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Solar Bag: A Water Disinfection Alternative for Rural and Remote Communities of the Peruvian Amazon

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in the Hubert Global Health Department
2018

Abstract

Solar Bag: A Water Disinfection Alternative for Rural and Remote Communities of the Peruvian Amazon

By Karin Camila Boynton

BACKGROUND: The remote communities of Perú represent portions of the population that are traditionally underserved in the water sector. While the Government of Perú recognizes its responsibility in the continued improvement of water services for rural populations, it has requested assistance in evaluating feasible alternatives to traditional water treatment modalities. In 2016, CARE Perú implemented an innovative solar disinfection technology in Bellavista, a rural and remote village in the Peruvian Amazon. The Solar Bag technology is composed of a water bladder with a titanium dioxide-coated mesh insert. The Solar Bag uses solar energy to activate a photochemical process that produces purified water appropriate for human consumption.
METHODS: This thesis was part of an existing CARE project, “Mi Bolsa Solar,” and used in-depth interviews and observations of eight female, head-of-household participants to identify gaps between knowledge and practice of the Solar Bag disinfection process and level of social appropriation of the Solar Bag technology. The CARE Peru Key Performance Indicators (KPI) served as the basis for the design of the qualitative study tools.
RESULTS: Themes extracted from the interviews included satisfaction with the Solar Bag product, health improvements, quality of the water from the Solar Bag, and the supply of Solar Bags and accompanying materials. Analysis revealed that a health promoter’s unwillingness to supply materials can be a barrier to the use of the Solar Bag. Analysis also showed that in the disinfection process, applying the alum, performing the sedimentation, emptying the bags, disinfecting the storage container and/or storing improperly can affect the quality of the water produced by the Solar Bag, thereby impacting participant satisfaction. Lastly, according to CARE’s monitoring and evaluation plan, the project had two positive outcomes related to social appropriation: high use of the Solar Bag on the day of visit and a high level of participant satisfaction. However, a third variable showed that participants did not appropriate the technology because it was not available in the rural market.
DISCUSSION: In conclusion, CARE Perú may need to consider providing more workshops that target quality control. Furthermore, potential changes in the design of the Solar Bag can help improve the user experience.

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Chapter 1: Introduction

Background on the project

CARE International has been working with the Government of Perú (GoP) in scaling access to safe drinking water across the country since 1983 (CARE, 2016). These projects focused on improving water supplies and strengthening the national infrastructure to pave the road for the scaling of drinking water services. The CARE-GoP partnership has helped produce a national, overall improvement of safe drinking water coverage from 55% in 1990 to 78% in 2015. This general trend includes an increase in the estimated proportion of the rural population using improved water sources from 44% in 1990 to 78% in 2015 (Joint Monitoring Programme for Water Supply and Sanitation, 2015).

Rural and remote communities in Perú represent 3.3 million people or 12% of the national population (CARE, 2016). In comparison to urban areas, however, the Peruvian government has historically underserved the rural, Amazon communities in the water service sector where only 53% of the Ucayali province has access to potable water, compared to 91% in Lima (INEI, 2018). This disparity places the remote Amazonian communities in greatest need of water quality interventions (Alexander, 2017). While the GoP is committed to the continued improvement of drinking water services for rural and dispersed populations, it has requested assistance from CARE in evaluating low-cost alternatives to traditional drinking water infrastructure for these communities.

This thesis addresses the need of the GoP, while at the same time fulfilling the Emory Rollins School of Public Health (RSPH) requirement, "to apply the knowledge [students] have learned at Rollins into a public health setting," (Rollins School of Public

Health, 2018). To that end, this researcher partnered with CARE USA and CARE Perú to test an alternative water treatment device ("Mi Agua Solar") in the Peruvian Amazon. This project was a joint venture between CARE- Perú as the implementer of the "Mi Agua Solar" project; CARE-USA and USAID as sponsors; and Puralytics as the manufacturer and technical expert for the Solar Bag[1] water treatment technology. The Mi Agua Solar project resulted in three discrete data sets, two of which will be used for this thesis.

The Solar Bag technology

The "Mi Agua Solar" project makes use of the Puralytics-manufactured Solar Bag technology. Each bag consists of a plastic water bladder with a mesh insert and holds up to three liters of water. The mesh insert is coated with titanium dioxide (TiO_2) that absorbs UV radiation and disinfects the water, removing bacteria, viruses, protozoa, petrochemicals, herbicides, pesticides and heavy metals (Puralytics, 2017).

Image 1.1: The Solar Water Bag with the blue indicator dye added.

[1] The Solar Bag is usually marketed as gear for outdoor enthusiasts and emergency purposes.

Bellavista, Perú

In order to properly test the Solar Bag technology, it was necessary for CARE Perú to identify a community in need and want of a water treatment intervention. Working within the Amazon sector, CARE Perú set out to find a community which a) was rural and remote, b) had no government investment in water services, c) did not, at the time, benefit from municipal water delivery systems, d) had a population dependent on local, surface water, and e) had a population interested in participating in a water quality intervention (Mindreau, 2017). A visit in October 2016 determined that Bellavista met these requirements, and was therefore chosen as the intervention site.

The Mi Bolsa Solar Project was implemented for one year, from December 2016 to December 2017, in ten households across Bellavista in December 2016. The small village of Bellavista is located in the Peruvian Amazon, about one two miles east of the Ucayali River. The nearest town is Iparía, about 17 miles through jungle trails (See Map 1.1).

Map 1.1: Bellavista relative to the Ucayali River and the rest of Perú

The population of Bellavista varies with time and occupation. While some of the residents live in the village full-time, others are transient. For the most part, there are 10 - 15 families, and approximately 40-55 inhabitants in the village at any one time.

Before the "Mi Bolsa Solar" Project, the community members used the Huacashiria creek to meet all of its water and hygiene needs. Each family hauled about 75 L of water per day from the creek to their home. This water was used for all drinking, cooking, and washing. In the region, substantial rainfall increased the creek's water flow, which also increased the water's turbidity. The high turbidity requires users of this source to wait several hours for the water to sediment before consumption. Rainfall itself is also source of water, for as long as community members who have receptacles available for water collection.

In March 2017, CARE completed a preliminary assessment of the Mi Bolsa Solar project and uncovered information on common user mistakes in using the water technology. This researcher arrived on site in June 2017 and focused on gathering qualitative information from project participants about their knowledge of the bag disinfection process versus their actual practice of water purification. Additionally, the researcher attempted to determine the social appropriation of the Solar Bag technology at the household level. The results of this qualitative assessment would be used to inform the GoP on viable alternatives to traditional drinking water infrastructure.

Purpose and significance

This thesis will focus on assessing the social parameters of the "Mi Agua Solar" project, as outlined by CARE Perú's project Monitoring and Evaluation Plan (See table 3.1). The two major aims of this thesis will aim a) to identify gaps in knowledge and practice in the use of the Solar Bag technology and b) to determine the level of social appropriation of the Solar Bag as defined by CARE's monitoring and evaluation indicators. To conclude, this thesis will make recommendations to CARE Perú on lessons learned from the project and how future water treatment interventions within similar contexts may be improved.

Chapter 2: Literature Review

Background

Global status of drinking water

According to the United Nations, 663 million people live without access to improved drinking water sources and 1.8 billion people consume water contaminated by feces(United Nations, n.d.-a). In 2015, 159 million people could only access surface water (World Health Organization & UNICEF, 2017). In rural areas 80% of the population drinks water with basic treatment (The World Bank, 2018), up from 67% in 2000. The remainder of the world's population drinks water from limited, unimproved, or surface water sources.

Untreated water can be contaminated with waterborne pathogens, which in turn can cause an array of diseases, including diarrhea, dysentery, cholera, and typhoid. Globally, waterborne pathogens cause diarrheal diseases that kill two million people per year (World Health Organization, 2018). Additionally, untreated water may be polluted with inorganic materials, such as heavy metals. These can have a disastrous effect on the human nervous and reproductive systems.

Perhaps one of the most complex negative health effects from drinking untreated water is environmental enteropathy (EE). EE occurs when, "chronic exposure to fecal pathogens … cause inflammation and structural changes in the small bowel, which ultimately result in functional changes," (Korpe & Petri, 2012, p. 1). These functional changes can lead to malnutrition, which causes 21% of deaths in children under five years of age (Korpe & Petri, 2012)

Sustainable Development Goals and the Joint Monitoring Program

Sustainable Development Goal (SDG) 6.1 aims at making sure that by 2030, everyone has, “universal and equitable access to safe and affordable drinking water for all,” (United Nations, n.d.-a). That target will be evaluated with the following indicator: the “proportion of population using safely managed drinking water services,”(United Nations, n.d.-b).

The Joint Monitoring Program (JMP), the water and sanitation monitoring mechanism operated by UNICEF and the World Health Organization developed a “service ladder” for household drinking water that differentiates between the different types of water access. The five access categories include 1) safely managed 2) basic 3) limited 4) unimproved, and 5) surface water. The levels differentiate based on several parameters, including the protection of the water source, in-home access, and collection times (see Figure 2.1). For example, “basic” and “limited” access to drinking water involves collecting water from an improved water source. However, “basic” access requires no more than 30 minutes of collection time, while “limited” access may exceed 30 of minutes collection time (Borja-Vega & Aragon-Bricieño, 2018).

Drinking Water Ladder

SAFELY MANAGED	Drinking water from an improved water source which is located on premises, available when needed and free from faecal and priority chemical contamination
BASIC	Drinking water from an improved source, provided collection time is not more than 30 minutes for a roundtrip including queuing

LIMITED	Drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing
UNIMPROVED	Drinking water from an unprotected dug well or unprotected spring
SURFACE WATER	Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal

Table 2.1 – Drinking Water Ladder as adapted from the WHO/UNICEF Joint Monitoring Program, which categorizes different access to drinking water based on source protection, collection time, and in-home access.

Since SDG 6.1 calls for everyone to have access to "safely managed drinking water sources," the goal is in effect pressing for the highest quality of water for all (United Nations, n.d.-a).

Status of drinking water in Perú

Perú has had great advances in its progress towards the Sustainable Development Goals for access to drinking water. In 1990, only 55% of the total population had access to safely managed water (Joint Monitoring Programme for Water Supply and Sanitation, 2015). By 2015, these numbers had risen drastically to 78% of the total country population having access to safely managed water. This improvement is in part due to the government of Perú's reaction to the 1991 cholera epidemic. The incident motivated the restructuring of the Water and Sanitation framework, which decentralized water access management (Timoteo, 2000). However, important disparities come to light when comparing water access for urban populations in Perú versus rural populations. In 1990, 73% of urban dwellers had access to safely managed water, compared to only 13% of the rural populations. By 2015, although overall rates increased, the disparity remained; 86% of urban residents vs. 48% of rural residents were drinking from safely managed water.

Safely managed water is usually provided through municipal piped water networks. However, this traditional, centralized water infrastructure is expensive and unsustainable. This is especially the case for rural and remote populations, which rarely have the same access to treated water and government subsidies, as do urban dwellers (Mintz, Bartram, Lochery, & Wegelin, 2001). According to Mintz et al., "approaches that rely solely on time and resource-intensive centralized solutions will leave hundreds of millions of people without access to safe water far into the foreseeable future; a radical reorientation toward interventions to support these populations is urgently required," (Mintz et al., 2001, p. 1566).

Of the rural, Peruvian populations surveyed in 2015, 15% obtained water from surface water and unimproved sources (Joint Monitoring Programme for Water Supply and Sanitation, 2015). In Ucayali, the Amazonia province under focus, only 53% of households have access to potable water (INEI, 2018). The reasons for this urban-to-rural disparity have not yet been elucidated. In its 2017 report titled, "Progress on Drinking Water, Sanitation and Hygiene," the JMP argued that "further work is required to understand the relationship between inequalities in different elements of safely managed services, so that these can be more systematically monitored in the future," (Joint Monitoring Programme for Water Supply and Sanitation, 2017, p. 43).

From this researcher's observations, there are three main sources of water in the remote province of Ucayali: municipal piped water, rainwater, and surface water. The municipal water is available only in larger villages, with no current investment in the more remote populations. However, despite the municipal water access in these large villages, the flow of water is intermittent and unreliable. No official water quality reports were available to detail the microbiological quality of the piped water.

In an effort to alleviate the burden on centralized municipal systems and extend governmental assistance to underserved populations, a variety of alternative water purification technologies have been developed and implemented, both at the community- and household-level. According to Zin et al., point-of-use, household-based water treatment systems (technologies that treat water at the point where a user collects it) are the most cost-effective method of water purification, and – along with filtration, chlorination, flocculation and solar disinfection – hold great promise for the future of resource-limited areas (2013).

Alternatives for household-level water purification

While there are a vast number of ways to achieve water purification, the following review will focus on household-level water purification alternatives for natural rural settings. These alternatives include: boiling, chlorination & flocculation, filtration, and solar disinfection. All of these options are effective in reducing waterborne pathogens such as bacteria, viruses, protozoa, and fungi. For the purposes of this review, there will be a particular focus on the use of solar disinfection in the Americas.

Boiling

Boiling is a globally ubiquitous alternative to municipal water systems and has been used since ancient times as a method of water disinfection. It is easy to perform and therefore acceptable to most users across different cultures and socioeconomic status. Boiling involves applying heat to water until the temperature of the liquid rises to above 100°F. The hardiest pathogens, such as *Cryptosporidium parvum* and *Giardia*, are killed at temperatures ranging from 56-72°F. Allowing water to reach a roiling boil - as the WHO recommends in order to make water safe for human consumption - assures that the water has reached beyond that 56-72°F marker (World Health Organization, 2015). It provides a visual cue to the user that the water is finished disinfecting (CAWST, 2017) and may be allowed to cool before consumption. Boiling is useful against all pathogens, including *Campylobacter spp*., *Escherichia coli*, *Vibrio cholerae*, Hepatitis A, and *Giardia*. (World Health Organization, 2015).

While boiling as a water disinfection technique can be used in almost any context, it also has some limitations. Boiling requires fuel to create the heat applied to the water. Sosby (2002) points out that it takes about 1 kg of firewood to disinfect 1 L of water. This is a potential obstacle for consumers in resource-limited areas, as overpopulation and mismanagement of natural resources can lead to limited firewood supplies. Furthermore, there are opportunity costs related to gathering firewood such as missed education, employment, and childcare. Additionally, the use of indoor, solid-fuel cooking stoves contributes to fire-related burns and respiratory infections (World Health Organization, 2013). Even if other sources of biofuel are used (such as propane or butane in cook stoves), that fuel must be purchased, which represents an additional financial expense for households in developing contexts (Sobsey, 2002). Finally, while boiling is effective against all pathogens, it is not effective, against chemical contaminants. In fact, boiling will increase the concentration of harmful chemicals in drinking water, such as arsenic and lead (CAWST, 2017).

Chlorination and flocculation

First used in the United States and European public water systems in the 1900s chlorination is now used commonly as an inexpensive, simple (Sobsey, 2002), point-of-use water treatment system in developing contexts (Centers for Disease Control and Protection, 2014; Lantagne, Quick, & Mintz, n.d. ; Sobsey, 2002). Disinfection via chlorination involves adding a particular dose of chlorine compounds to water. Common forms of chlorine used include liquid and solid sodium hypochlorite, sodium dichloroisocyanurate tablet, and calcium hypochlorite (Sobsey, 2002; World Health Organization, 2005). Users applying the chlorination method follow packaging instructions, adding a designated dose of chlorine compound to the water. Afterwards, the water is agitated and allowed to sit for 30 minutes. This is the minimum amount of contact time necessary to inactivate pathogens in the water sample (Centers for Disease Control and Protection, 2014).

Chlorination is an effective disinfection technique for most bacteria and viruses. It is also an excellent option for storage, as the free chlorine residual will assure a continuous protective effect after initial disinfection. Chlorination is less effective against hardier, water-borne pathogens, such as protozoa. For example, the protozoa *Giardia lamblia* cysts necessitate more contact time with the chlorine than the standard 30-minute contact time with chlorine in order to be inactivated. Unfortunately, chlorination is completely ineffective against the parasite *Cryptosporidium parvum* (World Health Organization, 2005).

Furthermore, chlorination is not as effective in turbid waters and has the potential of being rejected by users due to taste and smell (Centers for Disease Control and Protection, 2014; Lantagne et al., n.d.). In terms of health impact, there are some concerns regarding the long-term health effect of exposure to the disinfection by-products of chlorine (Lantagne et al., n.d.). Finally, as is applicable to the Solar Bag project, there must be a reliable supply chain for chorine and opportunities to be conveniently purchased by users (World Health Organization, 2013).

Flocculation is often paired with chlorination and is used to clear highly turbid waters. Together, the methods are useful against bacteria, viruses, protozoa (Lantagne et al.) and some heavy metals (World Health Organization, 2013). Flocculation involves applying aluminum, iron, or lime salts to water. A chemical reaction ensues, resulting in charged particles that clump together and precipitate out of the water, or flocs (CAWST, 2017; Sobsey, 2002). The flocs can then be decanted out of the clean water. The elimination of this turbidity often helps with the microbiological quality of the water, as some pathogens attach themselves to the flocs and are removed along with the turbidity-causing particles (CAWST, 2017). Flocculation is very useful against turbid waters and heavy metals. A major disadvantage of the technique is that it involves multiple steps, necessitating a demonstration of the technique to new users (Lantagne et al., n.d.). Similar to chlorination, flocculation also requires a reliable supply chain in order for users to be able to purchase the chemical products (World Health Organization, 2013).

Filtration

Filtration – a popular alternative to water purification in the Water, Sanitation, and Hygiene (WASH) sector, developing contexts, and the market place – treats water by physically removing pathogens (Clasen et al., 2015). According to the CDC, the technique consists of "a physical process that occurs when liquids, gases, dissolved or suspended matter adhere to the surface of, or in the pores of, an absorbent medium," (Centers for Disease Control and Prevention, 2014a). Filtering devices incorporate different absorbent mediums in a variety of different manners, creating a plethora of filtering technologies, including ceramic and carbon filters (World Health Organization, 2005), granular media (i.e. sand), and fabric filters (Sobsey, 2002). Therefore, the use of these filters will depend on the unique instructions for the different devices.

Filters differ primarily by the size of pores in the absorbent medium. There are three pore sizes: micro, ultra, and nano. Microfiltration filters have pores sizes that range from 0.05 – 5.0 microns. Ultrafiltration devices have pores sizes ranging from 0.001-0.05 microns. Nanofiltration filters have pores sizes ranging from 0.008-0.01 microns (Centers for Disease Control and Prevention, 2014a). These differing pore sizes determine the type of pathogen affected. While a nanofiltration device is generally the most effective against protozoa, bacteria, and viruses, a microfiltration device is still effective against the larger pathogens such as *Cryptosporidium* and *Giardia* (Centers for Disease Control and Prevention, 2014a).

However, even nanofiltration devices are not guaranteed to remove all of the smaller diarrhea-causing pathogens, including bacteria such as *Campylobacter and E.*

coli, and viruses such as noro- and rotavirus (Centers for Disease Control and Prevention, 2014a; Lantagne et al.; World Health Organization, 2005). Also, there is no residual chlorine protection with filtration techniques, leaving the filtered water open for re-contamination (Lantagne et al., n.d.). Furthermore, filters often require cleaning maintenance, or back flushing, in order to remain clean of debris and effective against turbidity and pathogens. As is the case with the ceramic filters, users must be taught the correct filter cleaning techniques or risk damaging the device (Lantagne et al., n.d.). Finally, there is a dearth of studies on the health impact of different filtering devices(Lantagne et al., n.d.). Without this data, it is not possible to fully compare the health advantages of different filtration techniques with the other methods of water disinfection.

SODIS

Background

Solar disinfection (SODIS) is a popular method of disinfection across the world. McGuigan's systematic review on the existing literature on SODIS revealed that "the method has spread throughout the developing world and is in daily use in more than 50 countries in Asia, Latin America, and Africa," (McGuigan et al., 2012, p. 30) since it was first developed in the 1980s as a quick solution to disinfecting water meant for oral rehydration solutions (Centers for Disease Control and Prevention, 2014b). In 1991, the Swiss Federal Institute for Environmental Science and Technology began its investigation into SODIS as a household-level water purification system (Lantagne et al., n.d.). Since that time, it has been found that SODIS is highly accepted by users since it is inexpensive and easy to assemble, using readily available materials such as sunlight and plastic/glass bottles (Lantagne et al., n.d.). Additionally, the initial cost of the bottle purchase is the only financial investment required for this disinfection technique, limiting the amount of capital investment necessary to use the technology (World Health Organization, 2013).

The essence of SODIS is the inactivation of microbes through sunlight and UV radiation. In his 2004 review, "The Inactivation of Microbes by Sunlight: Solar Disinfection as a Water Treatment Process," Reed explains the difference between the two forms solar disinfection: optical and thermal. In optical disinfection, photosensitizer molecules in cells or the surrounding water absorb UV rays. By absorbing the UV rays, the molecules reach an excited state, causing chemical reactions that affect DNA, proteins, and lipids. These reactions lead to cell death, which in this case means the death of some waterborne pathogens (Reed, 2004). In thermal disinfection, the sunlight raises the temperature of the water to a point that is inhospitable to microbes. In other words, solar pasteurization occurs (Reed, 2004). SODIS takes advantages of both optical and thermal disinfection in order to inactivate diarrhea-causing pathogens (Centers for Disease Control and Prevention, 2014b).

Globally, SODIS is best used in between latitudes 15°N-35°N, and 15°S-35°S (CAWST, 2017) as these geographic regions receive sufficient, year-round sunlight to power the solar disinfection process. According to one study, it is necessary to expose the water-filled bottles (reactor) to $500W/m^2$ (Oates, Shanahan, & Polz, 2003) and 50-55°C for three to five hours (Sobsey, 2002) in order to reach pathogen inactivation thresholds.

Benefits and drawbacks of SODIS

There are many benefits to the SODIS technology. First, the technology is highly acceptable to users since it is simple and easy to implement. Second, while differing studies will be discussed below, there is a general consensus that SODIS has a proven positive impact on human health. Also, the use of a plastic bottle with a narrow neck helps to prevent recontamination of disinfected water (Lantagne et al., n.d.). Most importantly, SODIS is effective against a range of bacteria, viruses, and some protozoa, including *Cryptosporidium* and *Giardia* (Centers for Disease Control and Prevention, 2014b; Lantagne et al., n.d.).

However, the effectiveness of SODIS in removing pathogens decreases with the increase of water turbidity. Furthermore, the process requires plenty of time (minimum of six hours) and sunny weather in order to function. While the plastic bottles are durable, they require occasional replacement, necessitating a stable supply chain. Similarly, one user must employ multiple bottles in order to disinfect a sufficient volume of water for everyday use (Centers for Disease Control and Prevention, 2014b). Also, since there is no chlorine residual, the SODIS-treated water can become contaminated again (Sobsey, 2002). Finally, the user must be careful in selecting the type of plastic used in the SODIS process. For example, bottles made out of polyvinyl chloride (PVC) should not be used, as unwanted chemicals can leach into the treated water (CAWST, 2017).

Steps for SODIS method

In order to employ the SODIS method, users fill a 2-L polyethylene terephthalate (PET) with contaminated water. The bottom-facing side of this bottle should be painted black, in order to enhance the thermal disinfection effects (McGuigan et al., 2012). The user should then shake the bottle to oxygenate the sample (Centers for Disease Control and Prevention, 2014b), and then placed on a reflective surface in order to enhance optical inactivation (McGuigan et al., 2012). If it is a sunny day, the bottled should be exposed to the sun for six hours. If the weather is cloudy or overcast, the bottled should be exposed for two days (Centers for Disease Control and Prevention, 2014b).

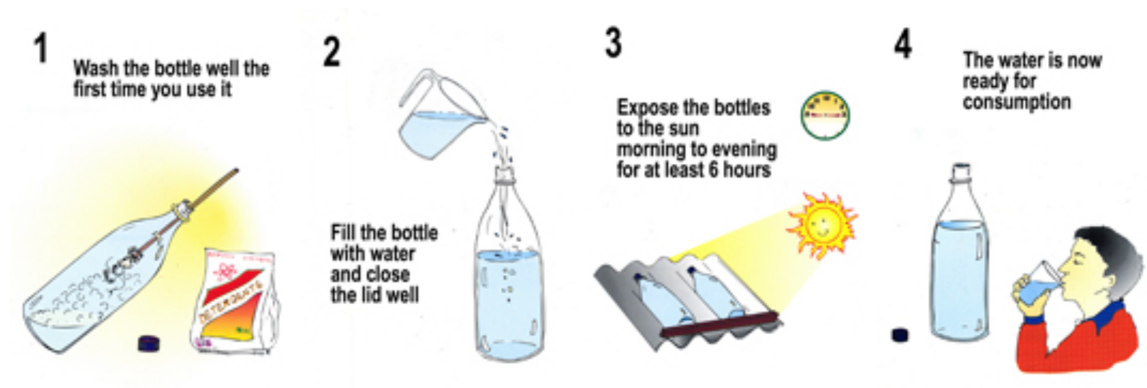


Figure 2.2 – Steps for SODIS Use (SODIS, 2018)

Enhancements to the basic SODIS model

There are a variety of enhancements, or alternations, to the basic SODIS model. Various laboratory-based, experimental studies have been conducted where researchers changed an aspect of the basic SODIS model in an attempt to enhance its disinfecting properties. Dessie et al. (2014), Amin et al. (2009), and Tedeschi et al. (2014) investigated the effects of differing factors that affect microbial inactivation, including water depth of reactor (water bottle), turbidity of water in the reactor, and reactor type and color. Borde et al. (2016) honed in on reactor size and the SODIS system's ability to produce large amounts of disinfected water. Gelover et al. (2006) and Mendez-Hermida et al. (2007) looked at the addition of Titanium Dioxide (TiO_2) to SODIS reactors and the effect on microbial inactivation.

Water depth, water turbidity, and reactor type: Dessie et al.'s 2014 study, "Solar disinfection: an approach for low-cost household water treatment technology in Southwestern Ethiopia," examined different aspects of SODIS in the inactivation of fecal coliforms. Clear and black PET bottles were filled with water of differing depths, pH, and turbidity and exposed to different solar intensities and water temperatures. Results showed greater fecal coliform inactivation was seen in water samples that: a) had reactors with shallower water depths; b) had lower turbidity measurements; and c) had reactors that had black paint on the bottom side. On the other hand, the positioning of the reactor, and water pH were not found to be associated to fecal coliform inactivation (Dessie A, 2014).

Tedeschi et al.'s 2014 study, titled "A pilot study of solar water disinfection in the wilderness setting," claimed to evaluate the use of SODIS in a Costa Rican wilderness setting. In actuality, the study focused on different drinking water containers available to the experienced wilderness trekker: Nalgene, Platypus, and PET bottles – the latter used as controls. These bottles were filled with water samples from a stagnant stream and placed on a reflective tarp, an item also commonly used by backpackers. *E. coli* and total coliforms were used as indicators of contamination. Results showed that all three container types had similar effects on decreasing *E. coli* and total coliforms in the sampled water (Tedeschi, Barsi, Peterson, & Carey, 2014).

Plastic bags as reactors: One other alteration to the standard SODIS model is the practice of using plastic bags instead of glass or plastic bottles. The review will look at two of those studies: Walker et al.'s 2004 "Development and evaluation of a reflective solar disinfection pouch for treatment of drinking water," and Dunlop et al.'s 2011 "Inactivation and injury assessment of Escherichia coli during solar and photocatalytic disinfection in LDPE bags." These two studies will be discussed later under the subheading "SODIS Studies with Similar Context to Bellavista."

Walker et al's 2004 study, titled, "Development and evaluation of a reflective solar disinfection pouch for treatment of drinking water," examined the effectiveness of a plastic pouch made from "food-grade, commercially available packaging materials," (Walker, Len, & Sheehan, 2004, p. 2545). The researchers made two versions of the pouch, one with reflective material and one with absorptive. Spring water was then artificially contaminated with *E. coli*, *Staphylococcus aureus*, *Salmonella enterica serovar*, or *Shigella sonnei* and then exposed to sunlight for six hours. Results showed decrease in pathogen load across all species. The authors therefore concluded that SODIS could be effectively adapted to plastic bag/pouch format with readily available material (Walker et al., 2004).

Dunlop's et al.'s 2011 study, "Inactivation and injury assessment of Escherichia coli during solar and photocatalytic disinfection in LDPE bags," looks at the use 2-L, of food grade low density polyethylene (LDPE) bags with a variety of modifications, and their effect on water artificially contaminated with *E coli*. Researchers in Ireland developed plastic pouches with a two-layered bottom. A reflective, absorptive, or composite material was placed between these two plastic layers in order to test different thermal and optical disinfection effects. TiO_2 powder was added to one of the reactors (which version was not specified). Results from the basic modifications – without any

TiO_2 powder, absorptive, or reflective materials – the pouch functions as a water disinfection device, achieving disinfection in 150 minutes. The modifications with reflective, absorptive, and TiO_2 material showed similar results in 120 and 90 minutes, respectively. The authors conclude that since the TiO2 powder was found to enhance SODIS disinfection, further efforts should be devoted to find a practical solution to the immobilization of the TiO_2 catalyst (Dunlop, Ciavola, Rizzo, & Byrne, 2011). In such a way, the catalyst (i.e. TiO_2) does not have to be decanted from the water sample after disinfection is complete.

Titanium dioxide: Several authors have published articles on the increased effectiveness of the SODIS process when titanium dioxide-coated materials are used in conjunction with standard reactors. TiO_2 is a metal oxide, wide-band semi-conductor (Byrne, Fernandez-Ibañez, Dunlop, Alrousan, & Hamilton, 2011). When irradiated with light, this semi-conductor will become excited, transferring an electron from the valence band to the electron band. This movement of electrons leaves what is called an "electron-hole pair" (Byrne et al., 2011). When these charged particles reach the TiO_2 material, a redox reaction occurs, producing reactive oxygen species (ROS). These ROS can destroy a range of chemical and biological water pollutants (McGuigan et al., 2012).

Gelover et al.'s 2006 study, "A practical demonstration of water disinfection using TiO2 films and sunlight," aimed to show the effectiveness of TiO_2 –coated reactors in eliminating fecal and total coliforms from naturally-polluted spring water. Additionally, the study aimed to measure the regrowth of bacteria in the samples once the disinfection process was complete (Gelover, Gomez, Reyes, & Teresa Leal, 2006). Researchers placed a reactor consisting of a TiO_2-coated, Pyrex glass cylinders within 2-

L PET bottles. This reactor was placed inside an aluminum-coated reflective box and exposed to the sun. Results showed that the TiO_2 SODIS reactors were more efficient at removing fecal and total coliforms, compared to the basic SODIS models. Additionally, the TiO_2-enhanced process showed no bacterial re-growth, a benefit not shared by the basic SODIS model (Gelover et al., 2006).

Mendez-Hermida's 2007 study in southern Spain, entitled, "Disinfection of drinking water contaminated with *Cryptosporidium parvum* oocysts under natural sunlight and using the photocatalyst TiO_2," examined the effects of the basic SODIS model and a TiO_2-enhaced SODIS system on inactivating *Cryptosporidium parvum* oocysts, an organism that can survive a variety of drinking water treatments. These researchers used 2-ml transparent polypropylene and borosilicate glass bottles, fitting the enhanced model with a TiO_2-coated insert and exposed all to sunlight. After eight hours, the TiO_2- enhanced model reduced oocysts viability from 98.3% to 37.7%. After 16 hours, viability was further reduced to 11.7%. In comparison, the traditional SODIS model reduced oocyst viability from 98.3% to 81.3% after eight hours of exposure, and to 36% after 16 hours (McGuigan KG, 2006). In other words, the TiO_2-enhanced SODIS model was more effective at removing *Cryptosporidium parvum* oocysts from the water samples, after eight and 16 hours of exposure.

Contexts in which SODIS is used

SODIS use at the global level

While there is a large canon of literature on SODIS use in developing countries, there are few studies that specifically focus on SODIS use in rural contexts, as is the purpose of this review. For this literature review, three articles relevant to SODIS disinfection in rural contexts were examined: Islam et al.'s 2015 study in coastal Bangladesh, du Preez et al.'s 2011 study in peri-urban and rural Kenya, and McGuigan et al.'s 2011 work in rural Cambodia.

Islam et al.'s 2015 article titled, "Effectiveness of solar disinfection (SODIS) in rural coastal Bangladesh," evaluates the use of SODIS to reduce fecal contamination from pond and harvested rainwater in rural, coastal Bangladesh. The authors collected data from 50 households and completed two rounds of fecal coliform and *E. coli* testing on participant's SODIS bottles. The results showed that SODIS reduced fecal coliform and *E. coli* contamination, reducing the risk of illness by 90-96%. However, this study did not have a high compliance rate, with only 34% of participants adopting the SODIS technology (Islam, Azad, Akber, Rahman, & Sadhu, 2015).

du Preez et al.'s 2011 study titled "Randomized intervention study of solar disinfection of drinking water in the prevention of dysentery in Kenyan children aged under 5 years," investigates the effects of SODIS on childhood dysentery, non-dysentery diarrhea, height, and weight in children aged six months to five years in peri-urban and rural settings in Kenya. The investigation had two study arms: 555 children in the group using SODIS and 534 children in the control group. Each participating household was trained on SODIS use and was given 2-L PET bottles per child in the household. The children's guardians were trained and asked to complete a pictographic journal detailing the child's daily bowel movement, differentiating between dysentery and non-dysentery diarrhea. Results from the study showed a 44% reduction in the incidence of dysentery days and 30% reduction in non-dysentery days (du Preez et al., 2011). Furthermore, the study showed an effect of SODIS on childhood height-for-age, with an average increase of 0.8 cm over the one-year follow-up (du Preez et al., 2011). No other study to date was able to show an effect of SODIS on anthropometry measurements. Unfortunately, du Preez et al. were not able to report on the compliance rate, as national elections disrupted the data collection.

McGuigan et al.'s 2011 study, "High compliance randomized controlled field trial of solar disinfection of drinking water and its impact on childhood diarrhea in rural Cambodia," focused on a study population of subsistence farming communities that collect water from unprotected boreholes. Similar to du Preez et al.'s study, McGuigan's study looked at the incidence of dysentery and non-dysentery diarrhea in children aged six months to five years. McGuigan also had a similar sample size as du Preez, with 426 children in the SODIS intervention group and 502 children in the control group (McGuigan, Samaiyar, du Preez, & Conroy, 2011). Parents or guardians were given training on completion of a pictographic journal, SODIS use and its correlation with water quality and their child's health. The study showed a reduction in drinking water contamination, which corresponded with at least a 50% risk reduction in dysentery and non-dysentery diarrhea (McGuigan et al., 2011).

McGuigan's study achieved a high level of compliance (90%) due to their recruitment model: participants were drawn from a pool of interested community members that attended an informational meeting on the project. "These circumstances ensured that the trial participants were the most motivated members of their community, and the allocation by lucky draw made SODIS a resource in the community where demand exceeded supply," (McGuigan et al., 2011, p. 7865).

SODIS use in the rural Americas

While there are few articles on SODIS use in in rural contexts at the global level, there are even fewer studies that look at the use of SODIS in a rural context in the Americas. Altherr et al.'s 2008 study focused on Nicaragua, while Mäusezahl et al.'s 2008 and Christen et al.'s 2011 articles looked at SODIS use in rural Bolivia.

Altherr et al's study, "Attitudinal and relational factors predicting the use of solar water disinfection: a field study in Nicaragua," had a cross-sectional design which honed in on poor, inaccessible farming communities in rural Nicaragua. The study looked at factors predicting both the intention to use SODIS and behavior surrounding future SODIS use. Eighty families from two communities were part of the study for a total of 81 interviewees. Results from interviews showed that SODIS users had fewer diarrhea episodes than non-SODIS users. Additionally, the results show that factors predicting intention of use include an overall positive attitude towards SODIS, as well as a perception that a high percentage of neighbors use SODIS. Factors predicting behaviors include knowledge of SODIS functioning and an overall positive attitude towards SODIS (Altherr, Mosler, Tobias, & Butera, 2008).

Altherr et al. concluded that, "for any behavior to start, some knowledge about the technology, a certain confidence, and a positive attitude need to be present or else the person is unmotivated to initiate the new behavior," (Altherr et al., 2008). More importantly, the study also showed that the promotion of the technology is a key aspect of developing the community's positive attitude towards the technology. The authors suggest that future studies aim at creating a positive attitude towards and confidence in the new technology.

Mäusezahl et al.'s 2008 study titled, "Solar drinking water disinfection (SODIS) to reduce childhood diarrhea in rural Bolivia: a cluster-randomized, controlled trial," evaluated the diarrhea reduction in children under five years old in rural Bolivia. The intervention group included 376 children and the control group was composed of 349 children followed for one year (Mausezahl et al., 2009). Participants' caregivers were trained in keeping a morbidity diary, detailing incidence of the children's diarrhea, fever, cough, and eye irritation. The author's concluded that, only 31% of participants in the intervention arm complied with SODIS use. A risk ratio of 0.81 was found between the incidence rate of diarrhea in SODS users and non-users. However, the confidence interval spanned the null (0.59 – 1.12), rendering the apparent reduction in diarrhea not significant (Mausezahl et al., 2009).

Christen et al.'s study, titled "Factors associated with compliance among users of solar water disinfection in rural Bolivia," looks at factors associated with SODIS adoption in subsistence farmers that rarely had latrines and collected water from unprotected wells. Evaluation data from a concurrent government program in 22 communities was reviewed in order to split participants into distinct, SODIS-use groups. These groups were then followed to derive household-level and campaign-level factors that affect SODIS adoption. Results showed that factors associated with SODIS adoption and compliance were female sex, latrine ownership, having a household with severely wasted children, and participation in SODIS promotional events (Christen et al., 2011).

The authors argue that this information can be used to identify early adopters of the technology in future interventions.

SODIS use in rural Perú

Literature on SODIS use in rural Perú was scarce with only two peer-reviewed publications on the topic: Halperin et al.'s SODIS sustainability study and Hartinger et al.'s Integrated Home-based Interventions Package study.

In their 2016 study, "Improving household air, drinking water and hygiene in rural Perú: a community-randomized-controlled trial of an integrated environmental home-based intervention package to improve child health," Hartinger et al.'s study population was 51 communities of small-scale farmers in rural Perú, most of which had piped water in their yard and used traditional, solid-fuel stoves. There were 248 children in the intervention group and 251 children in the control group. The intervention attempted to "reduce respiratory infections and diarrhea and to improve child growth in children less than 36 months, through an integrated environmental home-based intervention package (IHIP), comprising improved solid-fuel stoves, kitchen sinks, solar disinfection of drinking water and hygiene promotion," (Hartinger et al., 2016, p. 2090). The rationale behind this intervention was that each of these factors independently improves child health. Therefore, it was hypothesized that a combination of the factors could also have a positive effect on child health. Data was collected from caregivers on a weekly basis, including the children's anthropometric measurements and symptoms of diarrhea and respiratory illness. Results showed a 22% reduction in diarrhea episodes over 12 months. However, no statistical difference was found between the control arm and the intervention arm regarding acute respiratory infections and anthropometric measurements (Hartinger et al., 2016). This study depended on both spot check by field workers and mother's self-reported use of SODIS. The spot checks showed that about 60% of women used the SODIS system, while self-reported use was at 90%. In both cases, the figures reflecting use declined throughout follow up (Hartinger et al., 2016).

Halperin et al.'s 2011 article, titled, "Sustainability of solar disinfection to provide safe drinking water in rural Peru," sought to establish the prevalence and sustainability of SODIS use in rural Perú among female participants. The study population consisted of primarily subsistence farmers, unskilled laborers, and informal business owners. Households from this population had received a SODIS intervention after an earthquake in 2001. Ninety-six of those households were chosen to participate in the Halperin study. The study was rolled out in two phases. The first phase included two community meetings and qualitative interviews. The second phase collected qualitative data from household questionnaires and observations. Results showed that following the earthquake and subsequent SODIS intervention in 2001, 75% of the study population was relying on SODIS. Data collected in 2008, seven years later, showed that 42% of the study population was still using the SODIS intervention. The authors concluded that this showed sustainability of the SODIS technology within this context (Halperin, Paz-Soldan, Quispe, Paxton, & Gilman, 2011).

Efficacy of SODIS Interventions

Childhood diarrhea is caused by a verity of factors, including the consumption of unsafe water. Therefore, a reduction in childhood diarrhea is a typical indicator used to signal the health effect of a SODIS intervention. However, based on the relevant literature, the efficacy of SODIS to improve human health is somewhat unclear.

Some studies show a positive impact on human health. For example, Graf et al's 2010 study, "Health gains from solar water disinfection (SODIS): evaluation of a water quality intervention in Yaoundé, Cameroon," showed that SODIS use in households dropped the prevalence of diarrhea from 34.3% at baseline, to 22.8% at endline for the intervention arm (Graf J, 2010). Additionally, du Preez et al.'s 2011 study, showed a 44% and 30% reduction in dysentery and non-dysentery diarrhea days, respectively. The du Preez et al. study was also the first trial to show a protective effect of SODIS on anthropometry measurements (du Preez M, 2011). McGuigan et al.'s 2012 study, also examined the link between SODIS use and the reduction in dysentery and non-dysentery diarrhea in children aged six months to five years and showed a reduction in both dysentery and non-dysentery diarrhea with an incident rate ratio of 0.5 (95% CI 0.27=0.93, $p = 0.029$) and 0.37(95%CI 0.29<0.48, $p < 0.001$), respectively (McGuigan et al., 2011). Finally, Altherr et al.'s 2008 study, showed that, "more users reported no incidence of diarrhea in the last month than nonusers, whereas twice as many nonusers reported two or more incidences of diarrhea than users" (Altherr et al., 2008, p. 216).

There are other studies that point to the ineffectiveness of SODIS in improving human health. Mäusezahl's 2009 study results showed no significant reduction of childhood diarrhea in the study arm. Additionally, only 31% of the participants complied with SODIS use, In a similar context, Hartinger's 2016's study results showed an not significant reduction in mean childhood diarrhea from 3.1 episodes per child-year in the control arm to 2.8 episodes in the intervention arm (Hartinger et al., 2016).

The Gap between literature, knowledge, and research

As this review shows, there are many studies that look at the use of solar disinfection in developing countries across the world. However, few SODIS studies have been performed in the Americas, with even fewer ones set in rural contexts. Research studies of SODIS use in rural Perú were limited to two: Halperin et al.'s 2011 "Sustainability of solar disinfection to provide safe drinking water in rural Perú," and Hartinger et al.'s 2016, "Improving household air, drinking water and hygiene in rural Perú: a community-randomized-controlled trial of an integrated environmental home-based intervention package to improve child health." Experimental lab studies looking at the use of a SODIS system in the form of a pouch were limited to two as well: Walker et al.'s 2004 "Development and evaluation of a reflective solar disinfection pouch for treatment of drinking water," and Dunlop et al.'s 2011 study, "Inactivation and injury assessment of Escherichia coli during solar and photocatalytic disinfection in LDPE bags."

There is a need to study the use of a SODIS disinfection device in the form of a pouch in rural context in Perú. The Agua Solar study fills this gap. This study aims to provide insight on the efficacy of an enhanced SODIS pouch in a rural and remote context of the Americas. The findings from this study can be used to inform the Government of Perú, as well as NGOs and organizations working in a similar context, on viable alternatives to traditional water treatment.

Chapter 3: Methodology

Study setting and population

Geographic setting

The small village of Bellavista is located in the Peruvian Amazon, in the department of Ucayali. The nearest town to Bellavista is Iparía, which is located about 6 miles southeast of the village. Iparía, in turn, is located 60 miles south of Pucallpa. Pucallpa is the department capital and boasts an airport, a range of hotel options, running water, reliable electricity, and Internet.

Map 3.1 – Map of Pucallpa, Iparía, Bellavista, and the Ucayali River

Fieldwork in the Bellavista can be challenging. A seven-hour boat trip is required to get from Pucallpa to Iparía. From there, only a few access routes exist between Iparía and Bellavista all of which take a minimum of three hours travel through a combination of additional hiking and boat travel.

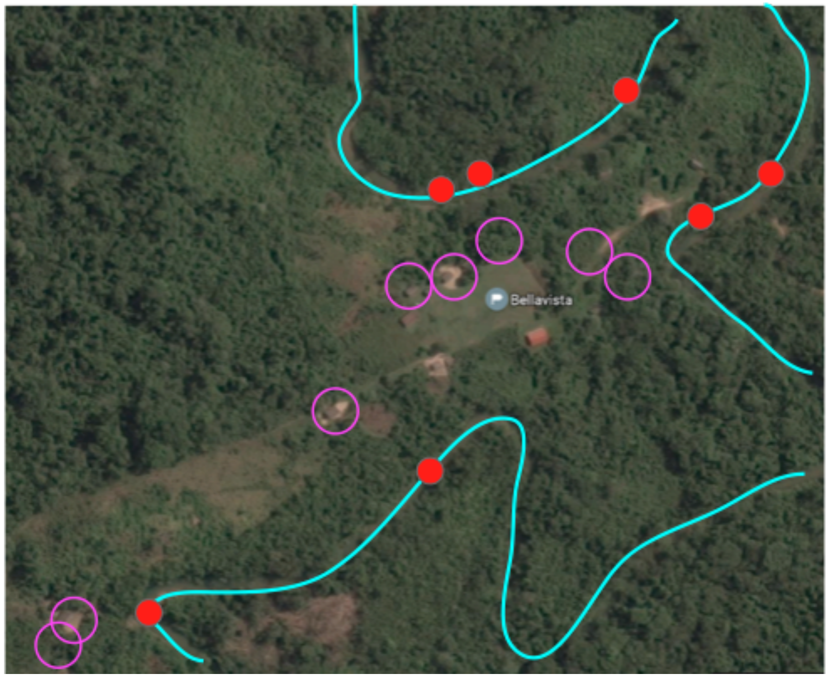
Study population

The population of Bellavista varies seasonally and by occupation. While some of the residents live in the village full-time, others are transient. For example, at least two families were out of town for a week, harvesting lumber, during the December 2016 visit. Other families live a more dispersed lifestyle with the children remaining in the village on weekdays while the parents are at the lumber camp only returning to the village on weekends. For the most part, there are 10 - 15 households, and about 40-55 inhabitants in the village at any one time.

Bellavista is composed of two sectors. The nuclear sector of Bellavista is clustered around the western shore in a bend of the Huacashiria creek. Eleven to twelve households and the local schoolhouse are in this sector. The satellite sector of Bellavista is located at a three-hour boat ride further west and is composed of three households.

Ethnically, the village is divided in two groups: Shipibo and Ashanika. While the majority of inhabitants are Ashanika, both groups speak their language intermittently. Spanish is spoken throughout the village. There was only one woman in the outskirts of the village who did not speak any Spanish; she only spoke Ashanika.

Before the implementation of the project in December 2016, the community members used the Huacashiria creek to meet all of its water, sanitation, and hygiene needs. Each family hauled about 75 L of water per day. Most families have a *puerto*, or location on the creek where they fetch their water.



Map 3.2 – A map of nuclear Bellavista. Huacashiria Creek is outlined in blue, households are circled in purple and *puertos* are signified by red dots

"Mi Agua Solar" project and site selection

This thesis is nestled within CARE Perú's "Mi Agua Solar" project. The aims of the Mi Agua Solar project were to monitor and evaluate the social, technical, and implementation parameters surrounding the use of the Solar Bag in an Amazon setting. It was therefore necessary to identify a community with specific features that indicated a need and desire to receive the water treatment intervention. CARE Perú developed site selection criteria that included the following elements: a) the community needed to be rural and remote, b) there was no significant government investment in water services, c) there were no municipal water delivery systems, and d) the population was dependent on local surface water as their main source of water (Mindreau, 2017a). A visit in October

2016 determined that Bellavista met these requirements. It was therefore chosen as the intervention site.

In December 2016, CARE Perú hosted a community meeting in Bellavista where ten study participants were trained in the use of the Solar Bag. Additionally, the CARE team explored with the study participants the best way to integrate the new technology into their daily lives.

The Solar Bag technology

Theoretically, the process of purifying water through the use of the Solar Bag is straightforward. The water is first collected from the creek with one container and brought to the participant's home. Then, alum (flocculent) is applied to the water before it is left to sediment overnight. The next morning the sedimented water is decanted into another container.

This water is then poured into the water bladder through a cloth pre-filter. A drop of indicator dye is added to the bag before it is placed in the sun for disinfection. Disinfection should take place within three to six hours depending on the weather. However, since the timing for disinfection depends on undeterminable weather, manufacturers added the indicator dye to the process. The dye disappears progressively with the water's increase exposure to UV radiation. Once the dye has disappeared and the water is transparent, it is ready for consumption.

After the water had been disinfected, it is poured into a storage container with a secure lid and spigot. This storage container is to be placed out of the reach of animals. In doing so, the integrity of the disinfected water is maintained.

Recruitment and Sampling

Recruitment

Recruitment for this research was achieved primarily though the community gatekeeper who was also the Mi Agua Solar project's community health promoter. This individual introduced the researcher to potential participants who met the study inclusion criteria. The researcher explained the purpose of the study and asked if the potential participants would be interested in participating in the study activities.

There were four participants that were not found through the gatekeeper but rather though the snowball method: a study participant that the researcher interviewed introduced her to other potential study participants (Hennink, Hutter, & Bailey, 2011).

Sampling

A set of inclusion criteria was developed in order to select the study participants. Recruitment focused on individual available from the pool of 10-15 households in the community. The inclusion criteria required that the study participant be: 1) female 2) head-of-household 3) participant in the Mi Agua Solar project, and 4) a resident of the nuclear Bellavista community.

CARE recruited female participants because in Bellavista it is women and girls that carry the brunt of water collection activities. Heads-of-household were recruited because in this community while the children may help with the water collection, it is the older female household member that manages the water quality, quantity, distribution, and use.

It was also necessary to recruit participants that had attended the December 2016 Solar Bag user orientation and had chosen to adopt the Solar Bag as a water purification system. During the December visit the bags were handed out to 13 female heads-of-household. At that time, one of the village families was out at their lumber camp and missed the information and user orientation session. When the researcher arrived in June 2017 that family was in the village. While the researcher gave her an orientation lesson and had follow-up visits for quality check, that user was not included in the final study sample. The concern was that her answers could be affected by her lack of experience using the Solar Bag system.

In the interval between the December 2016 orientation session and the researcher's arrival, a new family had moved into the village. This family had a female, head-of-household that was eligible for the program. Again, while the researcher gave her an orientation session and came for follow up visits, she was not included as part of the final sample due to her different level of experience with the Solar Bag system.

Finally, there were two participants that lived three hours further inland from the nuclear Bellavista community. Since June is the dry season in the Ucayali province, Huacashiria Creek was too shallow for boat transportation to this separate community. Since the data collection process takes at least a day and a half, these logistical constraints prevented a visit to the households further inland.

In total, the final sample included eight, female, head-of-household participants from the nuclear village with six months of experience using the Solar Bag technology. The unit of study is an individual woman participant.

Study design and procedures

The researcher's intention was to implement an ethnographic study design wherein the researcher would spend six weeks living in the community. In doing so, the researcher hoped to establish rapport with the community and participants. However, personal illness and a need for food supplies restricted the data collection times to three, one-week intervals separated by two weeks in between. On the first visit, introductions were made between the gatekeeper and the researcher. In the second week, the researcher collected interviews and observations for three participants. The final five sets of observations and interviews were collected during the third and final weeklong stay. In effect, the study took on a cross-sectional design.

Procedures

Observations and interviews took place at the participant's convenience. The researcher made an appointment with each participant to meet at her house to conduct both observations and interviews. In general, there were four parts to the encounter with each participant: 1) observation of the application of the flocculent, 2) observation of the filling of the Solar Bag and placement in the sun, 3) observation of the emptying of disinfected water into the storage container, and 4) interview with the participant. These encounters did not always take place in the order described above. Logistics and participant availability determined if observations took place before and/or after the participant interview. In general, the researcher aimed at having the interviews take place after observing the bag filled and placed in the sun for disinfection. Interviews and observations were completed with the study instruments described below.

In an attempt to maintain confidentiality, interviews took place during daylight hours, by appointment, and at the participant's home. However, strict privacy was not always possible. Children in the household disturbed two interviews. Other village members arriving on business interrupted two interviews. Another participant interrupted one interview and a visiting family member interrupted a final interview.

Study instruments

Key Performance Indicators

CARE Perú developed a set of Key Performance Indicators (KPIs) in their monitoring and evaluation plan in order to assess the social parameters of the Mi Agua Solar project. The social parameters included two major domains: "Knowledge and Practice of Solar Bag Treatment Process" and "Level of Social Appropriation." Knowledge and level of social appropriation were assessed through in-depth interviews with the female head of household. Practice of the Solar Bag technology was assessed through observations of the purification process from fetching the water to storage. The table below details CARE Perú variables and their corresponding indicators.

Variable	Sub-variable	Indicator
Knowledge and Practice of the Solar Bag Treatment Process	Water sedimentation within holding container: proper use of alum (flocculent) and waiting time	Turbidity level ≤ 5 NTU
	Solar Bag in use on day of	Use

	visit	
	Correct handling and use of pre-filter	Use of pre-filter
	Correct handling of Solar Bag during filling	When filling with water, the bladder is handled by the neck
	Application of blue dye to the water inside the Solar Bag	1 drop is applied
	Correct exposure of water bladder to sun	Bag is placed on a location that does not receive shade
	Correct time exposure of water bladder to sun (3-6 hours)	Blue indicator dye disappears
	Storage of treated water that is ready for human consumption in appropriate holding containers	Holding container has lid and spigot and is paced out of reach of animals
	Proper drying of the Solar Bag after use	When not in use, the Solar Bag is empty and hung upside down
Level of Social Appropriation	Ease of incorporation of the Solar Bag in daily life	Use of the Solar Bag is verbalized and proof is evident
		Level of participant satisfaction with the Solar Bag

		Local substitutes do not replace the use of the Solar Bag

Table 3.1: Social Parameters as defined in CARE's monitoring and evaluation plan

Knowledge and practice of the solar bag treatment process

Observations and in-depth interviews were used to compare and contrast the participant's knowledge of the Solar Bag with the participant's observed use of the bags. The correct use of the Solar Bag includes the following steps:

1) The participant must apply alum to the source (creek) water she has fetched for disinfection. The correct way to do this is to tie a piece of string to the chuck of CARE-provided alum, and to stir the string in circles around the bucket. There are different dosages for different volumes of water bucket. For average buckets of water (i.e. 15-20 L), the participant should stir the string-tied alum 20 times. Smaller buckets (i.e. 10 L or less) required 10 stirs with the string-tied alum. When stirring, the participant should be careful to allow the string-tied alum to complete full circles as it is stirred into the creek water. This will assure that the alum has enough contact with the contaminated water.
2) Participants should then allow this water to sediment overnight. This step will ensure that the water has enough time to allow flocculants to form and descend to the bottom of the holding container.
3) The following day participants decant the sedimented water in order to remove flocculants.

4) Then they fill the Solar Bag with low-turbidity water. Participants should take care to use the provided pre-filter while filling the Solar Bag, in order to remove any large particulate matter and help preserve the Solar Bag. Participants should also make sure to handle the Solar Bag by the neck while filling it, in order to maintain the bag's stability and avoid placing fingers inside the bag.
5) Next, participants should add one drop of indicator dye to the water and place the cap on the bag.
6) After shaking the bag in order to mix the dye with the water, participants place the bag out in the sun. Bags should be placed in a location where no shade is cast on the bag during the solar disinfection process. The writing on the bag should be face down in order to avoid casting shade on the water. Bags should be left out in the sun until the indicator dye disappears. On a sunny day, the dye could disappear in about three hours. On a sunny day, the process could take six hours.
7) After the indicator dye disappears, participants should empty the Solar Bag water into a storage container with a lid and spigot. The storage container should be properly disinfected before the Solar Bag water is emptied into it. The container should be kept out of the reach of animals in order to avoid recontamination of the Solar Bag water.
8) The Solar Bag should be stored upside down in order to allow excess water to drip out and the interior of the bag to dry.

Social appropriation

CARE Perú defined social appropriation of the Solar Bag as a state in which the participants: 1) verbally articulated their use of the bag (and researcher observations proved this use), 2) regularly used the Solar Bag system, and 3) refused to return to untreated water once the project finished (Mindreau, 2017b). Since the interviews and observations were geared towards those indicators in the Mi Agua Solar project, this researcher used the same indicators for this evaluation.

Variable	Key Performance Indicator	Assessment Tool
Social Appropriation	Use of the Solar Bag is verbalized and proof is evident	Observation Guide Interview Guide
	Level of participant satisfaction with the Solar Bag	Interview Guide
	Local substitutes do not replace the use of the Solar Bag	Interview Guide

Table 3.2 – Social Appropriation Key Performance Indicators as modified for the Solar Bag project from the CARE "Mi Agua Solar" project. The last column defines the tool used to assess the Key Performance Indicators.

Interview Guide

In-depth interviews were conducted with a semi-structured interview guide, which was piloted during the first week of data collection. Revisions were made during a two-week break and a refined version was implemented for the second round of data collection. Final edits were not aimed at content but rather at details of translation that might elicit lengthier responses from participants.

The researcher asked open-ended questions from the interview guide and recorded participant answers on an iPhone VoiceMemo application. Additionally, the author took notes regarding participant behavior, demeanor, and body language in a notebook. After the interview was complete, the author listened to the recording and refined her written notes. The researcher transcribed the recordings between November 2017 and June 2018.

The author designed the interview guide so that the first four questions were simple and straightforward to help build rapport and put the participant at ease. The next six questions were aimed at obtaining the data most relevant to the study. The last three questions were used to "cool down" the participant and allow them a space in which to add their own ideas and recommendations for future studies.

The CARE Perú KPI questions were incorporated throughout the interview guide. For example, the fifth question asked participants to explain in their own words the Solar Bag disinfection process. This question was used to evaluate participants' "Knowledge and Practice of the Solar Bag Treatment Process." The second part of the fifth question asks participants to evaluate their preference between the processing times in the Solar Bag disinfection process versus the sedimentation-only process. This question was used to evaluate the "level of participant satisfaction." The tenth question asks participants to outline times and places when the Solar Bag is not used. This question was used to evaluate the KPI "local substitutes do not replace the use of the Solar Bag."

Other questions in the interview guide covered water quality, quantity, uses of water, Solar Bag durability, stress surrounding water use, and changes in participant's health and lives since using the Solar Bag. (See Appendix A for the complete interview guide).

Observation guide

An observation guide was used during the observations. The guide was designed to incorporate the "Knowledge and Practice of the Solar Bag Treatment Process" indicators from CARE PERU's monitoring and evaluation plan. The observation guide specified the following steps:

Steps to Water Purification using the Solar Bag	1. Alum is applied	2. Correct alum dosage is applied	3. Alum applied evenly throughout water
4. Sedimentation takes place overnight	5. Water is decanted and Solar Bag is filled	6. Pre-filter is used when Solar Bag is being filled	7. Solar Bag is handled by the neck when being filled
8. Indicator drop is added	9. One drop of indicator dye is added to water	10. Solar Bag is placed out in the sun	11. No shade is cast on the Solar Bag
12. Writing on the Solar Bag is facedown	13. Solar Bag is exposed to sun for at least 3 hours	14. Solar Bag is emptied into a storage container	15. Solar Bag is emptied only once the blue indicator

	during sunny days and 6 hours during overcast days		dye has disappeared
16. Treated water is stored in a container with a lid and spigot	17. Storage container is disinfected before use	18. Storage container is out of the reach of animals	19. Solar Bags are stored upside down

Table 3.3 – Key Performance Indicators for the proper steps to the Solar Bag disinfection process as adapted from the CARE "Mi Agua Solar" project for the Solar Bag project.

The researcher visited each participant at least twice at home and observed as the participant hauled water, applied flocculent, filled the Solar Bags, placed the Solar Bags in the sun, emptied the disinfected water into storage containers, and properly stored the Solar Bags while not in use. Notes on each step were taken in a notebook and compared to the modified CARE monitoring and evaluation KPI.

After the observation session, the author discussed with the participants any needed improvements on proper use of the Solar Bag. For example, the Solar Bag needs to receive at least three hours of direct sun exposure. If an observation session showed that the participant placed the bag in a part of the yard that received shade, the reasoning behind the direct sun exposure requirement was explained to the participant and the behavior corrected.

Data management and analysis

Storage

The author used the VoiceMemo app on a password-protected iPhone to record the interviews. Afterwards, the audio files were transferred to a password-protected drive on a secured Emory University server. The audio recordings were maintained at that location until transcription was concluded at which point the files were deleted.

Transcribing, coding, and analysis software

In order to analyze the data, the author first transcribed the interviews using the free software ExpressScribe. The software, MaxQDA (access obtained through class professor), was then used to code the data and develop both a code tree and codebook.

Codes for the data were developed with a combination of inductive and deductive methods. Deductive codes were developed prior to analysis through a literature review. Inductive codes were developed from the analytic review of the transcriptions. These codes gave way to themes that helped uncover the nuances behind the data.

Validity

Validity of the codes was assured through constant comparison (triangulation), and reflexivity. During several rounds of comparison, the author compared every coded quote to another quote coded under the same theme to make sure that the code was applied consistently. Reflexivity, defined as "a process that involves conscious self-reflection on the part of researchers to make explicit their potential influence on the research process," (Hennink et al., 2011) was also employed in the quality assurance process.

Ethics

This study was exempt from review according to the Emory University Institutional Review Board. However, the study still followed the standard IRB approval protocol and plans for recruitment, field methods, data analysis, and confidentiality were discussed in a classroom setting to ensure correct application of ethical principles.

Chapter 4: Results and Analysis

Description of participants

The demographic profile of the eight study participants was fairly homogeneous. All study participants were female, head-of-household, Bellavista residents between 14-70 years of age. All subsist on small-scale farming as well as hunting and gathering for food. Six households were of Ashanika ethnicity, while the other two households were Shipibo.

Due to the multi-family-structured households, six of the eight participants lived in a household where at least one member dedicated their time to the lumber trade. Participant # 6 was married and had no children but lived in the same household as Participant #5 who had no husband but did have a young child. The other six participants had children ranging from one to 48 years of age.

All eight participants accessed their water from the same creek in the same fashion: standing on the shore, dipping their buckets into the creek, and then carrying that water back to their house. All eight participants were used to practicing natural sedimentation without any chemical catalysts.

A comparative analysis of participants' knowledge and practice yielded information on the gaps between the two categories. Extensive segmenting and thorough analysis of the interviews revealed information on social appropriation of the Solar Bag, as defined by CARE Perú.

Knowledge of the solar bag purification process versus the practice of that process

Table 4.1 summarizes the steps of the disinfection process that participants mentioned in their interviews, versus the steps they performed in practice. The information under the "I" column was found in the in-depth interviews, whereas the data under the "O" column was observed during observations.

	#1		#2		#3		#4		#5		#6		#7		#8	
	I	**O**	**I**	**O**	**I**	**O**	**I**	**O**	**I**	**O**	**I**	**O**	**I**	**O**	**I**	**O**
Alum is applied	✓	✓	✓	✓	✓	-	✓	-	✓	✓	✓	✓	✓	-	✓	-
Correct alum dosage is applied	✓	✓	✓	✓	-	-	✓	-	✓	✗	-	✗	✓	-	✓	-
Alum applied evenly throughout water	-	✓	-	✗	-	-	-	-	-	✗	-	✗	-	-	-	-
Sedimentation takes place overnight	✓	✓	✓	✓	✓	-	-	-	✓	✗	✗	✗	-	-	-	✗
Water is decanted and Solar Bag is filled	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	-	✓	✓

Pre-filter is used when Solar Bag is being filled	-	✓	✓	✓	-	✓	✓	-	-	✓	-	✓	-	-	-	✓
Solar Bag is handled by the neck when being filled	-	✓	-	✓	-	✓	-	-	-	×	-	✓	-	-	-	✓
Indicator drop is added	-	✓	-	✓	-	✓	-	✓	-	✓	✓	✓	-	-	✓	✓
One drop of indicator dye is added to water	-	✓	-	✓	-	✓	-	-	-	✓	✓	✓	-	-	✓	✓
Solar Bag **is placed out in the sun**	✓	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	-	✓
No shade is cast on the Solar Bag	-	✓	-	×	-	×	-	✓	-	✓	-	✓	-	×	-	×
Writing on the Bag is facedown	-	✓	-	✓	-	✓	-	✓	-	✓	-	✓	-	×	-	✓
Bag is exposed	✓	✓	✓	✓	-	-	✓	✓	-	-	✓	-	✓	✓	✓	✓

to sun for at least 3 hours during sunny days and 6 hours during overcast days																
Bag is emptied into a storage container	✓	✓	✓	✓	-	-	✓	✓	-	✓	✓	✓	✓	-	✓	-
Bag is emptied only once the blue indicator dye has disappeared	✓	✓	✓	✗	-	✗	✓	✓	-	✗	✓	✗	-	-	-	✗
Treated water is stored in a container with a lid and spigot	-	✓	✓	✓	-	✓	-	✓	-	✗	-	✓	-	-	-	✓
Storage container is disinfected before use	-	✓	-	-	-	✗	-	-	-	✗	-	✗	-	-	-	✓
Storage	-	✗	-	✗	-	✓	-	✗	-	✗	-	✓	-	-	-	✓

container is out of the reach of animals																
Solar Bag**s are stored upside down**	-	×	-	×	✓	-	-	✓	-	×	-	×	-	-	-	-

Table 4.1 – Results of Practice Observations and Knowledge Expressed in Interviews displayed per participant. Check marks under the interview (I) column denote information mentioned in interviews. Dash marks under the same column represent information that was not mentioned. Check marks under the observation (O) column represent steps taken properly, while dash marks mean steps that were not observed, and cross marks are steps performed improperly

From the table above, a few patterns are evident. First, while all participants can describe the basic steps of the Solar Bag purification process, none of the participants mention all of the details. For example, almost all participants mentioned the alum, overnight sedimentation, decanting and filling of the bags, indicator dye, and sunning steps. However, none of the participants described the correct application of the alum throughout the water sample, disinfecting the storage container before use, placing the storage container out of the reach of animals, or storing their Solar Bag upside down.

Second, although all eight participants did not mention several details of the purification protocol, all participants executed some of the steps correctly in practice. For example, while none of the participants mentioned disinfecting their storage containers properly before use, Participant #1 and #8 did so in practice. Similarly, while no participant mentioned storing the container out of the reach of animals, Participants # 3, #6, and #9 did so in practice.

Finally, the data show that while the participants were able to describe the basics of Solar Bag purification, many executed some of the steps incorrectly. For example, while six participants appropriately described the concept of alum dosage, two of those participants (#5 and #6) applied incorrect dosages of alum to the creek water while being observed. Similarly, Participants #2, #4, and #6 described emptying the Solar Bag water only after the indicator dye disappeared completely. However, in practice, participants #2, and #6, both emptied out their Solar Bags before the indicator dye had completely disappeared.

Other notable results include that none of the participants reported the correct application of the alum and, of the four participants observed performing that step, Participants #2, #5, and #6 performed the step incorrectly. Similarly, none of the women mentioned storing the Solar Bags properly when not in use. Of the five women that were observed storing their bags, four did so incorrectly.

Social appropriation

Use of the bags is verbalized and proof is evident

Based on the observation data, it is evident that all eight participants used the Solar Bag on a regular basis. The wear-and-tear on the bags made it evident that the bags had been in use for some time. Participant #3 needed two bags replaced due to mold growing on the inside, and Participant #6 needed one bag replaced for the same reason. Participant #1 had one bag replaced because it opened from the neck. Several participants had bags that took longer than six hours to disinfect water. The effect of an increase disinfection time is always seen after the Solar Bag has been used multiple times.

The interviews revealed some nuances to the observational data above. Participant #8 had stopped using the Solar Bags for some time between December 2016 and June 2017. This case is further discussed below, under "Barriers to Use." Similarly, participants described situations in which they would not use the Solar Bags and reverted to creek water. These cases are also discussed under "Barriers to Use." Several participants mentioned the increase of disinfection time after extended use of the Solar Bag. This issue will be further explored in "Barriers to Use."

Participant satisfaction

Results showed that participant satisfaction with the Solar Bag was high. The data showed that there were five different aspects to participant satisfaction: 1) satisfaction with the Solar Bag product; 2) satisfaction with health improvements; 3) satisfaction with the disinfection processing time; 4) satisfaction with the supply of Solar Bags and accompanying materials, and; 5) satisfaction with the quantity and quality of water the Solar Bag provides.

a. Satisfaction with the product

All eight study participants expressed satisfaction with the Solar Bags. The two participants without children mentioned liking the water that the Solar Bag produced.

Participants # 4 liked the water from the Solar Bag because she found it *"delicious"* and was constantly making more:

> *"I arrive [in the village] again and prepare another round of [Solar Bags], so that I can drink [the purified water]. I think the water tastes very delicious. It is very delicious for us. I want to drink some of that water all the time. All the time – I go and drink more. Others want to drink…. I'm always coming [home] to prepare more water, to be able to drink it."*

The remaining three of the six participants with children expressed satisfaction with the process of disinfecting water. For example, Participant #5 said, *"I like the bags because I like to prepare water throughout the day."* Participant #2 also liked the utility of the Solar Bag, saying, "*I like it a lot… because it is very pretty. Because I can use clean water from there."*

In addition to liking the Solar Bag because of its utility, the participants with children spoke to their position within the household now that she was the individual in charge of preparing disinfected water. When asked how she felt now that she was the individual in charge of preparing disinfected water, Participant #8 said, *"I like it because I am helping my family."* Participant # 2 responded with an emphatic *"Good! For me, it is good!"* and participant #6 said, *"It makes me feel very happy."* When asked what her husband thought of her position, Participant #2 responded with, "*Nothing, for him it's ok. He thinks it's ok because he gets to drink clean water."* Participant #6 expressed her wish for her husband to learn how to disinfect water so that he can make purified water as well. Participant #4, who lived with her grown son in the house, verified that the son preferred the water from the Solar Bag rather than the water from the creek: *"... even my son likes it. Now my grandchildren don't want to drink water from the creek. The only want to drink water from the Solar Bag."*

The satisfaction level in the cohort was high enough that all eight participants mentioned buying the Solar Bag if it were available in the rural market. Participants without children were willing to pay more for the Solar Bags- as high as 200 S/ (about $61). Participants with children in the household were willing to spend much less: 10-20 S/ only (about $3-$6).

b. Satisfaction with health improvements

All participants were asked if they had observed any change in their health and hygiene since they began using the Solar Bags. Mothers tended to report on their own health as well as the health of their children. Participant #1 spoke about the health improvements she saw in her family: *"My stomach doesn't hurt anymore. My kids' neither. They used to cry. I used to think they must have had a lot of... worms."* Women who were not mothers tended to focus on their and their partner's health. Participant #6 explains:

> *"When I didn't use [the Solar Bag water], it was just like that- normal. I didn't get sick even when I drank the water [from the creek] ... [my husband's] stomach hurt…but [not anymore] because he drinks clean water."*

Four participants had more trouble understanding the question regarding changes in their hygiene since they started using the Solar Bag. When asked, Participant #6 laughed and answered, *"Yes, we wash our hands, we don't eat with dirty hands*."

Participant #2 answered:

> *"Yes, I take a shower… and when I go to the bathroom- I go to the bathroom, I come back, I have to wash my hands… I used to do it before [too]. My mom taught me how to do that."*

Other participants understood the question clearly. For example, Participant #1 answered, *"Ah, I wash my hands with [Solar Bag water], sometimes with water from the creek… plates I [still] wash with creek water."* Participant #8 said, *"The same… I keep doing things the same way."*

c. Satisfaction with the disinfection processing time

All participants were asked to evaluate the difference in treatment times (Solar Bag versus natural sedimentation) and to comment on that difference. Three participants did not understand the question and were therefore unable to answer. For example, Participant #1 explained, *"Oh, I don't understand! (chuckles)… I misunderstood (speaks Ashanika to sister) … I don't understand that question."*

Other participants had difficulty understanding the question but attempted to provide an answer. Some sounded unsure of their answers or some contradicted themselves. For example, Participants #2 and #3 said they liked that the Solar Bag disinfection process took longer than the natural sedimentation but only after extensive probing. Additionally, when they finally provided an answer their tone of voice conveyed that they had low conviction:

> *"Interviewer: Does that [disinfection time] seem like a lot to you?*

Participant: Mmm… yes.

Interviewer: Would you like it to be less time?

Participant: Well… yes."

(Participant #3)

Similarly, Participants #2 and #5 both change their answers, first saying that the Solar Bag disinfection took too long and then that disinfection took too little time:

"Interviewer: How does that time seem to you?

Participant: That time?

Interviewer: Yes. Is it too much?

Participant: Mmmm… yes.

Interviewer: So it takes all day to disinfect. Does that seem like a lot of time to you or a little?

Participant: Little…."

(Participant #2).

d. Satisfaction with the supply of Solar Bags and accompanying materials

All participants were asked how many bags they had been given, how many bags had broken, and if they had used all of their supply of alum and indicator dye. Participant #2 was the only one to have used all of her alum and indicator dye. All of the other participants still had the original supply of alum and indicator dye that was provided to them in December 2016. Similarly, only Participant #3 said that she had no bags replaced between December 2016 and June 2017. All of the other participants needed at least one of their bags replaced since they first received them in December 2016.

As will be explored in the section titled "Areas for Improvement", participants needed to obtain store-bought plastic bottles to carry their treated water. They also needed more containers for the disinfection process and for storage.

e. Satisfaction with the quantity and quality of the Solar Bag water

Seven participants were asked how long their treated water lasted, and furthermore, to evaluate their satisfaction with that time frame. Participant #6 said that her water lasted her two days and that it didn't need to last any longer because, *"when we keep [the treated water] for too long, it's no good anymore… it has- it looks like- phlegm comes out and it becomes white inside."* Participant #5 and #8 agreed with this opinion, citing the same reason: "*the water becomes bad after a while. This phlegm forms in it,"* (Participant #5). Participant #4 mentioned not needing any more water, *"my water lasts me a week… because, look it's just me here. I am alone."*

Participant #2, however, was asked how much water she would want every day. At first she said that she would like five buckets of treated water every day. Later on, she changed her response and said, *"One bucket of treated water is enough, because we only use [that water] to drink."*

All participants were asked to evaluate the differences in the water from the Solar Bag and the water from the creek. Participants #2, #3, and #7 all commented that the Solar Bag water was blue, in comparison to the colorless creek water. Participants #1 and #5 mentioned that the creek water is more turbid that Solar Bag water: *"yes, well... the first one we drank was turbid water."* Participants #2, #4, #7 said the Solar Bag water was more delicious than the creek water. Participant #4 explains: *"It's more delicious,* *more delicious than the creek water… when the creek water is turbid, it is not good. That's why when it's going to rain, I haul my creek water and prepare Solar Bag water."* However, Participants #1, #2 and #3 claimed that there was no difference in the taste, while Participant #7 said that it had a different smell. Participants #1 and #3 were confused by the question and needed much probing:

"Interviewer: What difference do you see between the two bags?

"Participant: No… (silence)

Interviewer: What differences do you see?

Participant: What do you mean?

Interviewer: For example, the water from over there looks the same as from the bag?

Participant: Yes, the same (unsure)

Interviewer: Does it have the same color?

Participant: Mmmmm… same taste"

(Participant #1)

Two of the six participants with children mentioned liking the water from the Solar Bag. For example, Participant #1 said that she liked the Solar Bag because, *"...you can drink it. Now we don't have to drink water with microbes in it… and I like preparing it too... now my children don't have to drink dirty water. Me neither."*

Local substitutes

Aside from creek water, there was only one other source of water for the community: rain. All eight participants stated that they got their water from the creek, although one participant mentioned using rainwater for household purposes. The data revealed three themes surrounding local substitutes: incorporation into daily life; barriers to use of the Solar Bag, and intentions for future behavior.

Incorporation into daily life

Results showed that participants used Solar Bag water despite potential obstacles, such as work and travel. Participants#1, #2, #4, #6, and #8 mentioned taking the water with them in bottles when they travel outside the village.

> *"I also take water with me when I go to Pucallpa. Sometimes I'm sitting down [on the beach] waiting for the collective boat to come by. Sometimes my sons want to drink water, so for that reason I take water with me. Mmmhmmm, because the Ucayali [River} is turbid."*
>
> (Participant #1)

All eight participants mentioned taking prepared water in bottles when they went to work in the agriculture fields of the lumber camps. Participant #2 had her husband carry a storage container with prepared water whenever he left for cultivation. Participant# 4 sends her son off to hunting and to the lumber camps with Solar Bag water placed in plastic water bottles purchased in town: *"I fill up two bottles and he takes them. To his work… I take care of my son."* Participant #1 also sends her husband hunting and to the lumber camps with Solar Bag water in plastic bottles from town. Participant #7 takes the entire purification system when she goes to the lumber camps with her husband- alum, dye drops, bags, and storage containers:

"When we go [to the camps] we go for a whole week. I take everything with me so I can prepare water over there. It's very important we have clean water."

Barriers to use

Participants describe five barriers to the continuous use of the Solar Bag: poor weather, product design, product durability, and the supply chain.

a. Weather

One of the eight participants mentioned that when the weather is overcast, the Solar Bags do not work as much and she goes to the creek for water,

"When the weather is like it is today, when the sun is not shining, we have to drink (creek) water… water we let sediment" (participant #5).

b. Product design

The product design also caused issues for some participants. The bag is constructed with a hanging loop at the top of the bag, instead of the bottom. This means that the bag cannot be hung upside down to allow for water drainage after use. Combined with the high humidity in the area, this results in mold growing inside the bag. Participants # 3 needed two bags replaced due to mold growth, while Participant #6 needed one bag replaced for the same reason.

Additionally, the Solar Bag has a narrow neck and mouth, preventing proper cleaning. It was observed that Participant #5's bag had a cockroach in it during disinfection and all eight participants' bags accumulated a layer of sediment after prolonged use. Since the bag can only be partially opened, it cannot be properly cleaned on the inside in order to reduce the residue and eliminate insects.

c. Product durability

In addition to product design and weather, participants also described the durability of the Solar Bag. The Solar Bag of Participant #1 tore open at the neck. Furthermore, Participant #4 described the effect of the wear-and-tear of the disinfection process on the Solar Bag's effectiveness:

> *"The new bags make the [indicator dye] disappear quickly… but once [the bags] get a bit old… they take longer [to complete the process]… it takes twice as long. I have tested it. That way nothing will deceive me…"*

This means that instead of taking three to six hours to purify water, the Solar Bag started taking six to twelve hours to complete the task. When asked how this difference in time seemed to them, several participants had trouble understanding the concept, and therefore were unable to provide reliable answers.

d. Supply chain

Also evident in the data were issues with the supply chain of materials for the Solar Bag process. There are two factors that affect the supply chain of the Solar Bag purification system parts. First, not all of the parts of the system (i.e. the Solar Bag and indicator drops) are sold in Perú. The alum and storage containers can be purchased in

Pucallpa and Iparía. However, the Solar Bags and the indicator drops can only be obtained from CARE via the health promoter.

There was also a specific bottleneck in the supply chain: the health promoter was in charge of replacing parts to the system as participants needed. However, Participants #2, #6, and #8 mentioned having issues with the health promoter regarding replacement parts.

> *"My bag did not work, it was broken... so [the health promoter] said he would give me more… he went around with his sons giving everyone else bags, but I had to keep asking him…I asked him why should he be able to change out his old bags for new bags every week? And in comparison, the rest of us have to go ask him for replacements. When he found out [CARE investigator} was coming to the village, that's when he finally arrived at my house and gave me a new bag."*
>
> (Participant #2)
>
> *"I used to use the bags, I liked them… but the [health promoter] wouldn't give me new ones when my old ones broke… I had to be begging and like that it's not fair. I stopped using the bags because I was not going to be begging… he finally gave me new bags because you all were showing up, so I started using [the Solar Bags] again."*
>
> (Participant #8).

In addition to lacking access to replacement bags, Participant # 2 mentioned finishing the alum and indicator drops and also having trouble obtaining those from the health promoter:

"[the alum] is about to finish [again]. I have it here… I don't want to use it too much because the [health promoter] doesn't want to give me any more. I don't know why. He is arguing with us. So that's why, you know, I don't want to finish it too fast. The [indicator dye] too."

Finally, seven of eight participants mentioned missing other materials essential to the disinfection process. While participants were given two buckets of 12 L each, it was necessary to have three buckets to complete the disinfection process: one bucket for sedimentation, one bucket for holding decanted water, and a third bucket that holds the previous treatment's disinfected water. Additionally, since decanting water loses about half liter of water with flocs, one 12-L bucket can only sediment enough water for three Solar Bags:

"A cow broke one of my buckets. So now I just have that old one over there…. this old one and the one you guys gave me. I can't use all four of my bags with just two containers, there won't be any space to hold the [treated] water"

(Participant #7)

Additionally, CARE did not provide all the materials needed to purify, store, and carry disinfected water. Three buckets are necessary to complete the disinfection process: one for storage, one for sedimentation, and one for decanting. Since participants were only provided with two buckets, they had to supplement the third on their own, a feat not always possible for the remote and impoverished population: *"sometimes I want to prepare water, but sometimes I don't have enough buckets,"* (Participant #1). Similarly, Participant #3 had to ask her sister for a town-bought plastic bottle to carry her water to work every day. When asked how the project could be improved, Participant #2 mentioned something similar, "*you could give us more cups, so we can have something to drink out of.*"

Intentions for future behavior

All eight participants used to get their water from the creek and allowed it to sediment naturally. Since the Solar Bag intervention began, four participants have used water from the Solar Bag to the exclusion of all other sources. Four participants, however, mentioned that when they cannot use the Solar Bags, they revert to creek water which they treat only by allowing the water to sediment naturally.

Six of the eight participants admitted that once the Solar Bag project finished and there were no more bags available for free distribution, they would return to using naturally sedimented creek water. When asked if she would return to creek water after the project was finished, Participant #5 responded, *"Of course, we will get our water from the creek, let it sediment naturally.*"

Participant #1 and Participant #4, however, did not want to return to using creek water, but were unsure of how they would treat their water once the Solar Bag project reached its conclusion.

> *"What will I do? I am not going to argue. That is how it is…I also want to drink clean water…I didn't like the creek water. I still don't like it. I don't like water like that. I like only water that I prepare from the Solar Bag."* (Participant #4*)*

Areas for improvement in the project

Each participant was asked how she thought the project could be improved. Three participants were confused by the question and were unable to answer. Participant #3 simply said "yes" to all probes but sounded unsure of her answer:

"Interviewer Do you need more information… more buckets…

Participant: Mmmm… yes.

Interviewer: What can we do to improve the project or help you?

Participant: Mmm… yes.

Interviewer: how can we help?

Participant: Mmmm

Interviewer: Are things ok the way they are now?

Participant: Yes."

Similarly, Participant #7 laughed at the questions, evidently embarrassed that she did not understand. Participant #5, on the other hand, misunderstood the question and answered:

> *"Well, you can… you can support us with something… how can I tell you… something with the water, you know. Like, you know, a well, piped water, something like that. So that we aren't going so far away to help fetch water."*

Two participants mentioned needing more storage buckets: *"… more buckets would be nice, I don't always have enough buckets to prepare water,"* admitted Participant #8. Participants #5 and #6 mentioned wanting larger storage containers. Participant #2 explains:

"I needed more buckets so that I could gather my water so that I would not have to be making drips to fetch water all the time. I've already gone five times. I would rather have two large holding containers rather than having to go fetch water all the time. I would like to have two buckets. Large ones."

Chapter 5: Discussion

In consideration of all the findings of this evaluation process, a few of the results are notable in determining: programmatic areas to avoid common user mistakes; the adequate performance of the Solar Bag in the field; and the level of social appropriation, as defined by CARE Perú.

Results of the analysis between knowledge of the steps of the SODIS process and actual practice showed that most of the participants knew the basic steps to the SODIS process: apply alum, allow sedimentation overnight, decant water into the Solar Bag, add a drop of indicator dye, and place the Solar Bag out in the sun. Furthermore, most participants understood that there was a specific dosage of alum required to treat the water depending on the volume of water to be treated. Most participants also knew that the Solar Bag was to be left out in the sun for different amounts of time, depending on the sun's intensity. However, the analysis of the observational data showed significant gaps between reported knowledge and actual practice. Specifically, five gaps are important to note: 1) incorrect dosage and application of alum; 2) improper sedimentation of the alum-applied creek water; 3) Solar Bags emptied before the dye disappears; 4) the water storage container is not disinfected before use and 5) the Solar Bags are not stored properly.

Another key result from the analysis was the discrepancies between the steps that were not reported by the participants, but the observation that they in fact did perform the step. For example, not every participant reported applying the alum during her explanation of the disinfection process. However, every participant performed the step in practice. Only two participants, #5 and #6, performed the steps incorrectly by applying the incorrect dosage of alum. Both Participant #5 and #6 counted ten stirs when applying the alum to the water when they should have been applying 20 stirs for the corresponding volume to be properly treated. Both of these participants lived in the same house. It is likely that both participants had the wrong understanding of the process and reinforced that misunderstanding by observing each other's (incorrect practice). It is also possible that one participant passed on her incorrect knowledge to the other.

Three of the other four participants were also observed performing the stirring step incorrectly. The drag of the water on the string and alum causes the alum to remain stationary while the string moves in circles. If this is done incorrectly, then the alum does not have enough contact with the entire volume of contaminated water and flocculation does not occur effectively. It is possible that this occurs because the participant was not trained to understand the importance of the contact time between the alum and the water. Without that knowledge, it is possible that the participant does not realize how much the number of stirs matters during this step of the treatment process.

The data also revealed that sedimentation of the alum-applied water was occurring incorrectly. In her interview, Participant #5 said she allowed the alum-applied water to sediment overnight. However, when her practice was observed, it was evident that she applied the alum to the creek water, immediately before decanting it. Similarly, Participant #6 admitted that she does not allow the alum-applied creek water to sediment overnight and she followed the same procedure as Participant #5. As mentioned above, this similarity in incorrect practice is probably due to the fact that both participants lived in the same household.

This incorrect sedimentation step was also seen in Participant #8. She only allowed her creek water to sediment for two hours with the alum before she decanted the water and filled the Solar Bag. While she does not live in the same household as Participants #5 and #6, there might still be an explanation of this behavior. When the health promoter did not deliver the necessary materials to Participant #8, she stopped using the Solar Bags for about two months. It is possible that once she started treating her water again, she forgot the correct execution of some steps.

The errors with sedimentation are important in this context because improper sedimentation leads to incomplete flocculation. All three participants that performed this sedimentation step incorrectly reported that their treated water was only good for a few days before it developed ”phlegm” and became “bad.” Independent trials by the researcher showed that this “phlegm” was actually water still in the process of flocculating. If the water is not allowed enough time to form flocs after applying the alum this process will continue, even after placing the water into the disinfected or stored Solar. The continuation of the flocculation process leaves the “phlegm” and leads participants to think that the water is “bad.” As will be explored below, this preventable outcome significantly impacted participant satisfaction with the quality and quantity of the Solar Bag water..

Perhaps the most pronounced result was the discrepancy surrounding the knowledge of when to empty the Solar Bags and the practice. The participants were instructed to sun their Solar Bags for three hours on sunny days and six hours on overcast days. In practice, brand new Solar Bags disinfect water in three to six hours, as indicated by the disappearance of the blue indicator dye. However, after multiple uses, the Solar

Bags wear out and, over time, are not as efficient in disinfecting the water. Therefore, it takes longer for the indicator dye to disappear. Participants, however, were not cautioned as to this natural degradation of the bag and the need to allow the water additional disinfection time. Therefore, five of the eight participants emptied their Solar Bags too early, while the water was still blue.

The most consequential result was seen in the incorrect storage practices on the treated water. Of the five participants observed preparing their storage containers, only two were seen to used a disinfecting agent (i.e. soap or chlorine) when cleaning the receptacle. The other three participants rinsed out their storage container with creek water. This was a problem since the creek water was contaminated with microorganisms. Therefore, when the Solar Bag water was emptied into the storage container, it is likely tat the treated water became immediately re-contaminated with disease-causing microorganisms. Consequently, not only has the participant has lost 15-20 hours of water preparation time, energy, but they also re-exposed herself and her family to disease-causing pathogens from the untreated creek water used to rinse the storage container.

This finding is consistent with previous research on household water storage. In their article, Benwic et al. (2018) postulated that particular factors were associated with post-treatment household water contamination. Similar to Bellavista, Benwic et al. identified that using untreated water to clear the storage container is a risk factor for re-contamination. The authors also name a number of other risk factors – including leaving dishes wet after washing, using a ladle or scoop to retrieve water from the storage container (instead of a spigot), "having an untreated water storage container that appeared dirty on the outside, and cows living within 10 m of the household" (Benwic et al., 2018, p. 1) – which were seen, but not recorded in Bellavista.

Reygadas et al. (2015) also explored factors associate with post-treatment contamination. They found that the risk of household water recontamination increased when: storage containers were not covered, had a wide opening, or necessitated the need to use a ladle (Reygadas, Gruber, Ray, & Nelson, 2015). These risk factors were observed in Bellavista. However, the researcher did not record them.

Social appropriation

According to CARE Perú, social appropriation is defined as a) the Solar Bag is used on the day of the visit and proof of use is evident, b) a high level of participant satisfaction, and c) local substitutes do not replace the use of the Solar Bag.

Results showed that all eight participants used the Solar Bag on the day of the researcher's visit, and were satisfied with a variety of aspects surrounding the Solar Bag. All eight participants said they would continue using the Solar Bag disinfection process as long as the materials were provided. All eight participants claimed to be willing to pay for the materials, if they were available in the rural market. However, six of the eight participants admitted that once the Solar Bags were no longer distributed free of charge, they would return to using creek water and allowing it to sediment naturally. Consequently, it can be argued that while participants readily adopted the Solar Bag disinfection system, and satisfaction surrounding its use was high, the population of Bellavista did not socially appropriate the Solar Bag[2].

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[2] According to CARE Perú's definition

As described previously, Halperin et al.'s study showed that after eight years, the SODIS intervention was still in use in 42% of the study population (2011). The key difference between these study results is that the CARE projects required resupply from the NGO, rather than the free market, as was the case in the Halperin study. It can therefore be argued, that if the Solar Bag products were available on the free, rural market, some participants might continue using it. This is evident by the fact that participants mentioned they were willing to pay 10-20 S/. ($3-$6) per bag if it were available for sale in Iparía.

Barriers to sustained use

Interview data revealed that while participants were satisfied with many aspects of the Solar Bag, the supply chain of materials was a barrier to the use of the Solar Bag. The interviews and observations revealed that in order for the Solar Bag disinfection process to be completed correctly, it was necessary to have three buckets. CARE Perú only supplied participants with two buckets of water. This meant that participants needed to supply their own third bucket in order to complete the disinfection process properly. Obtaining this third bucket was often a burdensome financial load on participants that rarely had the money for new purchases such as plastic bottled and buckets. As a consequence, due to the lack of materials participants did not prepare as much disinfected water as was possible. Instead, participants would only be able to fill a fraction of the bags they were given to use, leaving the other bags unused.

As explained in the Chapter Four, there were also issues with CARE's health promoter. The health promoter, who also doubled as the village teacher, controlled the supply of Solar Bags and their accompanying materials. His slow response to replacements request adversely affected participants' satisfaction. Even more troublesome, was that his actions discouraged one participant from using the Solar Bags altogether. It can be argued that a more responsible and diplomatic health promoter could have improved the participants' experience, and therefore their satisfaction, with the Solar Bag. This idea is similar to Altherr et al.'s conclusion that "it will be beneficial for promotion activities to focus on…choosing a promoter that will be well accepted in the community and who is able to create confidence in the new technology," (Altherr et al., 2008, p. 218).

While this research supports Altherr et al.'s conclusion, in the case of Bellavista the health promoter was chosen based on his level of literacy and consistent residency in the village. No other adult village member met these essential criteria. Therefore, there were limited options in choosing a health promoter.

Limitations

As mentioned previously, fieldwork in the Amazon wilderness presents many logistical challenges. For example, the researcher could only stay in the community for one week at a time. There were some participants that were only in the village once a week on weekends. It was therefore necessary to visit the community two times in order to be able to interview all eligible participants.

Additionally, the combination of unpredictable weather and varying time schedules made it difficult to complete the interview and observation process in the desired order. In some cases, the researcher performed observations before the interview.

In other cases, she performed the sedimentation and storage one day, and the filling and sunning of the bags on another day.

Language barriers also made it difficult for the participants to understand some of the abstract concepts explored in our interviews. None of the participants could answer the question regarding their satisfaction with the disinfection process time. Participants claimed to be unable to understand the researcher even though she was speaking in Spanish. It became apparent that Spanish was the second language for the participants. Perhaps if the interview was conducted in Ahsanika or Shipibo, the participants would have been able to answer these questions.

Finally, the Key Performance Indicator framework could have been better organized. The original framework from CARE was oversimplified and did not show all the steps for a proper disinfection. This proved to be a complicating factor when attempting the observations. Without a thorough understanding of the details accompanying the disinfection process, it was difficult to gather the appropriate data. Once the incomplete steps were noted, the observation guide was adjusted to catch the extra steps.

Chapter 6: Recommendations

Recommendations

The aggregate analysis of the gap between knowledge and practice, as well as social appropriation, revealed key points surrounding knowledge and practice of the Solar Bag, as well as the community's appropriation of the technology. Based on these points, this researcher recommends the following improvements to the Agua Solar Project:

- **Institute a number of quality control workshops.** Based on the gaps between knowledge and practice surrounding use of the Solar Bag, CARE may need to invest in quality control workshops that help to address incorrect participant behavior. Behaviors to correct include:
    - Making sure that water sediments overnight after alum is applied. Failure to do so results in phlegm forming in the water, negatively impacting user satisfaction.
    - Identifying sunny spots on their property that receive no shade so that bags can be exposed to the sun. Community members can construct tables made of wood and lined with either a dark or reflective material in order to help accelerate the disinfection process.
    - Making the disappearance of indicator dye the primary marker for the completion of the water purification process. Participants should also be warned that the Solar Bag will deteriorate over time, making it necessary to leave them exposed to the sun for longer periods of time.
    - Reminding participants of the importance of disinfecting their storage containers before use.

- **Investigate alternative Solar Bag designs**. Alternate designs should take into account issues with storage as well as wear and tear. New designs of the Solar Bag should incorporate the earloop on the bottom side of the bag. In doing so, participants can hook their Solar Bags onto something and allow for the excess water to drain out, and in such a way, avoid mold issues. Additionally, manufacturers should consider making the TiO_2-coated mesh inset replaceable. This may facilitate an elongated product lifetime, reducing waste and maintaining the appropriate standards for water disinfection.

Conclusion

Studies show that a TiO_2 SODIS models can be more effective at removing disease-causing pathogens than the standard PET-bottle model (Gelover S, 2006; McGuigan KG, 2006; Mendez-Hermida et al., 2007). This thesis investigated the progress that has been made in adapting the TiO_2-SODIS technology to rural and remote contexts. Key results showed that participant satisfaction with the Solar Bag disinfection process was high. Participants were satisfied with the supply of Solar Bags and accompanying materials, their and their family's health improvements, and the quality of the water from the Solar Bag.

Despite this high level of satisfaction, analysis showed that there are several important barriers to using the Solar Bag that should be noted and addressed. Most important among them is the issue of the health promoter and the supply chain. In the case of Bellavista, the health promoter's uncooperative attitude and low (or slow) response to participant supply needs created a significant barrier for the continued proper use of the Solar Bag by a few of the participants.

Finally, the data also showed that while participants were eager to use the technology, there was no promise of sustained use after the program close. However, if the product were to be available, on the free market, at an affordable price (i.e. 10-20 S/., $3-$6) participants would use the technology. Due to this reason, this researcher does not recommend that neither CARE Perú nor the Government of Perú consider the Solar Bag as a viable alternative to traditional water treatment without addressing these access issues.

Appendix A

Bellavista Interview Tool

1. Before
   a. Where did you get your water?
      i. Was the water treated in any way?
      ii. What time did you bring your water?
      iii. Who was responsible for bringing the water?
   b. What did you use this water for?
   c. How much water did you bring every day?
   d. Did you worry about the quality of the water?
2. The Solar Bag
   a. Uses
      i. What things do you use the water in the bag for?
      ii. How much time does it take for the water you treat?
      iii. Do you use the bags when you go to the farm or to the wood?
3. Quantity of Water
   a. How much water do you bring per day?
   b. Does the amount of water given by the bag seem sufficient?
   c. With this change, do you drink more or less water than before?
4. Water quality
   a. What differences do you see between the water from the bag and the water you used to use before? The taste? The smell? The color?
5. The Process

a. Explain the process you take to treat your water with the solar bag?

i. When is it that you bring water? When do you apply the alum to the water? How long do you let the water settle? How long do you allow the bags to be in the sun? How do you know when they are ready?

b. How do you like that time this process takes? Is it less than before or more?

6. Duration of the bag

a. How many bags did you get the first time?

b. How many bags have failed?

c. Do you think that the bags go bad very fast?

7. Household Domains

a. Who brings the water saves?

b. Who handles the use of the bag?

c. How do you feel now that you have the power to prepare clean water?

8. Changes in your life

a. Has the health of you or your family changed since you started using the bag? How?

b. Has hygiene / sanitation changed for you or your family since you started using the bag? How?

c. Have you changed your concern about water (quantity, quality, and / or carry) since you started using the bag?

9. Satisfaction

a. Do you like the solar bag? Why?
b. Why do you use the bag?
c. When are the bags finished, how will your water be treated? Settle? Pills? Filter?
d. If they sold the bags in Iparia, would you buy them? How much would you pay?

10. Instances of non-use
    a. When you can't use the bag, where do you get your water for consumption?
    b. Do you treat that water in any particular way?
11. Conclusion
    a. If you are the next Iparia mayor and have some opportunity to improve the development of the communities, what project would you do? Bag? Water well? Filters? Chlorinated water? Pipes to each house?
    b. If I take this project to Santa Velita, how could I improve it? More bags per family? Biggest drums? More workshops on proper use?

Appendix B

Observations Tool

1. Proof of use
2. Sedimentation with alum
    a. If possible, the night before
    b. 20 stirs for ~17 L
3. Transfer to Bag
    a. manipulation of the bag by the neck
    b. correct use of the prefilter
4. Application of indicator drops
5. Bag exposed to the sun correctly
    a. Without shadow
    b. Drawings and writing on the bottom side
    c. Until the dye disappears
6. Storage Container
    a. Covered
    b. Out of reach of animals
    c. Washed / disinfected

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