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Assessment of Point of Use Household Water Treatment Technologies in Nzoia River Basin, Kenya

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***Abstract*— *Waterborne diseases caused by consumption of unsafe drinking water are a major health burden in most of the developing countries in the world. Lack of safe water perpetuates poverty. Safe drinking water and sanitation are the condition for physical health and intellectual, social and economical development. Point-of-use (POU) water treatment has been advocated as a means to substantially decrease the global burden of diarrhea and to contribute to the attainment of Sustainable development goals (SDGs). This study aims at assessing the point of use household water treatment technologies in Nzoia River Basin, Kenya. A survey research design was adopted and data collected for a period of 5 months. Total of 403 households were surveyed. Qualitative data was descriptively analyzed while quantitative data was analyzed using Statistical package for social scientists (SPSS). 62 % of the respondents used improved water sources (3 % piped water into dwellings, 7 % water piped into compound, yard or plot, 3 % public tap/standpipe, 6% tube well or borehole, 11% protected dug well, 31% protected spring and 1% rainwater collection). 38% used un-improved water sources (10 % unprotected dug well, 19 % unprotected spring, 1% tanker truck/cart with small tank, 8 % surface water - river, dam, lake, pond, stream, canal). For the (POU) water treatment technologies, 29% used chlorination with safe storage, 12% ceramic filteration candles, 2% combined coagulation/chlorine disinfection systems (PUR), 2% solar water disinfection (SODIS), and 1% bios and filteration (concrete). 54% of the respondents used the option of boiling to make household drinking water safe. Majority of respondents use improved water sources and chlorination with safe storage is the most preferred POU water treatment technology.*

***Keywords*— *Nzoia River Basin, Household, Point of use water treatment technologies.*

I. INTRODUCTION

The United Nations Sustainable Development Goals (SDGs) target 6.1 calls for universal and equitable access to safe and affordable drinking water. Globally, 1.1 billion people still lack access to improved drinking water supplies and use unsafe sources (UNDP, 2003). Even people who have access to improved water supplies such as household connections, public standpipes, boreholes, protected dug wells and protected springs may not have microbiologically safe water. Improved supplies are often contaminated with pathogens causing infectious diseases such as cholera, enteric fever, dysentery, and hepatitis. The World Health Organization (WHO) estimates that diarrheal diseases kill 1.6 million people yearly, mostly children under five years of age. This disease burden falls disproportionately on those in developing countries, where children experience multiple episodes of diarrheal disease each year (Kosek, et al. 2003).

Recent systematic reviews estimate 30-40% reductions in diarrheal disease with improving household drinking water quality at the POU, making such treatment more effective than improvements at the source (Clasen, et al. 2007).

The goal of POU household water treatment (HWT) and safe storage technologies is to empower people without access to safe water to improve water quality by treating it and storing it safely in the household. Promoting household water treatment and safe storage (HWTS) can be a cost effective intervention in preventing waterborne diseases. Households within Nzoia River Basin use chlorination with safe storage, coagulation/chlorination systems (PUR), solar water disinfection (SODIS), ceramic filteration candles, biosand filteration (concrete) and boiling as POU water treatment technologies. The present study was carried out to assess the household water supply situation in Nzoia River Basin, POU water treatment technologies in use and the rating of POU technologies based on the selected sustainability criteria.

II. MATERIALS AND METHODS

A. Description of Study Area

The study was carried out in Nzoia River Basin which lies entirely within Kenya along the border with Uganda in the Lake Victoria Basin. The Basin is located between latitudes 1^0 $30^'$ N and 0^0 $05^'$ S and longitudes 34^0 E and 35^0 $45^'$ E and has an area of 12,959 km^2 and a river length of 334 km up to its outfall into Lake Victoria (Figure-1). Safe drinking water coverage in Nzoia River Basin stands at 62% as compared to the national figure of 58% (83% in urban areas and 50% in rural areas) (WASREB, 2015).

This region has tropical humid climate characterized by day temperatures that vary from 16 °C in Cheranganyi and Mt. Elgon areas to 28 °C in the lower semi- arid plains of Bunyala. Night temperatures vary from 4 °C in the highlands to 16 °C in the semi-arid lowlands. The highest rainfall ranges from 1100 – 2700 mm annually. Lowest rainfall ranges from 600 – 1100 mm annually. The dominant topography consists of rolling hills and lowlands in the Eldoret and Kitale plains. The dominant land use in the region is agriculture and the main food crops include maize, sorghum, millet, bananas, groundnuts, beans, potatoes, and cassava while the cash crops consist of coffee, sugar cane, tea, wheat, rice, sunflower and horticultural crops. Dairy farming is also practiced together with traditional livestock keeping (WRMA, 2012).

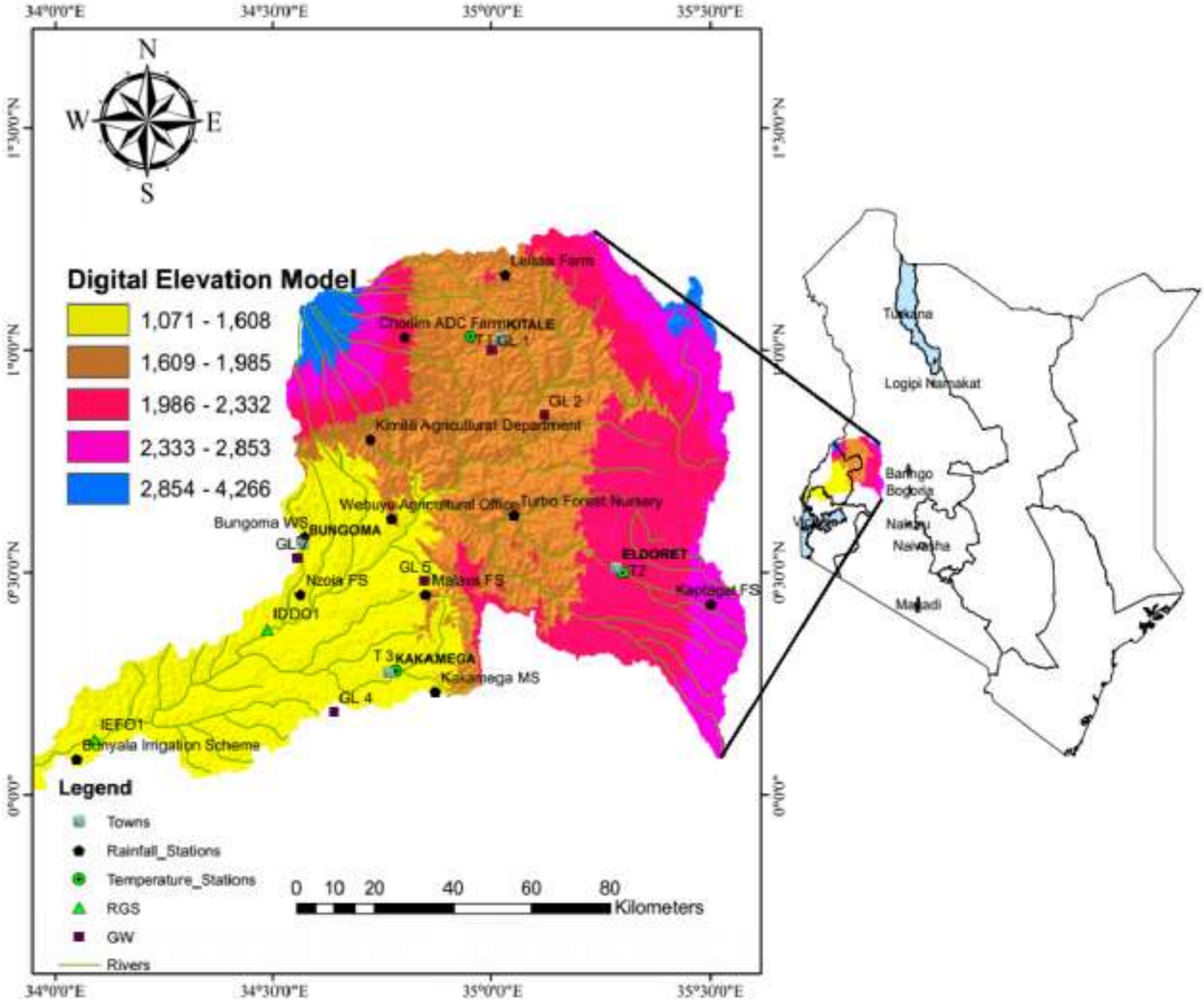

Fig. 1. Map of Nzoia River Basin, Kenya

Source: Author, 2017

The basin's population of approximately 3.5 million people live in the nine counties of Elgeyo/Marakwet, West Pokot, Trans Nzoia, Uasin Gishu, Nandi, Kakamega, Bungoma, Busia and Siaya. Groundwater is the main domestic water resource, supplying 78.8% of the residents leaving 21.2% for surface water resources. Many of the large piped schemes supplying the towns and rural areas have their intakes built on rivers, hence the classification under surface water.

B. Data Collection and Analysis

The survey was carried out from May, 2017 to September, 2017. The study adopted survey research design and sought to assess POU household water treatment technologies in Nzoia River Basin, Kenya. Random sampling was used to select Trans Nzoia (upper basin catchment), Kakamega (middle basin catchment) and Busia (lower basin catchment) counties from the nine counties of Nzoia River Basin for household survey. A pilot study (or pre-test) was used to identify errors and omissions, and to familiarize the Research assistants with the process and tools. The pre-test survey was conducted in the neighbouring Siaya County. 403 household questionnaires were proportionately divided amongst Trans Nzoia, Kakamega and Busia based on the number of households under each county. The households interviewed under each of the ward units were selected through multi-stage random sampling. This sampling technique was deemed ideal as it gave the targeted population equal chances of being represented. The unit of analysis in the study was the household. The household head was the targeted respondent.

The Key informant interview method was also used for more in-depth data collection from community members, and in particular, institutional representatives, who had diverse experiences on POU household water treatment technologies. The aim was to get information that would not easily be obtained from the other data collection methods. The Key informant interviews were conducted with selected community members based on their experience in the subject matter and experts from selected organizations. The national government, county government, parastatals, private sector and NGO officials were identified based on the work of their respective institutions in relation to POU household water treatment in the study area. A total of 51 key informant interviews were conducted with the Researcher capturing data on flip charts, note books and voice recording tapes.

Informed by the fact that some respondents get the motivation to share their views while in a group, focus group discussion was used to get in depth knowledge about POU household water treatment technologies in the study area. The FGD was chosen to provide more detailed interactive information as it created an environment in which the respondents freely discussed the issues at hand and were allowed to give their personal opinion regarding the issues. A total of nine FGDs were conducted with each FGD meeting having between 8-12 participants. The researcher also used observation checklists (WHO toolkit for monitoring and evaluating household water treatment and safe storage programmes) to collect additional data while in the field. Data processing involved data cleaning and identifying contradictions in the generated data and hot pursuits being made through face to face interviews. The responses given by various respondents were categorized into specific themes and sub-themes of either qualitative or quantitative data. Qualitative data was descriptively analyzed and presented in discussion form while quantitative data was analyzed using the embedded methods in Statistical package for social scientists (SPSS).

C. Ethical Consideration

The ethical approval for this study was obtained from the National commission for science, technology and innovation (NACOSTI) with issuance of research permit requiring adherance to all conditions spelt therein .At all levels of data collection, the relevant administrative officials were contacted and permission secured. All the necessary explanations about the purpose of the study and its procedures were explained with the assurance of confidentiality for the respondents.

III. Results and Discussion

In the study area, the age of the respondents ranged from 21 to 75 years (mean age 37.4±10.8 years). Majority of them were female respondent constituting 59%. The average family size of the total household surveyed was 5 (SD= 2). The majority of the households, 72% were rural followed by 16% per-urban and 12% urban. Majority of the respondents 57% used Jerricans (plastic containers), followed by 15% plastic tanks, 7% used clay pots and constructed concrete tanks, 6% drums (steel and plastic drums) and 4% constructed steel tanks and tins.

The World Health Organization (WHO)/United Nations Children's Fund (UNICEF) Joint monitoring programme for water supply and sanitation (WHO/UNICEF, 2015) classifies drinking water sources as follows; improved sources: piped water into dwelling, water piped into compound, yard or plot, public tap/standpipe, tube well or borehole, protected dug well, protected spring and rainwater.

Non-improved sources: unprotected dug well, unprotected spring, tanker truck/cart with small tank, surface water (river, dam, lake, pond, stream, canal, irrigation channel). For bottled water; because the quality of bottled water is not known, households using bottled water for drinking are classified as using an improved or unimproved source according to their cooking and washing water sources. Households that use bottled water as their main source of drinking water, in such cases, additional information must be obtained about the water source for other domestic purposes, such as cooking and hand-washing. Bottled water is considered an improved source of drinking water only when the household uses an improved water source for their other domestic uses.

In Nzoia river basin, 62 % of the respondents use improved water sources (3 % piped water into dwellings, 7 % water piped into compound, yard or plot, 3 % public tap/standpipe, 6% tube well or borehole, 11% protected dug well, 31% protected spring and 1% rainwater collection). 38% use un-improved water sources (10 % unprotected dug well, 19 % unprotected spring, 1% tanker truck/cart with small tank, 8 % surface water - river, dam, lake, pond, stream, canal, irrigation channel).

The study established the household POU water treatment technologies available in Nzoia River Basin as chlorination with safe storage, combined coagulation/chlorine disinfection systems (PUR), solar water disinfection (SODIS), ceramic filteration candles, biosand filteration (concrete) and boiling. The study results show that 54% of the respondents use boiling to make water safe for drinking, 29% chlorination with safe storage, 12% ceramic filteration candles, 2% combined coagulation/chlorine disinfection systems (PUR), 2% solar water disinfection (SODIS), and 1% biosand filteration (concrete).

Boiling water is one of the oldest and most common household methods used in the developing world to treat water. WHO notes that more than 90% of the population in Asian countries use boiling as the preferred method to treat their water (Clasen, 2009). When used properly, boiling is also one of the most effective ways to disinfect water. Although the boiling point of water at sea level is typically 100 degrees Celsius (depending on impurities in the water, which can affect the boiling temperature), studies have noted a reduction of bacteria and parasites even when water has been heated to only 70 degrees Celsius (Clasen, 2009). While suggestions vary on the length of time the water should be boiled, the WHO's Guidelines for Drinking Water Quality states that the water should simply reach a "rolling boil" (WHO 2008).

The advantage of this method is that many people are already familiar with the concept of boiling to treat water. The needed hardware (e.g. heat source and pot) are already in place in most homes and boiling kills most pathogens. However, the disadvantage of this method is that it does not remove chemicals (like arsenic) or turbidity from the water or necessarily improve taste. It doesn't also incorporate a safe water storage system component, thus one must be added in order to avoid re-contamination of the water. Boiling is not usually able to produce large quantities of water for a family and may be cost-prohibitive for low-income families. The method can be labor and time-intensive to collect wood, biomas, charcoal, etc., most of which typically falls upon women and children. The time taken to gather supplies and

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boil the water may detract children from schooling or other productive activities. Boiling water using wood, contributes to deforestation and depending on how and where the water is boiled, it may increase danger of other health hazards such as skin burns and indoor air pollution (Clasen, 2009).

Treating water with chlorine on a municipal level has been practiced since the early twentieth century and is a major contributor to the decline of waterborne diseases in US cities (Kotlarz, Lantagne, Preston and Jellison, 2009). Chlorine is most effective against bacteria such as E. coli and less effective against parasites (Arnold and Colford, 2007). POU treatment of water with chlorine (usually in the liquid form of sodium or calcium hypochlorite) is quite simple; first, you add a measured dose of chlorine to untreated water; then shake or stir the water to ensure adequate distribution. Let the water sit for a measured amount of time to allow the chlorine to act before using. Both the chlorine dosage and the length of time the water needs to sit is determined by the concentration of the chlorine solution, the volume of water being treated, and the level of turbidity in the water. The recommended chlorine dosage is often based on 20 litre volumes, the volume of jerry cans that are common in many parts of the world. In addition to liquid chlorine, chlorine tablets made of sodium dichloroisocyanurate (NaDCC) under brand names such as Aquatab, have been used in emergency situations for years; in the last decade these tablets have been marketed in developing countries as an alternative to liquid chlorine to treat water on a household level (Clasen, 2009). These tablets dissolve quickly (and visibly, which end-users typically like), and the water can be used within 30 minutes to an hour, depending on the dosage and the amount of water used.

A significant challenge to the chlorination method by either tablet or liquid is the issue of treating turbid water. Turbid water contains suspended organic particles and often looks cloudy or murky. When water is turbid, chlorine may be ineffective due to chlorine demand, the consumption of available chlorine by organic matter in the water before it is able to disinfect microbes. This obstacle in treating turbid water can sometimes be overcome by increasing the dosage of chlorine. However, it is often difficult for end users to accurately gauge how much to increase the chlorine dosage to compensate for the turbidity of the water. Additionally, the distinct taste and smell of chlorine-treated water has been found to be a barrier to end-users; unfortunately, when water is turbid, the increased chlorine and its interaction with the organic materials in the water further increases the unfavorable taste and smell of the water. Furthermore, chlorinating turbid water may make the water drinkable, but it will not reduce the cloudy, dirty look of the water, making it difficult at times to convince end-users that the water has been purified (Kotlarz et al., 2009).

Household filters potentially present certain advantages over other technologies. They operate under a variety of conditions (temperature, pH, turbidity), introduce no chemicals into the water that may affect use due to objections about taste and odour, are easy to use, and improve the water aesthetically, thus potentially encouraging routine use without extensive intervention to promote behavioural change.

Higher quality ceramic filters treated with bacteriostatic silver have been shown effective in the lab at reducing waterborne protozoa by more than 99.9% and bacteria by more than 99.9999%, and their potential usefulness as a public health intervention has been shown in development and emergency settings (Clasen, et al. 2006). Porous ceramic (fired clay) media are used to filter microbes from drinking water by size exclusion. Ceramic candle filters are made in more developed countries to exact specifications, and ceramic filters of either candle or pot design are made in developing countries, where production methods and filtration effectiveness can vary. While various "candle" ceramic filters (so named for their hollow cylindrical shapes) have been produced for years by commercial companies around the world, they are typically more costly and marketed to the middle class (Clasen, 2009). The ceramic pot is placed in a larger covered container (usually plastic) that has a spigot. The process of filtering the water is simple: one pours the water into the top of the pot and waits for it to filter through the ceramic and collect at the bottom of the plastic container (Murphy et al., 2010). The ceramic filter unit requires a periodic manual cleaning to remove the impurities left by the water; if it is not cleaned regularly, it is less effective; additionally, the flow rate of the ceramic filter appears to decrease over time even with periodic cleanings (Sobsey et al., 2008). The effectiveness of the pot-style filter is reduced if the production methods are not strictly adhered to. Both the porosity of the ceramic and the amount of silver applied to the pot impacts the efficacy of the filter; therefore, strict quality control measures must be maintained during the production process in order to maintain high filtration and treatment standards (Clasen, 2009). When used properly, several studies have shown ceramic filters to be effective in removing pathogens such as E. coli, and reducing diarrheal disease by as much as 40- 70% in households that use them (Clasen et al., 2006).

Slow sand filtration treatment of communal water has been in use for more than a century. In the early 1990's, a household-level version of the slow sand filter, the biosand filter (BSF), was introduced by a Canadian researcher with an important design change that allowed the system to operate with only intermittent water flow, unlike the continuous water flow needed with previous slow sand filters (Clasen, 2009). Enthusiasm for the biosand filters by several NGOs has led to it being distributed in a number of developing countries around the world.

Elliott et al. (2008) describes the gravity-fed mechanics of the BSF as follows: one; water is poured into a concrete or plastic chamber filled with locally available sand; two; the water goes through a diffuser plate (made of either plastic or metal) that distributes the water more uniformly in the sand and prevents disturbing the biolayer; three; there is an outlet pipe that is elevated in order to allow the filter to maintain a layer of water above the surface of the sand; four; due to the constant layer of water above the sand, the sand bed remains wet and causes a biolayer of microorganisms (referred to as the schmutzdecke) to form. The schmutzdecke is one of the key components that removes pathogens in the filtration process. It may take up to 30 days for the biolayer to become well established; during this interim period, it is recommended that the filtered water also be treated with another form of disinfection to ensure that it is microbiologically safe (CAWST, 2010). Five; the water filters through the sand and gravel layers and drains to the bottom of the container; there it reaches the outlet pipe, which naturally conducts the water to the outside for collection; and six; biosand filters need to be cleaned periodically; otherwise, the flow rate will slow. Cleaning BSFs consists of removing the top several centimeters of sand and replacing the water on top (Elliott et al., 2008).

The biosand filter can be made out of local materials and the containers are typically made of either concrete or plastic. The concrete filters tend to be more durable than the plastic ones. With either type, the amount of sand and gravel needed for the filter means this is a heavy product (a concrete version can weigh up to 260 lbs) and can be labor intensive to produce and install . Consequently, biosand filters are usually made relatively close to the areas in which they will be used (Clasen, 2009). Once a BSF is installed, however, there is little to no maintenance involved beyond a periodic scouring of the top part of sand and water. The ease of use and relative lack of maintenance may be one reason that BSFs have one of the highest rates of continued use by consumers in follow-up study surveys (approximately >85%) (Sobsey et al., 2008). In a recent follow-up study of biosand filter use in the Dominican Republic, 90% of the households involved in the original intervention were found to still be using their biosand filters one year later (Aiken et. al, 2011).

Multiple studies have demonstrated the efficacy of BSFs in reducing water pathogens like E. coli and improving water turbidity, especially as the biolayer grows over time (Elliott et al., 2008). One of the greatest advantages of the BSF system compared to other non-electric POU technologies is that it can produce large volumes of treated water (0.25 to 1 liter per minute or ten to hundreds of liters per day), which can then be used for household purposes beyond drinking water (Clasen, 2009; Sobsey et al., 2008). This feature is especially important for households with multiple families occupying the same dwelling. The biosand filtration system has the highest upfront cost of the POU systems examined under this study.

POU water treatment based on combined coagulation/chlorine disinfection systems in Nzoia River Basin use PUR. In light of the challenges chlorine treatment faces in areas where the water is turbid, a combined chlorine-coagulant point of use treatment system was developed by the American-based company, Proctor & Gamble (P&G). The chlorine-coagulant treatment system comes in individual packets that contain both a powder that coagulates heavy metals, organic material and microorganisms, and powdered chlorine in the form of calcium hypochlorite. One packet is used to treat approximately 10 liters of water.

The chlorine-coagulant sachet system is relatively easy to use: one; open the sachet and pour all the contents into a container containing the untreated water; two; stir the water for approximately five minutes; three; wait for the suspended organic materials in the water to collect and settle to the bottom of the container; four; when the water looks clear and the organic matter has settled to the bottom, pour the water into another (clean) storage container that has a cheese cloth or thin cloth material over the opening to filter out the clumped organic matter; five; allow the treated water to sit for an additional 20 minutes before using in order to allow ample time for the chlorine to disinfect the water (P&G Children's Safe Drinking Water, 2011).

One of the main benefits of the chlorine-coagulant system over the chlorine-only approach is that there is a visible change in the look of the water, which may induce people to adopt this POU treatment more readily (Reller et al., 2003). In a randomized control study in western Kenya, all 191 participants in the chlorine-coagulant group preferred the treated water to untreated water; furthermore, there was a 25% reduction in diarrheal disease among the children using the chlorine-coagulant system during the study compared to the control group (Crump et al., 2005).

While some studies suggest that end-users are more enthusiastic about the cholorine-coagulant system than the chlorine-only system, the general uptake of this POU is spotty. In a study in Guatemala, researchers found households' uptake of chlorine-coagulant packets to be quite low (between 27 and 35%), suggesting that ongoing education and advocacy needed to take place (Reller et al., 2003).

Countries started using solar energy (ultraviolet radiation + infrared heat) to treat unclean water in the mid 1980s. This method of water treatment has four main steps: one; collect clear, plastic polyethylene terephthalate (PET) bottles that are approximately 1-2 liter in size; two; clean the bottles; three; fill the bottles with untreated water and shake them to aerate the water; and four; close the bottles and place them horizontally to full sun exposure for at least 6 hours. The amount of sun exposure time needed to effectively treat the water depends on multiple factors: bottle size, cloud coverage, latitude, altitude, season, and the turbidity of the water are the main factors to take into consideration when determining the treatment time. If the weather is rainy or cloudy, it is recommended that the bottles be left out for 1-2 days in order to ensure that the water has been exposed to ample sunlight (Swiss Federal Institute for Environmental Science and Technology/Department of Water and Sanitation in Developing countries (EAWAG/SANDEC), 2002).

Typically, the bottles are stored on rooftops or on the ground during the treatment process. If there is a large amount of turbidity in the water it can affect the UV radiation; as a result, highly turbid water should undergo a filtration process of some kind before using the SODIS method. The amount of treated water produced using SODIS depends on the number and size of bottles a family has (example: 5 liter bottles = 5 liters of treated water after sun exposure).

Several studies have documented the effectiveness of SODIS in reducing the incidence of diarrheal disease in communities. In two studies in India, the estimated diarrheal incidence rate among children was reduced from 40 to 75% when the family treated their water with the SODIS method (Rai et.al, 2010; Rose et al., 2006). The main complaints from the villagers were that the SODIS method takes too much time and that the water smelled and tastes bad (Rainey and Harding, 2005).

The five household POU technologies; chlorination with safe storage, coagulation/chlorination systems (PUR), solar water disinfection (SODIS), ceramic filteration candles and biosand filteration (concrete) have an evidence base from laboratory and intervention studies that they are effective in treating household drinking water; but how sustainabile are they? Although POU technologies may demonstrate effectiveness both in laboratory and field studies, this does not necessarily mean that they will do so over long periods of time in actual use within the households. The effectiveness of POU technologies may be seriously undermined and waterborne disease risks and burdens will remain high if people treat water intermittently, go for long periods without treating, treat only some of the water they consume, or provide treated water to only some household members while others consume contaminated water. People must be sufficiently motivated and committed to integrate POUs into their daily lives.

The overarching need for any POU technology is that it should be sustainable: it becomes part of the daily routine of every household member, who uses it for drinking and other high level purposes (e.g., food preparation and handwashing) all of the time. Key features of a sustainable POU technology are that the technology;

- Should be able to consistently produce sufficient quantities of microbiologically safe water to meet daily household needs.
- Should be effective in treating many different water sources and quality levels including turbid and high organic content waters.
- Should require relatively small user time to treat water, thereby not significantly contributing to already substantial household labor time burdens.
- Should be low cost; relatively insensitive to income fluctuations, not causing households to stop treating water because they cannot afford to purchase the technology or continuously replace it.
- Should have a reliable, accessible and affordable supply chain for needed replacement units or parts for which consumers are willing and able to pay.
- Should maintain high post-implementation use levels after cessation of intensive surveillance and education efforts, as in field trials and marketing campaigns.

This study presents and applies a scoring system to rate and compare POU technologies based on five of these six sustainability criteria: water quantity produced, ability to treat a range of water qualities, ease of operation and time to treat water, cost per liter of water treated, and supply chain requirements. For each criterion, a technology is assigned a performance score of 1 to 4, with 1 for poor, 2 for fair, 3 for good, and 4 for very good performance.

Beginning with the first criteria of Water quantity produced; for all members of a household to use only treated drinking water, the ability of a household water treatment technology to produce sufficient volumes is critical. The number of units needed or doses applied increases user processing time and the risk that the user will rely on additional untreated sources of water for drinking. We score water quantity production based on producing 20 litres within 4 hours of applying the treatment, a sufficient quantity to meet all critical drinking water needs of a 5-member household (WHO, 2005). Technologies producing 20 litres of water in 4 hours by using one unit (in the case of chemicals) or applying up to one dose of water receive a score of 4. Such technology produces sufficient quantities of treated water to meet all daily needs. Technology receives a score of 3 if 2-3 units of the technology or 2-3 doses of water have to be applied to provide 20 litres in 4 hours. Technology receives a score of 2 if 3-4 units of the technology or 3-4 doses of water have to be applied to provide 20 litres in 4 hours; and finally the technology will receive a score of 1 if 5 or more units or doses of water have to be applied to meet the criterion.

For chlorination, it is supplied as concentrated liquid or tablets, designed for treatment of large quantities of water with a small volume of chlorine (5-10 mL or 1 tablet per 20 litres of water), allowing users to treat multiple unit volumes, chlorine as POU water treatment gets a score of 4. Coagulation/chlorination system such as PuR comes in sachets for a 10 litre volume of water, hence it scores 3. SODIS uses 1-2-L PET bottles, requiring 10-20 bottles per day for 20 litres of daily household water. The limited amounts of water treated per bottle may result in people using and possibly consuming both SODIS-treated and untreated water (Altherr, et.al 2006); hence a score of 1. Ceramic Filters flow rates are about 1-3 litres per hour, but decline with use and accumulation of impurities on filter element surfaces. At optimal flow rates, a filter can produce approximately 8 litres in 4 hours and 20 litres in about 10 hours. This has a score of 3. Biosand Filters have water flow rates of 0.25-1.00 litre per minute, easily allowing for the production of tens to hundreds of liters of water per day; hence a score of 4.

The second criteria is: Application of technology to a wide range of water qualities allowing for treatment robustness. The applicability of the treatment technology to a wide range of water qualities is key because of differences in water sources and spaciotemporal and seasonal fluctuations in water quality. Technologies that improve water quality and reduce microbes under a wide range of source water quality conditions provide households with high quality water regardless of source water quality. Technologies that can provide consistent microbial reductions in waters with high turbidity and organic matter are scored higher in treatment robustness. Technologies that reduce turbidity and/or organic matter and provide similar or higher microbial reductions as for water of higher quality score a 3, but those with enhanced production such as biosand filters score 4. Technologies not removing organic mater and turbidity but still maintaining effective microbial reductions score a 2. Technologies unable to remove turbidity and/or organic matter and providing less microbial reduction efficiency under poorer water quality conditions score a 1. With chlorination; waters with high organic matter and particles can interfere with chlorine disinfection efficacy, cause production of compounds with objectionable taste and odor, and create consumer scepticism about effectiveness due

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to the unchanged appearance of the water. This scores 2. Coagulation/chlorination systems can remove turbidity, organic matter, and microbes through flocculation and settling, aesthetically improving waters and facilitating chlorine effectiveness; this scores 3. For SODIS due to decreased penetration of UV light, it is less effective in waters having high turbidity and color and in bottles that become scuffed from daily use. Users have inadequate guidance on how to determine when raw water is too turbid or colored or bottles are too worn out for adequate UV light penetration. This scores 1. Ceramic and Biosand Filters can remove turbidity, organic matter, and microbes. These filters are simple to clean manually to restore efficacy and flow rate if too much particulate matter accumulates; hence ceramic filters score 3 and biosand filters score 4 due to enhanced production.

TABLE 1. Evaluation of Point of use water treatment technologies based on five selected sustainability criteria in Nzoia River Basin, Kenya.

Point of Use Water Treatment Technologies	**Selected Sustainability Criteria**					
	Water quantity produced by the technology	**Ability to treat a range of water qualities**	**Ease of operation and time taken to treat water**	**Cost per liter of water treated**	**Operation supply chain requirements**	**Overall score**
Biosand filters	4	4	3	2	4	17
Ceramic filters	3	3	3	4	3	16
Free chlorine (liquid)	4	2	4	4	1	15
Free chlorine (tablets)	4	2	4	3	1	14
SODIS	1	1	1	4	4	11
Coagulation/chlorination	3	3	2	1	1	10

The third criteria is: Ease of process use/operation and time taken to treat water. Adoption and consistent use of POU technology by households is influenced by both ease of treatment process performance and the time required of the household member tasked with treatment. The more straight forward the operation and maintenance of the technology, the greater the likelihood that it will be adopted and used successfully. This criterion is based on the sum of scores for three elements: process ease, process duration, and process maintenance requirements. For chlorination; the user needs only to measure out the liquid or dispense the tablet, add it to the water, mix briefly and allow for some contact time. Many liters of water can be batch treated within 30 minutes. Except for keeping the water vessel clean and protected from contamination, no maintenance is required. This scores 4. Under Coagulation/chlorination systems; the sachet or tablet needs to be added to 10 litres of water, stirred vigorously for a few minutes, and allowed to sit for 30 minutes. A floc will form and settle at the bottom of the container. The water must be decanted and filtered through a cloth filter into another container, and settled floc must be properly disposed of. Containers and utensils for treatment must be available and in satisfactory condition. This scores 2. The SODIS process can be laborious due to the need to manage many bottles of water daily. Households must plan ahead to anticipate daily water needs. PET bottles, which hold only 1-2 litres each, must be filled with water, shaken to aerate, placed in sunlight for a period of hours, recovered after exposure, and emptied. Sufficient bottles must be available to meet daily water needs and must be replaced when damaged. This technology cores 1. Ceramic Filters have the water poured into the top of the filter as needed and flows by gravity into a storage vessel for immediate use. Filter elements require periodic cleaning by manually scrubbing and rinsing to remove the accumulated impurities. This scores 3. Biosand Filters use the same operation as ceramic filters; require periodic cleaning by manually scouring the top few centimeters of sand and then decanting and disposing of the overlying water; hence it scores 3.

The fourth criteria is: Cost to treat water. POU technology cost is an important criterion for adoption and sustained use. For our purposes, we assume households treat 20 L of water per day for 365 days. For some technologies, this may require the purchase of multiple units of the technology to produce 20 L/day for a year (i.e., PuR sachets and chlorine bottles or tablets). The cost of each technology are calculated (in USD) as dollars/L/year. For technologies that are one time purchases this approach may overestimate the cost, but it does provide a consistent basis for comparison. Using this system, technologies are assigned scores based on 0.01$/L reference point. This approach to calculating POU cost does not take into account many other cost-related factors but it does provide a simple, uniform basis for comparison. For chlorination, a bottle of chlorine solution can treat >1000 L of water for about $1 and potentially lasts months. Chlorine tablets are more expensive than liquid chlorine at $0.01 to 0.001/L; hence we score 4 for liquid chlorine or 3 for chlorine tablets. Coagulant/chlorine system has the cost of a PuR sachet ranging from $0.003/L (production cost) to >$0.010/L (end user cost without subsidy) and this scores 1. SODIS requires only a continuous supply of PET bottles, which can be collected as discarded bottles, or may need to be purchased at low cost; hence it scores 4. Ceramic Filters have the cost of a filter unit as $8-10 and a replacement of porous ceramic pot element as $ 4-5. This score 4. Biosand Filters have a one-time cost of $25-100, depending on the country and implementer, hence it has a score 2.

The fifth criteria is: Operation supply chain requirements for the technology. Consistent use of a POU technology will also be affected by access to operation supply chain requirements. The need for a periodic or continuous supply can be a hindrance to sustained use of a technology, and currently available technologies have supply chain requirements. For this category, supply chain refers to logistical components the user requires to continue using the technology once received or introduced, not the logistical components necessary to make the technology available to the user by implementers. Technologies not requiring any type of supply chain for continued use score a 4. Technologies requiring periodic replacement or replacement parts score a 3. Technologies requiring a continuous supply of consumables to support continued use score a 1.

Chlorination requires a constant supply of consumable chemicals that consumers must be willing and able to purchase regularly. Free chlorine can be locally or regionally produced and distributed in bottles purchased by users that treat hundreds tothousands of liters before a repeat purchase is necessary. Chlorine tablets can be purchased in individual units or in multiple units (bottles and blister packs) and require regular or periodic repeat purchase. This scores 1. Coagulation/Chlorination sachets or tablets are manufactured in few locations, imported to most countries, and require unit purchase for every 10-20 L of water; this too scores 1. SODIS requires no commercial supply chain as long as used PET bottles are available; this receives a score of 4. Ceramic Filter units provide long use periods with one-time purchase, but require a supply chain for replacement of broken parts (filter elements and container faucets). This scores 3. Biosand filters are a one-time purchase and have no parts prone to breakage, so require no supply chain for replacement parts; hence a score of 4.

Scores for the POU technologies are summarized in Table 1. The overall sustainability ratings from highest to lowest are Biosand filters, Ceramic filters, Free chlorine (liquid), Free chlorine (tablets), SODIS and Coagulation/chlorination.

IV. Conclusion

Biosand filters, Ceramic filters, Free chlorine (liquid), Free chlorine (tablets), SODIS and Coagulation/chlorination technologies can substantially improve the microbiological quality of water and reduce diarrheal diseases but problems of sustained technology use in households still persist. For chlorination and coagulation/chlorination, the need to continuously repurchase a consumable product may cause households to forego treating water when financial resources are inadequate. Once interrupted, it may be difficult for households to start treating water again. For technologies producing relatively small quantities of water, such as solar disinfection and coagulant-disinfectant products, the required time and effort to treat sufficient water quantities for all daily household uses may contribute to declining use rates and consumption of both treated and untreated water, undermining their overall effectiveness. Ceramic and biosand filters are able to overcome sustainability obstacles by requiring only one-time purchase, producing sufficient water for daily household use with little time and effort.

Understanding the human behavioral factors that drive people to adopt and continue using household POU technologies is also crucial for widespread adoption and continued effective use. Expanding filter production, marketing, distribution for effective and sustained use also requires knowledge of economic factors. Better information is needed on factors that influence filter uptake and continued use by communities and households. Going a day without safe water means being at risk. Practicing POU water treatment and safe storage needs to be done at all times in order to minimize or prevent health risks

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