher water flow rates. In addition, as it was installed inside the kiosk, it did not require construction of a protective cage. However, the main challenge was to ensure that the chlorine tablets were not in contact with water when the water did not flow. Thus, a valve should be installed before the chlorination system and the latter should be placed at a slight slope to allow draining of the system by gravity. To facilitate the water outflow from the chlorine cylinder when the chlorinator is not in use, while fine-tuning, we recommend to drill large holes (e.g. 3 mm) rather than small holes (e.g. 1 mm).

The supply of adequate chlorine tablets was a big challenge and a local supplier of slowly dissolving tablets of the right size (1" ⌀) still needed to be found. In case the tablets would not be found locally, importing them from abroad, although not the most sustainable solution, should be considered. If importing the tablets would not be feasible, devices able to accommodate 3" tablets could be fabricated and tested. This, to avoid the unpleasant and time-consuming task of resizing 3" tablets. In any case, to check the performance of these bigger devices, trials should be carried out.

V Conclusion

Three types of passive chlorinators were manufactured, installed, and put into operation in six different supply schemes in rural Kenya. Their adaptability to the local context was assessed from fabrication to operation. The dosage consistency at the tap was evaluated and water quality after 24 h storage in jerrycans was studied.

The tap-attached AkvoTur chlorinator was easy to fabricate, install and to operate. In addition, it showed a good robustness as only a minor repair was necessary during fieldwork period. The T-chlorinator showed a medium complexity. Nonetheless, it was still suitable for the local context. More components should be fabricated and assembled, and since the device was placed inline, installation required greater efforts (PVC pipe cutting and leak repairs). Furthermore, for the chlorinator installed in Kyuso, additional operational tasks were necessary (device drainage to avoid chlorine tablets to be in contact with stagnant water, filter cleaning). The T-chlorinator had the best robustness with no repairs needed. As for the BlueTap chlorinator, it was complex to install and operate. In fact, the doser consisted of several components (> 30), installation was challenging (GI pipe cutting and leak repairs), refilling the doser was complicated (multiple steps required), and the chlorine logistics was time consuming (chlorine production in the lab, transport to the kiosk). In terms of robustness, many repairs were needed: from minor, such as the replacement of components, to major, such as the disassemblage of the bypass to check for the presence of any blockages.

In terms of Dosage consistency at the tap, the BlueTap chlorinator showed the best performance with a score of 88%. The AkvoTur had a DC of 69% and the T-chlorinator of 63%, the latter with a noticeable difference between sites. For a continuous water regime (Kyuso), DC was of 89%, in line with Dössegger et al., 2021, while for an intermittent regime (Kivui), DC was lower, namely 41%. In fact, for an intermittent regime, more variables, such as any residual chlorinated water in the system and a fluctuating moisture content of the tablets, could possibly affect the consistency of the dosage. In particular, dry and wet tablets could release chlorine differently, hence, affecting the dose of the first water flushes passing through them.

Considering the local context of Mwingi North, the most suitable chlorinators were the AkvoTur and the T-chlorinator. They were user friendly from fabrication to operation, and they were built with locally available material (PVC pipes and fittings). The main drawback with these devices was the local supply of 1" slowly dissolving tablets (TCCA). Some trials were performed using calcium hypochlorite tablets. However, chlorine dosage at the tap was not consistent (unpredictable, several FRC readings > 4 mg/l) and the tablets in contact with water formed a thick paste in the cylinder thereby clogging it. To ensure the performance of the chlorinators, it was essential to use slowly dissolving TCCA tablets that did not crumble upon contact with water. A temporary solution was available through a partnership with the NGO Water Mission, nonetheless, for a future scale up, other ways to access the tablets might need to be explored. If a suitable solution for the tablet supply will be found, the uptake chances and the probability of long-term application for the T-chlorinator and the AkvoTur chlorinator could be high.

The BlueTap chlorinator was tested for the first time in the field. Its complexity and the time invested to operate it, made it less suitable for the rural setting considered. Furthermore, all components were imported from overseas, making its cost and implementation unsustainable. Nevertheless, it could be a good solution for sub-county level health centres, or private clinics, that might look for a chlorinator with a higher dosage consistency (DC = 88 %). Moreover, employee in the health sector might be more at ease with the operation of the device.

FRC consumption was not significantly different between clean and uncleaned jerrycans. And no difference was observed in FRC decay between categories with various degrees of biofilm colonisation. However, a simple and visual way to quantify biofilm in the inner walls of water containers was provided and could be further employed. The average 30 min and 24 h chlorine demand between the water source of Kyuso, Mitamisyi and Mumo were significantly different, evidencing the importance of considering each site separately to select a suitable chlorine dosage at the tap. After 24 h storage, 50% of jerrycans with initial FRC $\geq$ 1.5 mg/l and with water of low turbidity (< 10 NTU) were free from *E. coli*. The frequency of protection decreased for lower FRC dosage and for more turbid water. In addition, 50% of jerrycans with FRC $\geq$ 0.2 mg/l and 77% of jerrycans with FRC $\geq$ 0.5 mg/l were free from *E. coli* after 24 h storage. This suggests that adequate chlorine dosage and residual can help protect jerrycans from *E. coli* recontamination, yet it is not a guarantee of compliance with WHO guidelines for low health risk water (0 *E. coli* CFU/100 ml). The high turbidity of the waters analysed might explain the lower effectiveness of chlorination compared to other studies. Therefore, water quality improvement interventions such as turbidity treatment were suggested. This, to increase the effectiveness of chlorination, as well as improve the aesthetic characteristics of the water, and reduce the demand for chlorine; the latter could also be beneficial in terms of taste acceptability by users. Finally, we found that despite the subjective evaluation of colour, the FRC pooltester readings were representative of the most accurate readings taken with the analytical instrument (*rho* = 0.9, p = 0.000). This manual and easy-to-use device could sufficiently inform on the chlorine concentration in the water, particularly on chlorine overdose that could dissatisfy water users and potentially cause health issues.

In conclusion, this Master thesis provides an overview of the technical performance of three different passive chlorinators under the rural conditions of Kenya. A better understanding of the challenges encountered during field work in a rural setting for construction, installation and operation of the chlorinators was given. In addition, water quality in jerrycans after disinfection was discussed. Some recommendations were presented for devices already installed and for future installations. To ensure that future chlorinators could be installed and operated directly by local people, a strong emphasis was laid on working closely with the local partner so as to share capacity building; eventually, instruction manuals were developed. Ultimately, if a suitable solution for the TCCA chlorine tablets supply will be found, there is a good chance of uptake of the AkvoTur and T-chlorinator. Thus, the current and future chlorinators could improve access to safer water in the Mwingi North sub-county, and consequently help achieving target 6.1 of the SDGs addressing safely managed drinking water services for all.

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Appendix

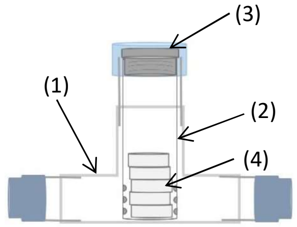
I T-chlorinator - Fabrication and dosage manual

Lisa Appavou (Eawag) 04.11.2021, Kyuso, Kenya

<u>CONSTRUCTION & DOSAGE MANUAL: T-chlorinator</u>

<u>Introduction:</u>

This instruction manual is based on fieldwork experience in Kyuso, Kenya, between October and December 2021.
The construction of the chlorinator can be performed differently than described in the document, according to the locally available material. The last part of the manual ("Notes") informs about construction alternatives. For this reason, it's important to read the entire manual before construction.



(1) Tee (2) Chlorine containing cylinder (3) Lid of chlorine containing cylinder (4) chlorine tablets

!** Read the <u>entire</u> manual before construction **!

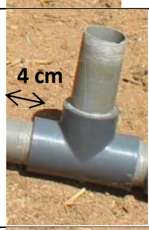
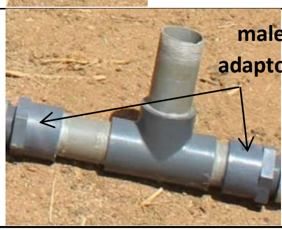
<u>Material needed:</u>

component	quantity	picture
1 ½'' PVC Tee (without threads!) → base structure of the device	1	
(1 ½'') PVC gate valve • *dimension depends on the pipe diameter*!	2	
1 ½'' PVC pipe 20 cm long with threads on one side → tube where to insert the chlorine containing cylinder	1	
1 ½'' PVC lid with threads → to make the chlorinator airtight	1	
1 ¼'' PVC pipe 10 cm long → chlorine containing cylinder	1	
1 ½'' PVC pipe 20 cm long → for lid of chlorine containing cylinder	1	
1 ½'' PVC male adaptor → to connect the chlorinator to the piped scheme	2	
Hacksaw → to cut PVC pipes	1	
File → to file the chlorine containing cylinder lid	1	
PVC cement	1	

Lisa Appavou (Eawag) 04.11.2021, Kyuso, Kenya

→ to build the chlorine containing cylinder and its lid		
Hammer → to flatter the PVC disk for the lid of the chlorine containing cylinder	1	
Ruler → to measure the distance between the holes of the chlorine containing cylinder	1	
Mark pen → to mark the points where to drill the holes	1	
Thread tape → to seal the thread	1	
Drilling machine → to drill holes on the chlorine containing cylinder and to cut PVC disk for the chlorine containing cylinder lid	1	
1 mm drill bit	1	
3 mm drill bit	1	
1 ¾" hole saw	1	
1 ½" hole saw	1	

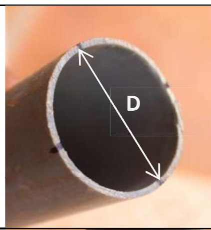
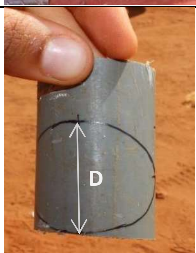
Chlorinator construction:

Tee - assemblage	
Insert around 9 cm of 1 ½'' PVC pipe into the perpendicular entry of the Tee in order to have 8 cm of pipe emerging from the Tee. Glue the Tee and the pipe. *Figure: Tee with vertical tube.*	
Insert a small length of the 1 ½'' PVC pipe in each of the longitudinal hole of the Tee. Glue. The length of the emerging part should be around 4 cm each side to allow fixation of male adaptors. *Figure: Tee with vertical and horizontal tubes.*	
Glue male adaptor to longitudinal tubes. *Figure: Assembled Tee with vertical and horizontal tubes and adaptors.*	

- 2 -

Lisa Appavou (Eawag) 04.11.2021, Kyuso, Kenya

<table>
<tr><th colspan="2">Chlorine containing cylinder - fabrication</th></tr>
<tr><td colspan="2">• <u>Tube (upper part)</u></td></tr>
<tr><td>Use 8.5 cm of the 1 ¼’’ PVC pipe to build the upper part of the cylinder (tube).</td><td></td></tr>
<tr><td>On one end of the pipe, divide the circumference into 4 and mark it.

Figure: pipe circumference with diameter D marked every 45°.</td><td>
</td></tr>
<tr><td>Draw a line formed by two waves and two valleys. The height of the waves must be half the diameter of the tube (D/2).</td><td>
</td></tr>
<tr><td>Cut with the hacksaw.</td><td></td></tr>
<tr><td colspan="2">• <u>Bottom lid (bottom part)</u></td></tr>
<tr><td>Use the remaining 1.5 cm of the ¼’’ PVC pipe.</td><td></td></tr>
<tr><td>Cut it in half vertically.</td><td></td></tr>
<tr><td>Use one of the half piece just cut and trace an oval with shorter diameter in the flat (vertical) dimension of the piece and with longer diameter on the round dimension of the piece. The shorter diameter of the oval should be the diameter (D) of the pipe, i.e. 1 ½”.</td><td>
</td></tr>
<tr><td>Cut the piece and file it. The piece should enter the bottom part (tube) of the chlorine containing cylinder (see “Assemble the two parts” below).</td><td></td></tr>
</table>

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• <u>Assemble the two parts</u>	
Before gluing the lid (bottom part) with the tube (top part), make sure that the cylinder with the lid fits into the Tee. To do this, place the lid inside the tube, without gluing them, and insert the tube into the Tee. If the lid is too large, it may distort the shape of the cylinder not allowing it to be inserted /removed from the Tee. *Figure: chlorine containing cylinder inside the Tee.*	
Before gluing, make also sure that the bottom lid stays inside the cylinder so that the glued part will not be stressed by the water flow. *Figure: bottom of the chlorine containing cylinder-the dashed line represents the bottom lid.*	
Glue the two parts with PVC cement. *Figure: bottom of the chlorine containing cylinder.*	

Lid for chlorine containig cylinder - construction	
Cut 1.5 cm of the 20 cm long PVC pipe listed in the material needed. Place it vertically on a surface and cut it in half. Repeat 3 times to have 6 half pieces. *Figure: two half pieces of pipe.*	
Set a small fire. Using the plier, place 5 half pieces on the fire to heat them enough that they are pliable. Then, use the hammer to flattern them. *Figure: flattering a half piece with the hammer.*	

Lisa Appavou (Eawag) 04.11.2021, Kyuso, Kenya

<table>
<tr><td>Using the drilling machine and the appropriate hole saw, cut
• one disk of 1 ¾” diameter, and
• four disks of 1 ½” diameter.

Figure: drilling machine with hole saw and PVC disk just cut.</td><td></td></tr>
<tr><td>Glue all the 1 ½” diameter disks together with PVC glue.

Figure: glueing the disks together.</td><td></td></tr>
<tr><td>Wait for the glue to dry. File the sides of the cylinder so that it enters the chlorine containing cylinder. Make sure it fits exactly, it does not have to be loose.

Figure: half chlorine containing cylinder lid.</td><td></td></tr>
<tr><td>Glue the piece just fabricated to the 1 ¾” diameter disk to form the lid for the chlorine containing cylinder.

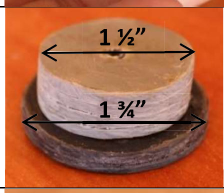
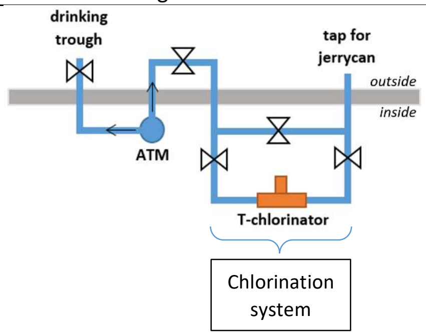
Figure: lid for chlorine containig cylinder.</td><td></td></tr>
<tr><td>File the larger disk so that it has the same outer diameter of the 1 ½” pipe. When the chlorine containing cylinder and its lid are placed inside the Tee assemblage, you should manage to close the outer cylinder with its lid with threads.

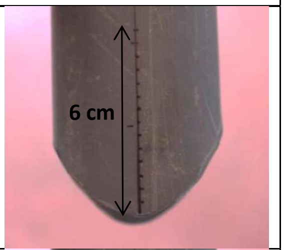
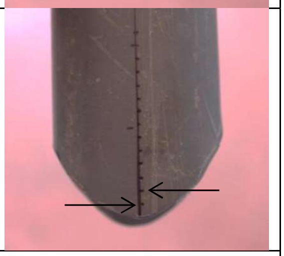
Figure: chlorine containig cylinder with its lid.</td><td></td></tr>
</table>

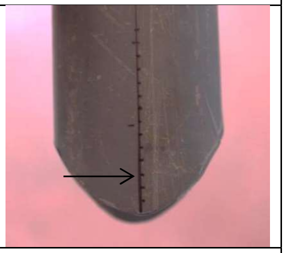
<table>
<tr><th colspan="2">Chlorinator installation</th></tr>
<tr><td>The chlorinator should be installed in a bypass.</td><td></td></tr>
<tr><td>A gate valve should be placed before and after the chlorinator to isolate the system in case of problems, or to allow chlorine tablets refill without interfering with water users.</td><td></td></tr>
<tr><td>For best chlorine efficiency, a filter should be put before chlorination. If turbidity is very high more filters in series can be installed.</td><td></td></tr>
<tr><td>- If the kiosk has a permanent kiosk attendant, all the system can be placed inside the kiosk.</td><td><u>Every evening</u> or in case there are <u>no people fetching water for more than 15min</u>, the kiosk attendant has to:
- remove the chlorine containing cylinder, or
- if a tap is installed in the bypass, open the tap to drain out the water in the pipe.</td></tr>
</table>

Lisa Appavou (Eawag) 04.11.2021, Kyuso, Kenya

	This, to avoid the chlorine tablets to stay in contact with stagnant water.
- For a water ATM, install a valve accessible to the people before the "chlorination system" by keeping the system inside the kiosk for security reason. • Make sure there is a slope between the valve placed outside the kiosk and the tap to allow water to drain out. *Figure: Example of a scheme where the valve for the jerrycans tap is placed outside the kiosk just before the chlorination system. This way, if the water is not fetched or the drinking trough is used, the tablets don't sit in water.*	

Chlorine dosage:

Dosage at the tap should be selected according to the site characteristics, i.e. chlorine demand of water and jerrycans. Perform some jerrycans experiments: - Borrow a 20 l jerrycan from a household - Chlorinate it with a known dose, e.g. 4 mg/l - Measure FRC at filling and note the value (A) - Measure FRC after 24 h storage (B) - 24 h chlorine demand correspond to (A)-(B) - To obtain the dose to aim at the tap, add 0.2 mg/l to the chlorine demand just calculated → dose at tap = FRC_0 – FRC_24h + 0.2 (mg/l) - Start with that dose and adapt if community complains	
Mark the bottom of the chlorine containing cylinder with a 6 cm long vertical line. Mark a point every 4 mm on the line. You should mark around 15 points. Do it for both sides of the cylinder. *Figure: cylinder with drilling points.*	
Start by drilling 2 holes of 1 mm on both sides. Every time you drill a hole on one side, you should drill it on the other side as well. *Figure: cylinder with drilling points-holes should be drilled in the two points indicated by the arrows.*	
Start by filling the cylinder with 3 chlorine tablets (or up to half the cylinder). Close the cylinder with the lid. Insert the cylinder in the chlorinator and close it with the lid with threads. The chlorinator should be airtight now. Let the water run for around 15 seconds. Measure the Free residual chlorine (FRC) at the tap. Taking into account community	

acceptability, aim for a FRC ~ 2 mg/l at the tap. For turbid water (> 10 NTU), aim for 4 mg/l (WHO guidelines).	
If the FRC is not enough, drill the next hole and measure the FRC again. *Figure: cylinder with drilling points- holes should be drilled in the point indicated by the arrow.*	
If the dosage is not enough, iterate up to around 15 holes.	
If the dose is still not enough. Start enlarging the holes from the bottom with the 3 mm drill bit. If necessary, enlarge all the holes.	
If the dosage is still not enough, drill holes also on the left and right of the main vertical line. Keep left-right symmetry when drilling the holes. *Figure: cylinder with drilling points.*	
In general, finding the right dosage is an iterative process. If the dosage is too high, the cylinder has to be replaced, some holes have to be closed (with PVC cement, for example), or some tablets removed.	
Make sure that the cylinder has symmetric holes on both sides, and left-right.	

<u>Notes:</u>

If (flat) PVC plates are available, they can be used to build the lid of the chlorine containing cylinder.	
If a heat gun is available, it can be used instead of the fire to remodel the pipe pieces.	
If the 20 cm PVC pipe has no threads on one side, make the treads using a pipe threader. For best performance, use a soft PVC pipe rather than a hard PVC pipe.	
Always use gloves to handle chlorine. In case of contact with chlorine, rinse abundantly with water.	
Chlorine tablets don't have to sit in stagnant water. - If there is stagnant water in the chlorinator, a PVC disk can be placed in the chlorine containing cylinder to elevate the level where the chorine tablets sit. In this case, a 3mm hole should be drilled to avoid water to be trapped in the bottom part. - Or, glue the disk with PVC cement before assembling the chlorine containing cylinder (gluing the tube with the bottom lid). In this case the 3mm hole would not be necessary	
Dosage can also be adjusted by changing the number of tablets in the cylinder.	

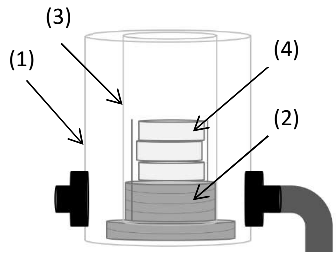
II AkvoTur chlorinator - Fabrication and dosage manual

Lisa Appavou (Eawag) 09.11.21, Kyuso, Kenya

CONSTRUCTION & DOSAGE MANUAL: AkvoTur chlorinator

Introduction:

This instruction manual is based on fieldwork experience in Kyuso, Kenya, between October and December 2021.
The construction of the chlorinator can be performed differently than described in the document, according to the locally available material. The last part of the manual ("Notes") informs about construction alternatives. For this reason, it's important to read the entire manual before construction.



(1) vessel (2) bottom plate (3) chlorine containing cylinder (4) tablets

!** Read the entire manual before construction **!

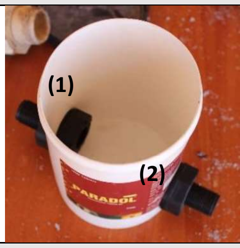
Material needed:

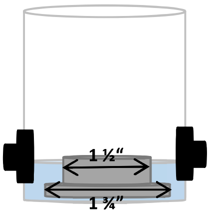
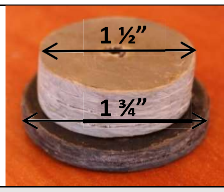
component	quantity	picture
PVC vessel with lid (Ø = ca 9cm, height = ca 15cm)	1	
1 ½'' PVC pipe with the same length as the height of the vessel → chlorine tablet should fit inside	1	
1 ½'' PVC pipe 20cm long → to construct the "bottom plate"	1	
½'' PVC bulkhead → water inlet and outlet of the vessel	2	
½" PVC elbow with threads (female) → water tap	1	
Hacksaw → to cut PVC pipes	1	
File → to file the "bottom plate"	1	
PVC cement → to build the "bottom plate" and glue it to the vessel	1	
Plier → to help hold the pipe pieces while on the fire	1	
Hammer → to flatter the PVC disk for the "bottom plate"	1	

Lisa Appavou (Eawag) 09.11.21, Kyuso, Kenya

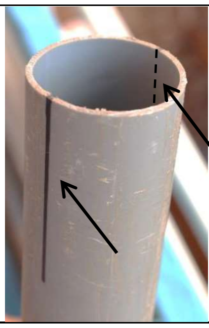
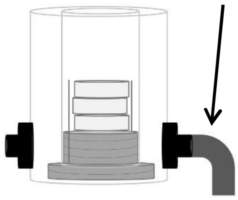
Thread tape → to seal the thread	1	
Mark pen	1	
Drilling machine → to drill holes on the vessel and to cut PVC disks for the "bottom plate"	1	
½" hole saw	1	
¾" hole saw	1	
1 ½" hole saw	1	
1 ¾" hole saw	1	

Chlorinator construction:

Vessel - preparation	
Use the drilling machine and the ½" hole saw to drill a hole (1) on the lowest side of the vessel. Drill a second hole (2) on the opposite side. The holes should accommodate the bulkheads. Use threat tape to seal the threads and screw the bulkheads. *Figure: vessel with the two bulkheads.*	
"Bottom plate" - fabrication	
Cut 1.5 cm of the 20 cm long PVC pipe listed in the material needed. Place it vertically on a surface and cut it in half. Repeat 5 times to have 10 half pieces. *Figure: two half pieces.*	
Set a small fire. Using the plier, place the half pieces on the fire to melt them enough that they are pliable. Use then the hammer to flattern them. *Figure: flattering a half piece with the hammer.*	

Using the drilling machine and the appropriate hole saw, cut • two disks of 1 ¾” diameter, and • eight disks of 1 ½” diameter.	
Determine the number of disks needed. To do this, put some water in the container and wait for it to come out of the bulkheads. Place the two 1 ¾" diameter disks inside the vessel, one on top of the other. Then, one after the other, pile the 1 ½" diameter disks until there is no more water on the last disk. **The total height of the “bottom plate” should be bigger than the level the water reaches when stagnating inside the vessel. In other words, if there is no water flowing, the chlorine tablets put on the “bottom plate” don’t have to be in contact with water.** *Figure: AkvoTur scheme where the level of stagnant water is slightly lower than the height of the “bottom plate”.*	
Glue all the 1 ½” diameter disks together with PVC glue. *Figure: glueing the disks together.*	
Wait for the glue to dry. File the sides of the cylinder so that it enters the 1 ½” diameter pipe. Make sure it fits exactly, it doesn’t have to be loose. *Figure: half “bottom plate”.*	
Glue all the 1 ¾” diameter disk together with PVC glue.	
Glue the 1 ½” diameter cylinder to the 1 ¾” diameter circle to form the “bottom plate” *Figure: “bottom plate”.*	
Vessel and “bottom plate” - assemblage	
Place the “bottom plate” inside the vessel, at its center. Make sure the surface is dry and then glue it. Wait for at least 20 minutes so that the glue dries. *Figure: “bottom plate” glued on the vessel.*	
Chlorine containing cylinder - preparation	

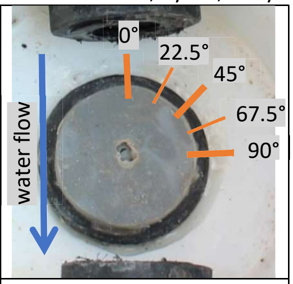
Lisa Appavou (Eawag) 09.11.21, Kyuso, Kenya

Place the 1 ½'' PVC pipe on the “bottom plate”. Cut few millimeter of the pipe to be able to close the lid of the vessel. Make sure the pipe touches the vessel lid (for more stability).	
Remove the pipe from the “bottom plate”. On one end of the pipe, draw with a marker a vertical line 2 mm thick and 6 cm high. Do the same on the opposite side. *Figure: chlorine cylinder with marked slits.*	
Cut the slits with the hacksaw.	
Place the chlorine cylinder on the "bottom plate" and fill it halfway with 1" TCCA tablets. *Figure: AkvoTur chlorinator with chlorine tablets and without lid.*	
Finally, screw the elbow with threads on one of the bulkhead. *Figure: scheme of the AkvoTur chlorinator.*	

<u>Dosage setup:</u>

Dosage at the tap should be selected according to the site characteristics, i.e. chlorine demand of water and jerrycans, and community acceptability. Perform some jerrycans experiments: - Borrow a 20 l jerrycan from a household - Chlorinate it with a known chlorine dose, e.g. 4 mg/l - Measure FRC at filling and note the value (A) - Measure FRC after 24 h storage and note the value (B) - 24 h chlorine demand correspond to (A)-(B) - To obtain the dose to aim at the tap, add 0.2 mg/l to the chlorine demand just calculated - → dose at tap = FRC_0 – FRC_24h + 0.2 (mg/l) - Start with that dose and adapt if community complains	

Lisa Appavou (Eawag) 09.11.21, Kyuso, Kenya

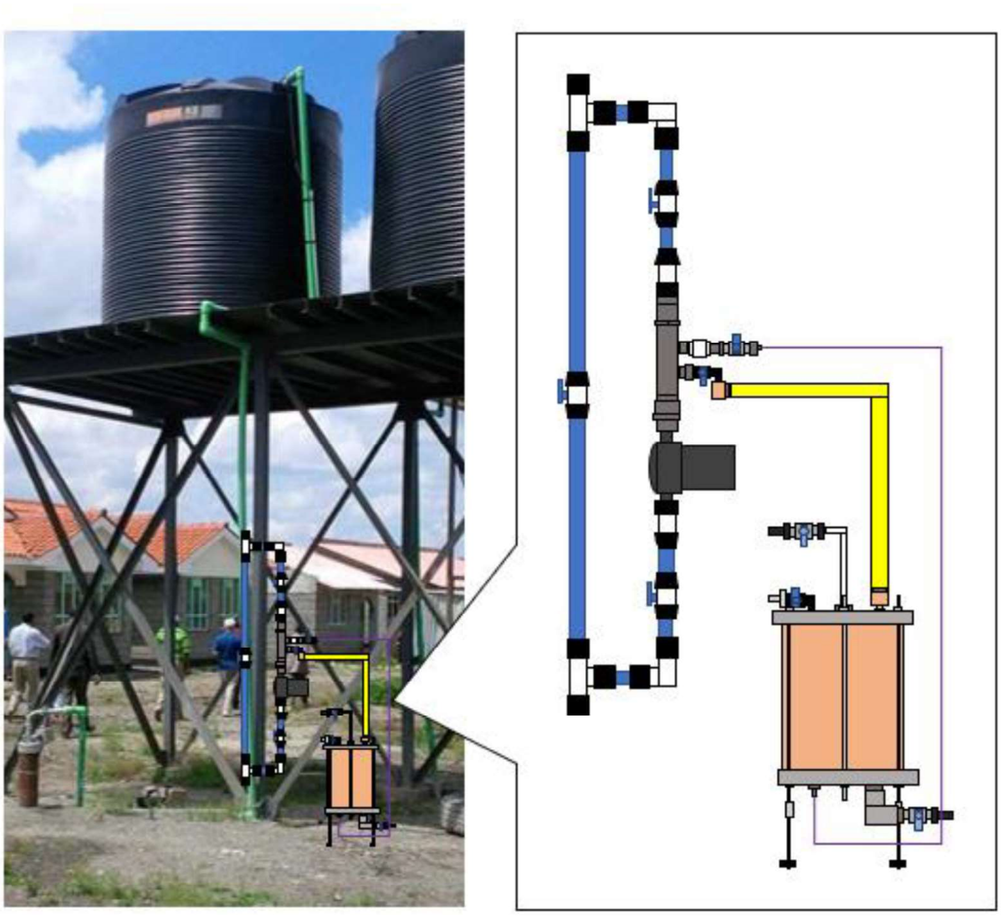
The pipe has two vertical slits to allow the water to erode the TCCA chlorine tablets. The dosage can be adjusted by turning the pipe, therefore the slits. Dosage will be highest with the slits in the direction of flow (slit at 0°) and lowest with the slit at 90° to the direction of flow. *Figure: dosage adjustment.*	
Dosage can also be adjusted changing the number of tablets in the cylinder.	
Start by putting the slits at 90°. Measure the FRC at the tap. If the dose is not enough, rotate the cylinder at 67.5° and measure the FRC at the tap. Repeat until the wanted dosage is reached. For maximum chlorine dose put the slit at 0°, for minimum dose put it at 90°. • If the slit is at 0° and the dosage is not enough, make the slits wider. Or, add chlorine tablets. Or, reduce the water flowrate before chlorination, so that water sits more time in contact with the chlorine tablets. • If the slit is at 90° and the dosage is too high, reduce the number of tablets in the chlorine cylinder. Or, replace the cylinder and cut the slits narrower.	

<u>Notes:</u>

The chlorinator can only handle flow rate of 12 l/min otherwise it overflows. For higher flow rate (~ 15 l/min), use ¾” PVC bulkheads instead of ½” ones.
The valve to open and close the tap has to be placed before the chlorinator to avoid tablets to sit in water when water is not fetched.
Chlorine tablets don’t have to sit in stagnant water. When water is not fetched, make sure the water level inside the vessel is lower than the “bottom plate” height.
The “bottom plate” has to be placed in the center of the vessel. When the cylinder and the tablets are placed inside the vessel, make sure water flows through the vessel without overflowing. Overflowing can happen if the water flow is too high or if the “bottom plate” is too close to the water outlet.
If (flat) PVC plates are available, they can be used to build the “bottom plate”.
If a heat gun is available, it can be used instead of the fire to remodel the pipe pieces.
Always use gloves to handle chlorine. In case of contact with chlorine, rinse abundantly with water.

III BlueTap chlorinator - Installation manual (written by Tom Stakes, BlueTap)

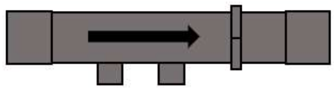
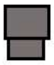
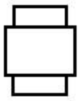
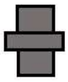
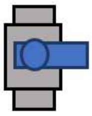
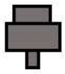
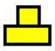
Chlorine Doser Installation Instructions

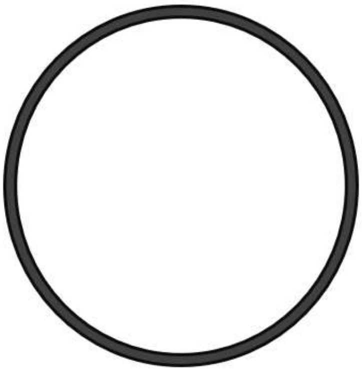
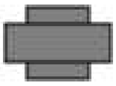
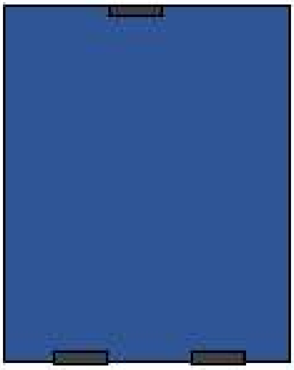


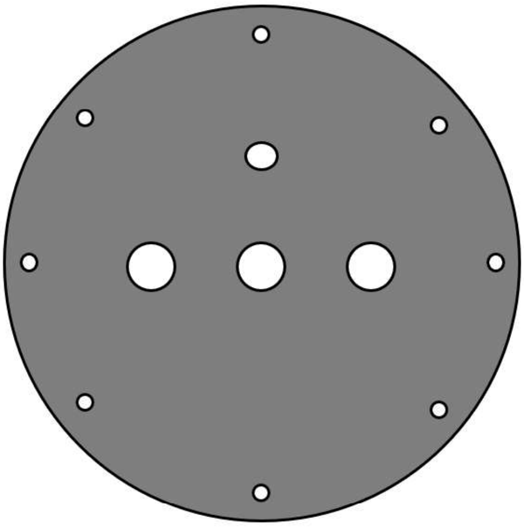
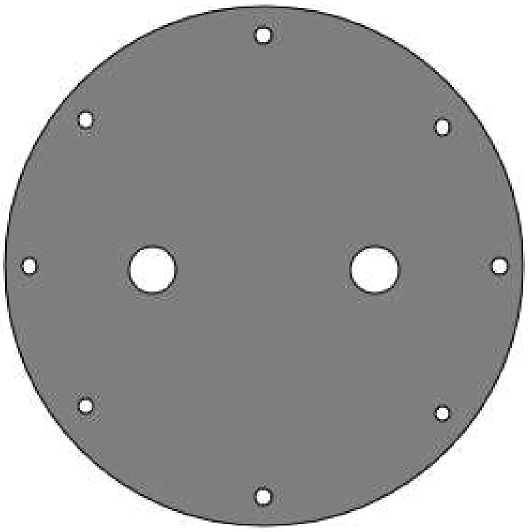
Required tools

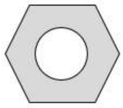
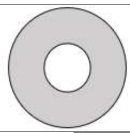
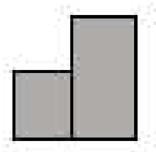
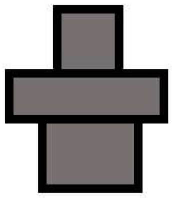
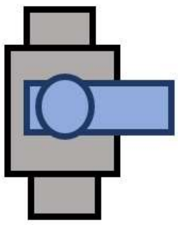
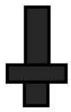
- Pipe cutters
- PTFE tape
- PVC Cement
- 2 x 8mm wrench
- 2 x pipe connector to thread into a 1" BSP thread
- 1 x particle filter
- 3 x ball valve
- 2 x T-junction
- 2 x Elbow connector

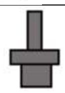
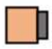
Kit list

Part	Identifier	Quantity	Diagram
Venturi Tube	BTCD - 001	1	
3/4" to 1" expander (F x F)	BTCD - 002	1	
Elbow valve	BTCD - 003	2	
3/4" spigot	BTCD - 004	2	
PVC check valve	BTCD - 005	1	
3/4" nipple	BTCD - 006	8	
3/4" PVC valve	BTCD - 007	1	
3/4" microtubing connector	BTCD - 008	2	
3/4" hose quick connect female	BTCD - 009	1	

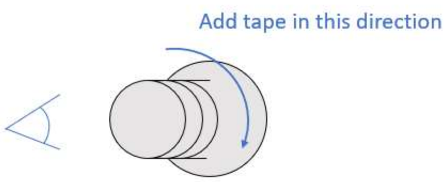
240mm o-ring	BTCD - 010	**2**	
3/4" union	BTCD - 011	3	
Flexible PVC bag	BTCD - 012	1	

Top lid with 4 threaded BSP ports	BTCD - 013	1	
Bottom lid with 2 threaded BSP ports	BTCD - 014	1	
250mm OD PE80 pipe section	BTCD - 015	1	

M8 threaded rod 0.5m	BTCD - 016	8	
M8 nuts	BTCD - 017	16	
M8 washers	BTCD - 018	16	
M8 adjustable feet	BTCD - 019	4	
M8 threaded connector	BTCD - 020	4	
3/4" elbow	BTCD - 021	1	
3/4" to 1/2" reducer (M x M)	BTCD - 022	1	
1/2" ball valve	BTCD - 023	2	
1/2" to 13mm hosetail	BTCD - 024	3	

1/2" pressure relief valve	BTCD - 025	1	
3/4" hose quick connect male	BTCD - 026	1	
3/4" to 13mm hosetail	BTCD - 027	1	
13mm hose	BTCD - 028	0.5m	
Hosetail for elbow valve	BTCD - 029	1	
3/4" hose	BTCD - 030	1m	
3/4" hose quick connect hose adapter	BTCD - 031	2	
1.6mm ID PVC tubing	BTCD - 032	5m	

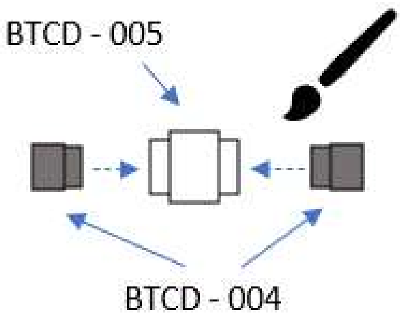
NOTE – before threading component wrap PTFE tap once around the thread. The tape should be wrapped clockwise as you are looking at the thread, as in the diagram below:



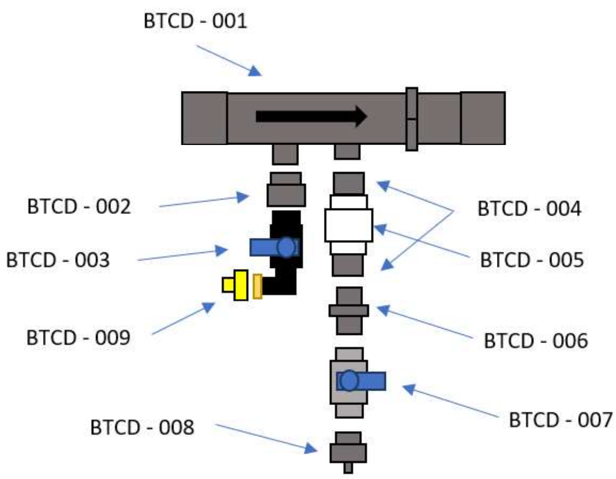
INSTALLATION INSTRUCTIONS

Assembling inline dosing section

1. Join the ¾" PVC spigots to the PVC check valve using the PVC cement
2. Leave to set for as long as is required

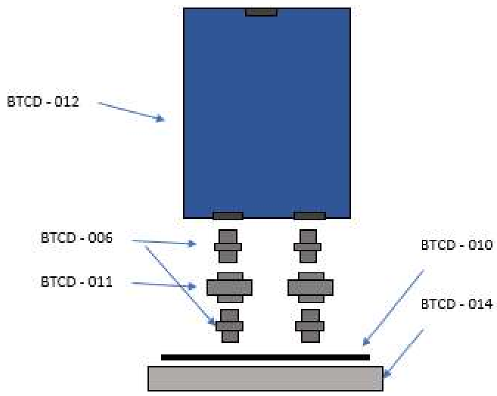


3. Assemble the components for the inline dosing section as shown in the diagram below
    a. Ensure that the arrow is facing the direction shown in the diagram

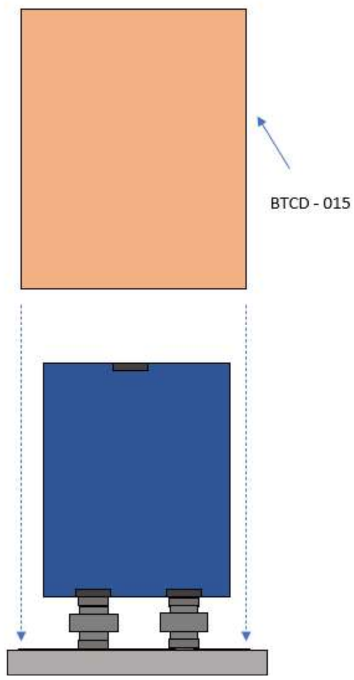


Assembling the internal pressure vessel

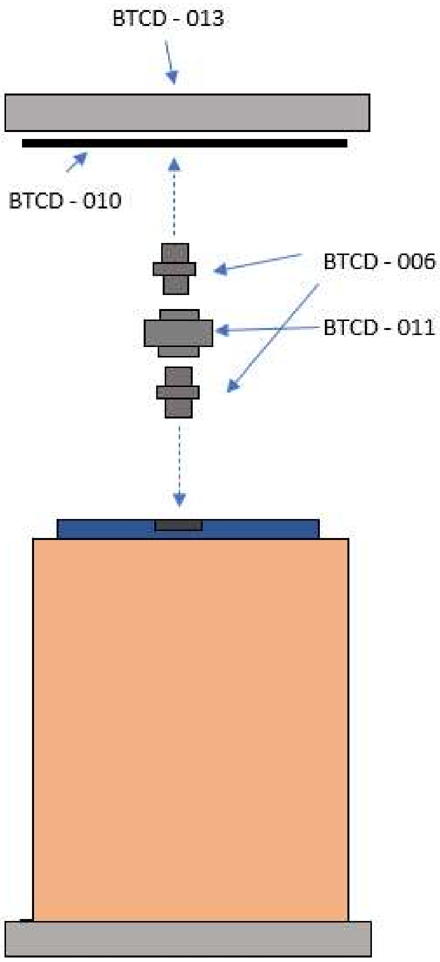
1. Place the 240 mm o-ring into the groove on the inside of the bottom lid
2. Thread two ¾" nipples into the holes in the bottom lid
3. Thread two ¾" nipples into the connectors on the bottom of the PVC bag, as show in the diagram below
4. Connect the PVC bag to the bottom lid using two ¾" union



5. Slide the PE80 pipe over the PVC bag so it sits in the groove in the bottom lid, on top of the O-ring

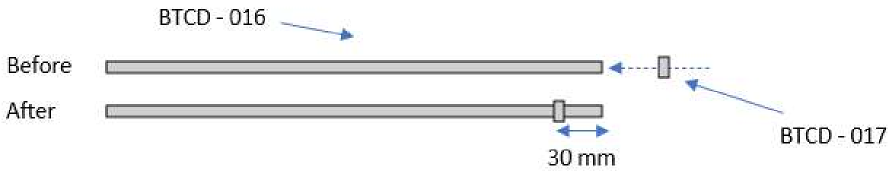


6. Thread a ¾" nipple into the top lid – make sure this is threaded into the same side as the groove for the O-ring
7. Place an O-ring in the groove in the top lid
8. Thread a ¾" nipple into the top oof the PVC bag
9. Connect the top lid and the PVC bag using a ¾" union as shown in the diagram below

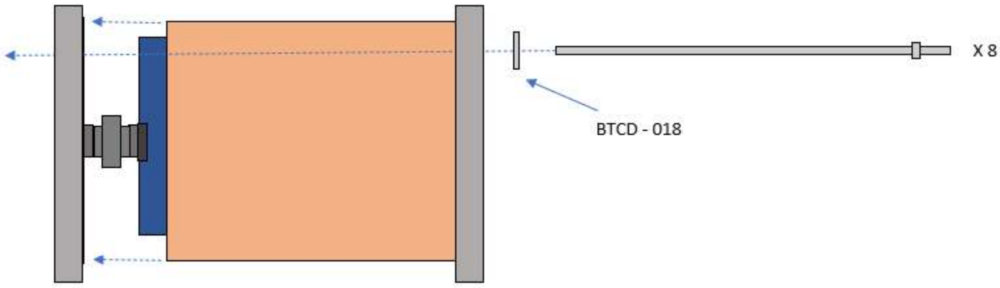


Assembling the external pressure vessel

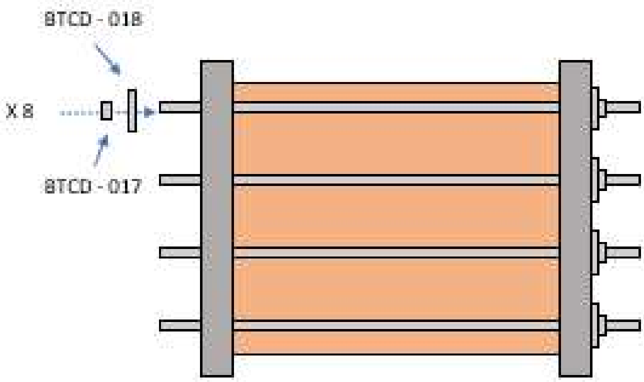
1. Thread an M8 nut onto the M8 rod so that the nut is 30mm from the end of the rod
2. Repeat this for all 8 M8 rods



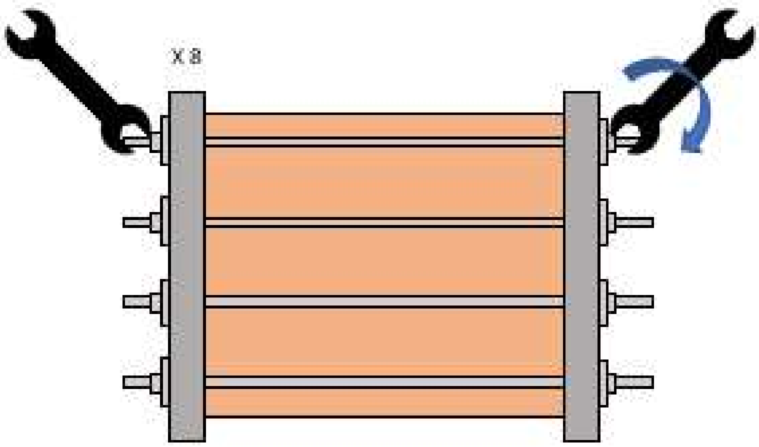
3. Slide the M8 rods through holes in the bottom and then the top lid. Ensure an M8 washer is placed between the nut and the lid
4. Repeat this for all M8 rods
5. Slide the open end of the PE80 pipe into the groove on in the top lid



6. Place an M8 washer over the open end of each of the M8 rods on the top lid
7. Thread an M8 nut onto the open end of each M8 rods so that it is flush with the M8 washer

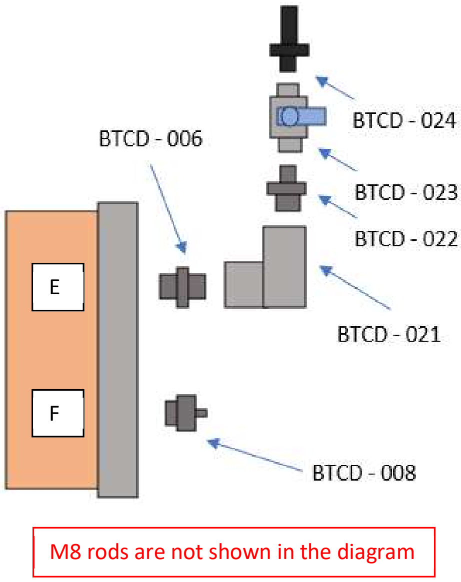


8. Tighten the nuts on the pressure vessel using two M8 spanners as shown in the diagram below
9. Repeat for all 8 rods



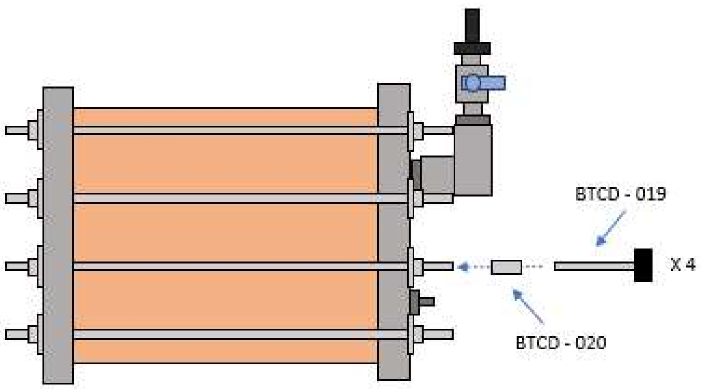
Assembling the bottom lid plumbing

1. Assemble the components on the bottom lid (with two holes) as shown in the diagram below
    a. BTCD – 006, 021, 022, 023 and 024 are threaded into hole **E**
    b. BTCD – 008 is threaded into hole **F**



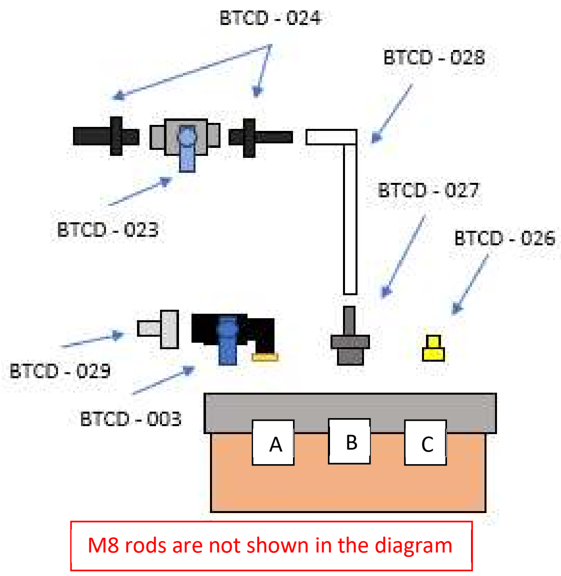
Adding the feet to the pressure vessel

1. Attach the M8 threaded connector and an M8 adjustable foot to the end of an M8 rod on the bottom lid
2. Repeat for four of the rods on the bottom lid, attaching the connector and the foot to **alternate** rods

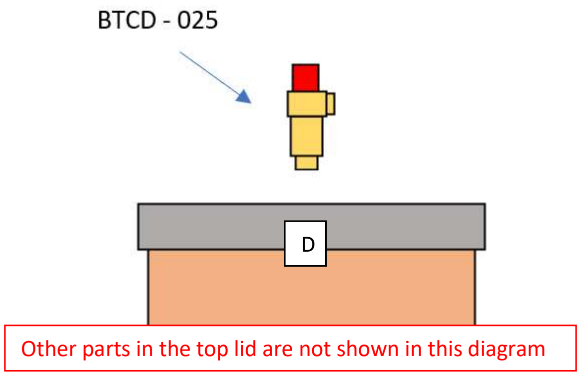


Assembling top lid plumbing

1. Assemble the components on the top lid (with four holes) as shown in the diagram below
   a. BTCD – 003 and 029 are attached to hole **A**
   b. BTCD – 027, 028, 024 and 023 are attached to hole **B**
   c. BTCD – 026 is attached to hole **C**

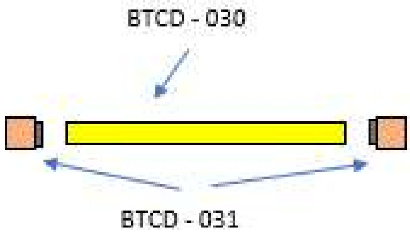


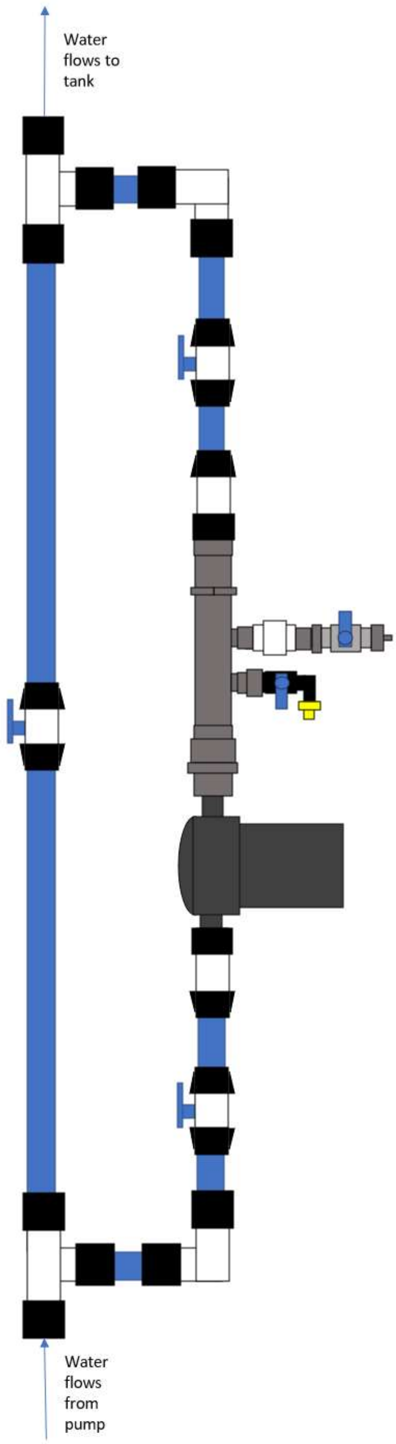
2. Thread the pressure relief valve into hole **D**



Assembling the pressurization tube

1. Attach the ¾" quick connect hose adapters to the ¾" hose as shown in the diagram below

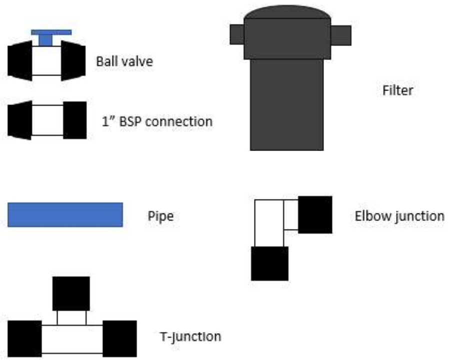




Inserting the Venturi Tube into the pipe

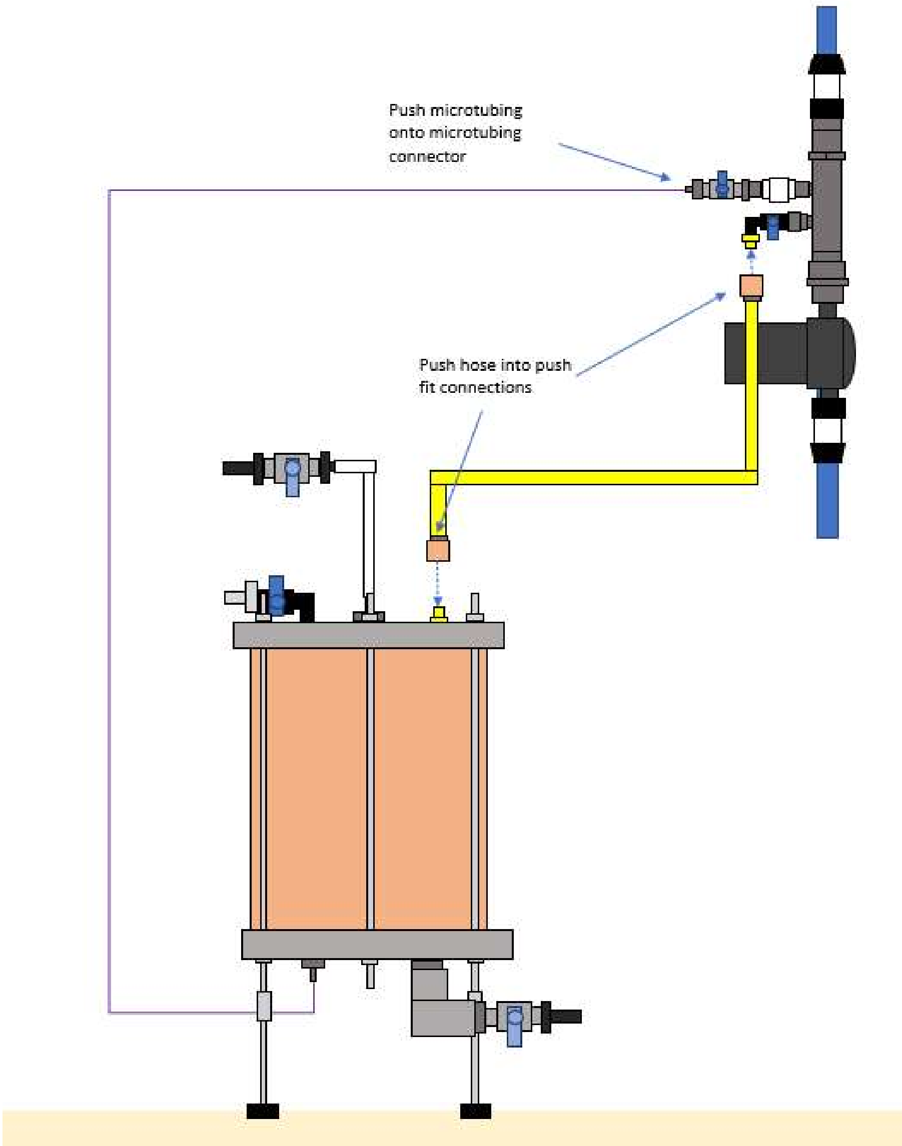
1. Insert the Venturi tube and particle filter into the inlet pipe to the storage tank. The Venturi Tube and particle filter should be installed on a bypass as shown in the diagram

a. Refer to the cover image which shows how the bypass fits into the tank inlet pipe



Attaching the pressure tubing and the micro tubing

1. Push the microtubing onto the microtubing connector on the Venturi tube and the microtubing connector on the bottom lid, as shown in the diagram
2. Attach the yellow pressurization tubing to the hose connectors on the Venturi tube and the top lid, as shown in the diagram
    a. The tubing may need to be shortened to ensure there are no kinks in the tube



IV BlueTap chlorinator - Refill and dosage manual (written by Tom Stakes, BlueTap)

Thomas Stakes (BlueTap)

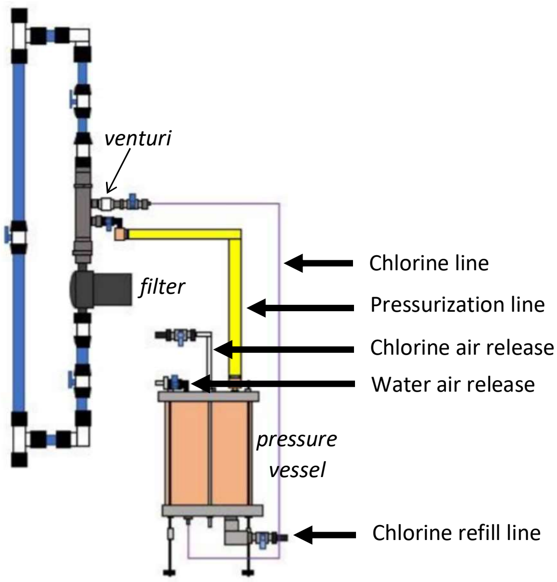
The Doser Explained

The doser might look complex but it's not as complex as it looks. Inside the pressure vessel is a bag of chlorine. Water from the mainline pipe surrounds this bag.

There is therefore, a line to put the water into the vessel, called the pressurisation line and a line to get chlorine from the bag into the venturi called the chlorine line.

The other two things on the top are both for releasing air when it gets trapped.

The other important line is the refill line on the bottom of the chlorine doser. This is used for refilling the chlorine bag with chlorine.



Refilling the chlorine doser

The doser must be topped up every 3000L of water that passes through it. At a flow rate of 30l/min this is about every 1.5 hrs of pump operation. At 60l/min it would be every 45 mins. If this is the first ever refill, fill the pressure vessel with water by turning on the pump and opening the pressurization line valve.

1. Ensure the pump is off so no water is passing through the doser. If you can, close the pressurisation line valve before you do this.
2. Close the pressurisation line valve (if you haven't already) and the venturi line valve.
3. Place the bucket of chlorine on top of the doser.
4. Attach the hose to the tap on the bucket of chlorine and secure with a hose clip. (note this only needs to be done on the first refill).
5. Attach the other end of the hose to the hose barb on the refill line and secure it with a hose clip.
6. Put the end of the chlorine bag air release into a closed container such as a jerry can.
7. Open the water air release valve and place the end of the hose into the jerry can.
8. Open the chlorine refill line valve and open the tap on the bucket of chlorine.

Thomas Stakes (BlueTap)

9. You should see water come out of the water air release line and into the jerry can, this indicates that the chlorine is refilling.
10. Whilst the chlorine is refilling, open the chlorine air release valve to release any trapped air in the bag. When chlorine starts to come through this line, close the valve.
11. When water the water stops coming out of the water release line, the refill is complete. Close the valve on the chlorine refill line.
12. Close the valve on the water air release.
13. Open the pressurisation line valve and the chlorine line valve.
14. Turn the pump back on. If possible, open the water air release valve to release any trapped air in the pressure vessel. Note that shutting the valve on the pressurisation line before you turn the pump off means that you don't have to do this.
15. When the chlorine bucket is empty or nearly empty. PUT ON GLOVES, remove the hose from the bucket and carefully put the end of it into the jerry can to drain the remaining chlorine in the chlorine line. Once the chlorine line is empty, tuck the top of the tubing away so that it does not lie on the ground.

Adjusting the Dose of the Chlorine Doser

When installing the doser, we tend to start with the lowest chlorine dose and adjust it higher if required. Therefore the main process you will need is increasing the dose.

To increase the dose

1. Ensure the pump is off. If you can, close the pressurisation line valve before you do this.
2. Decide how much you want to change the dose by. This will determine how much microtubing you want to cut off. A general rule is that to increase the dose by 10%, cut off half a meter of microtubing. Decide how much microtubing you want to cut off. We will call this length the CUTOFF LENGTH.
3. Close the pressurisation line valve.
4. Close the chlorine line valve.
5. Release the pressure in the pressure vessel using the water air release valve.
6. PUT GLOVES ON
7. Pull the chlorine microtubing off the microtubing adapter which is connected to the Venturi. Keep this tubing ABOVE the level of the chlorine doser.
8. Clamp the microtubing so that the clamp is the CUTOFF LENGTH away from the end.
9. Cut the microtubing around 5cm (2") away from the clamp on the side of the clamp which is closest to the Venturi.
10. Put the new end of the microtubing back onto the microtubing adapter and unclamp the clamp.
11. Open the pressurisation line valve and the chlorine line valve.
12. Turn the pump back on. If possible, open the water air release valve to release any trapped air in the pressure vessel. Note that shutting the valve on the pressurisation line before you turn the pump off means that you don't have to do this.

To decrease the dose

For this, you need to completely replace the microtubing. You may want to change to lower diameter microtubing if you need a dramatically lower dose. This process is much easier if the chlorine bag is relatively empty before you begin.

1. Ensure the pump is off. If you can, close the pressurisation line valve before you do this.
2. Decide how long the microtubing should be and cut some spare microtubing to this length. Each half meter extra of microtubing decreases the dose by around 10%.
3. Close the pressurisation line valve (if you haven't already)

Thomas Stakes (BlueTap)

4. Close the chlorine line valve.
5. Release the pressure in the pressure vessel using the water air release valve.
6. PUT GLOVES ON
7. Remove the microtubing from the microtubing adapter which is connected to the Venturi
8. Put the end of this microtubing into a jerry can on the floor and let it drain of chlorine. This will take a while as the whole chlorine bag will be draining.
9. When the microtubing has finished draining, place a small cup or other container underneath the microtubing adapter which is attached to the bottom lid. Then remove the microtubing from this adapter by carefully pulling it.
10. Attach the new tubing to both microtubing adapters.
11. Open the pressurisation line valve and the chlorine line valve.
12. Turn the pump back on. If possible, open the water air release valve to release any trapped air in the pressure vessel. Note that shutting the valve on the pressurisation line before you turn the pump off means that you don't have to do this.

V Summary of sites characteristics

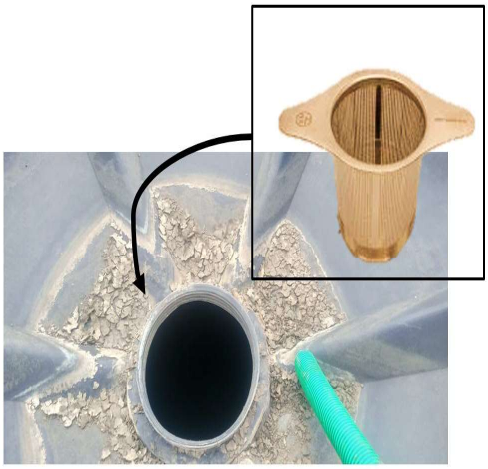
	Kyuso	**Kivui**	**Mitamisy**	**Kitumbini**	**Mumo**	**Ivonyanga**
FundiFix management	partial	full	full	full	partial	partial
Kiosk operation	non-automated	automated	automated	automated	non-automated	automated
Chlorinator	T-chlorinator	T-chlorinator	AkvoTur	AkvoTur	BlueTap	BlueTap
Chlorine type	TCCA tablets	TCCA tablets	TCCA tablets	TCCA tablets	NaOCl solution	NaOCl solution
Target FRC	$\sim$ 1.3 mg/l	$\sim$ 1.3 mg/l	$\sim$ 1.5 mg/l	$\sim$ 1.1 mg/l	$\sim$ 1.5 mg/l	$\sim$ 1.5 mg/l
Water source	surface	groundwater	groundwater	groundwater	groundwater	groundwater
Turbidity	$\sim$ 200 NTU	$\sim$ 5 NTU	$\sim$ 5 NTU	$\sim$ 5 NTU	$\sim$ 20 NTU	$\sim$ 5 NTU
Jerrycan experiments	yes	no	yes	no	yes	no

VI Poster on advice on chlorinated water consumption

The advertisement of chlorinated water consumption was posted at the six kiosks.

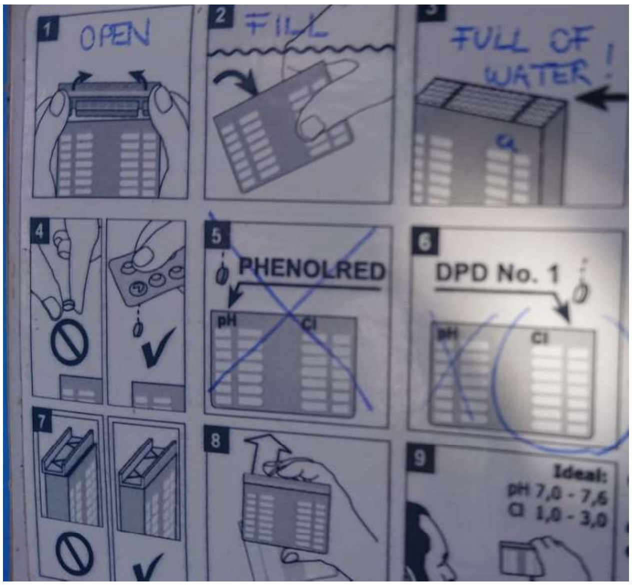
VII Reservoir outlet and tank, Kyuso rock catchment.

Water outlet of the Kathinge reservoir.



Left: tank of the Kyuso rock catchment and water pump powered by petrol. Right: upper part of the tank without lid, the water was pumped inside the tank using the green pipe; a picture of a filter is shown in the box.

VIII Step-by-step explanation on how to use the pooltester

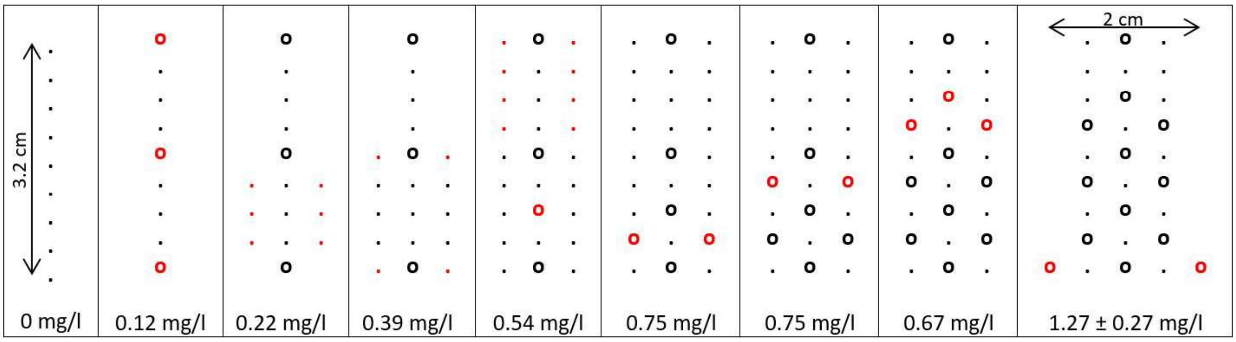


The step-by-step explanation was provided on the pooltester box distributed to the kiosk operators for the chlorine monitoring.

IX Central tendency and dispersion of 30 min, 12 h, and 24 h chlorine demand in jerrycans

	Kyuso			Mitamisyi			Mumo		
chlorine demand	**30 min**	**12 h**	**24 h**	**30 min**	**12 h**	**24 h**	**30 min**	**12 h**	**24 h**
mean (mg/l)	1.0	2.1	2.3	0.3	1.1	1.6	0.1	0.4	0.5
SD (mg/l)	0.2	0.4	0.3	0.2	0.7	0.4	0.1	0.1	0.1
n (-)	9	8	2	20	20	11	10	10	8

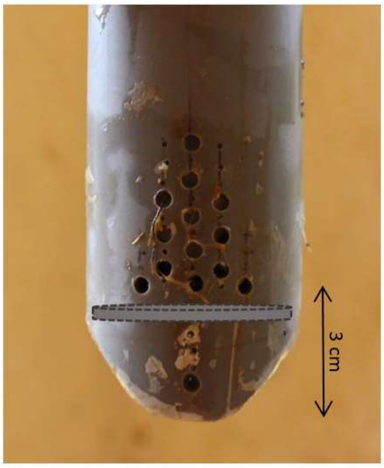
X T-chlorinator chlorine dosage adjustment - holes drilling on cylinder



Legend: . 1mm drill o 3 mm drill red: modifications from the previous setting

Specifications:

- Q $\sim$ 50 l/min through the chlorinator
- Chlorine cylinder: filled with TCCA tablets (uneven shape)
- Vertical distance between holes = 4 mm
- Horizontal distance between holes = 5 mm



Comments:

- Adding holes in the top part does not change the dosage as adding them in the lower part of the cylinder.
- The first line of holes is places 3 cm from the bottom of the cylinder.
- The three holes below the disk allow any residual water to flow out the cylinder bottom.

XI Statistical results of Wilcoxon test. Difference in the average 24 h and 30 min chlorine decay in clean versus uncleaned jerrycans

		Kyuso		Mitamisyi		Mumo	
		clean	unclean	clean	unclean	clean	unclean
24 h chlorine demand	**n**	0	2	4	7	3	5
	p	NA		0.78		0.14	
	W	NA		12		13	
	r	NA		0.09		0.53	
30 min chlorine demand	**n**	2	7	6	14	3	7
	p	0.47		0.32		0.36	
	W	10		29.5		15	
	r	0.24		0.22		0.28	

W corresponds to the Wilcoxon test statistic, and r corresponds to the effect size of the difference between groups.