A School-based Trial Protocol in Community Promotion of Solar Water Disinfection (SODIS): A Case Study of Ndagwe Sub County, Central Uganda

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A School-based Trial Protocol in Community Promotion of Solar Water Disinfection (SODIS): A Case Study of Ndagwe Sub County, Central Uganda.

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CANDIDATE THESIS DECLARATION[1]

I declare that this thesis, which I submit to RCSI for examination in consideration of the award of a higher degree PhD is my own personal effort. Where any of the content presented is the result of input or data from a related collaborative research programme this is duly acknowledged in the text such that it is possible to ascertain how much of the work is my own. I have not already obtained a degree in RCSI or elsewhere on the basis of this work. Furthermore, I took reasonable care to ensure that the work is original, and, to the best of my knowledge, does not breach copyright law, and has not been taken from other sources except where such work has been cited and acknowledged within the text.

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Finally to God be the Glory.

ABBREVIATIONS

CFU	Colony Forming Units
DALYs	Disability Adjusted Life Years
DEHA	di(2-ethylhexyl)adipate
DEHP	di(2-ethylhexyl)phthalate
DWD	Directorate of Water Development
EAWAG	Swiss Federal Institute of Environmental Science and Technology
GBD	Global Burden of Diseases
HWTS	Household Water Treatment and Safe Storage
IRR	Incidence Rate Ratio
JMP	Joint Monitoring Program
MDG	Millennium Development Goal
MoES	Ministry of Education and Sports
MoFPED	Ministry of Finance, Planning and Economic Development
MoL	Ministry of Local Government
MWE	Ministry of Water and Environment
NTU	Nephelometric Turbidity Units
PEAP	Poverty Eradication Action Plan
PET	Polyethylene Terephthalate
RCSI	Royal College of Surgeons in Ireland
SODIS	Solar Disinfection
TDS	Total Dissolved Solids
TNTC	Too Numerous to Count

UBOS	Uganda Bureau of Statistics
UN	United Nations
UNICEF	United Nations Children's Emergency Fund
WASH	Water, Sanitation and Hygiene
WHO	World Health Organisation
WIL	Water is Life

SUMMARY

Improvement in microbial quality of drinking water by solar disinfection (SODIS) results in reduced diarrheal episodes among users. In this study, a randomized cluster stepped wedge study design was used to assess the use of primary school pupils as community promoters of SODIS technology in Ndagwe sub county, central Uganda. The intervention (SODIS) was introduced to pupils in the different school clusters at different time points throughout the year. Pupils were to only drink SODIS treated water both at school and home during intervention period. The effect of SODIS on prevalence of diarrhea and gastro-intestinal complaints severe enough to cause pupil absenteeism was monitored. In addition to SODIS treatment, the study also assessed a field comparison SODIS efficacy in both glass and PET reactors.

Results revealed that school children were effective promoters of SODIS with community use of the technology improving from 4.9% at baseline to over 60% post-intervention. SODIS also significantly improved microbial quality of water with 61% and 72.7% of all treated samples meeting the 0 CFU/100 mL WHO conformity standard for drinking water for both *E. coli* and *E. faecalis* respectively. In comparison, only 13% and 16 % of untreated samples met this standard for both bacteria respectively.

Generally, overall pupil absenteeism due to diarrhea and gastro-intestinal complaints was not significantly associated with SODIS treatment (IRR 0.63 CI 0.29 to 1.39 p= 0.222). However, absenteeism due to diarrhea and gastro-intestinal complaints was significantly associated with phase of SODIS intervention. In the last phase when all pupils were using the intervention absenteeism significantly (IRR 0.51, CI 0.31 to 0.83 p=0.012) dropped from a baseline average of 1.9± 2.2 days to 0.2±0.6 days. Finally, no significant difference was found in SODIS efficacy between glass and PET reactors under real field conditions

CHAPTER ONE: INTRODUCTION

1.1 Water, Sanitation and Hygiene: A Global Perspective

In 2000, 189 nations agreed to free people from extreme poverty and multiple deprivations by the year 2015 through the establishment of the eight Millennium Development Goals (MDGs) (Travis *et al.*, 2004). One of these goals (MDG 7c) was to halve by 2015 the number of people throughout the world without sustainable access to safe drinking water and basic sanitation (UN, 2012) . Progress of goal number 7c is monitored by the UNICEF and WHO Joint Monitoring Program (JMP) which makes bi-annual reports on access to drinking water and sanitation and the progress of related targets under MDG 7. Due to logistical constraints related to monitoring of microbial and chemical quality of water, the JMP uses the proportion of people using improved or unimproved water source and sanitation facilities (Table 1.1) as proxy indicators to assess global population access to safe water and sanitation. Improved water sources are those that are protected from outside contamination particularly from faecal matter. However, the sources may not be adequately protected and therefore may not supply safe water. Consequently, the number of people with access to safe water as reported by the JMP may be overestimated.

Table 1.1: Improved and unimproved water sources and sanitation facilities

	Drinking Water	Sanitation
Improved	Use of: ▪ Piped water into dwelling, yard or plot ▪ Public tap or standpipe ▪ Tubewell or borehole ▪ Protected spring ▪ Protected dug well ▪ Rainwater collection	Use of: ▪ Flush or pour-flush to: – Piped sewer system – Septic tank – Pit latrine ▪ Ventilated improved pit (VIP) latrine ▪ Pit latrine with slab ▪ Composting toilet
Unimproved	Use of: ▪ Unprotected dug well ▪ Unprotected spring ▪ Cart with small tank or drum ▪ Tanker truck ▪ Surface water (river, dam, lake, pond, stream, canal, irrigation channel) ▪ Bottled water (considered to be improved only when the household uses drinking water from an improved source for cooking and personal hygiene)	Use of: ▪ Flush or pour-flush to elsewhere (that is, not to piped sewer system, septic tank or pit latrine) ▪ Pit latrine without slab, or open pit ▪ Bucket ▪ Hanging toilet or hanging latrine ▪ Shared or public facilities of any type ▪ No facilities, bush or field (open defecation)

Source : WHO/UNICEF JMP, 2012

TABLE 6 Definitions of improved and unimproved drinking water sources and sanitation facilities

1.1.2 Global Safe Water Coverage

The target on access to improved drinking water sources world-wide is reported to have been met in the year 2010, five years ahead of schedule (UN, 2012; WHO/UNICEF JMP, 2012). However, it is currently estimated (WHO/UNICEF JMP, 2012) that over 783 million people world-wide are still without access to sustainable and safe drinking water and the projection is that about 605 million worldwide will still have no access to safe water by the year 2015. The

developing world, especially the Sub-Saharan Africa (SSA) region, is still greatly under-served. Unlike other regions that met their MDG targets for safe water access in 2010, the region is yet to meet its own target of 75% population access to an improved water source (Figure 1.1). Only 19 countries in the region are on track to meet the MDG target for water and sanitation by 2015. Rural areas and the poorest communities are the least reached in terms of water supply with women and children bearing the greatest burden of the water scarcity problem since they are responsible for sourcing and collecting the water. In fact over 62% women, 9% girls and 6% boys are responsible for water collection in households without piped water in SSA compared to only 23% of the men (WHO 2009a). It is estimated that there are five times as many people in the rural areas without access to safe water as there are in urban areas and that 84% of people still using surface water, live in the rural areas (UN, 2012; WHO/UNICEF JMP, 2012).

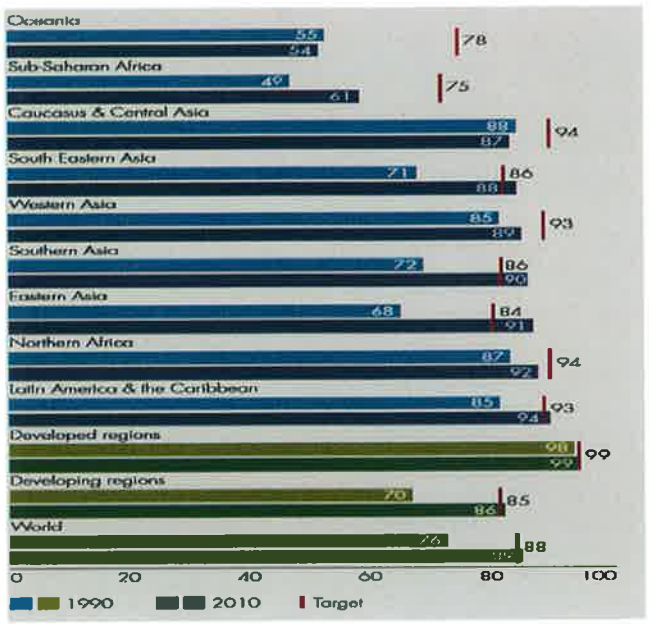


Figure 1.1: Percentage proportion of population using an improved water source 1990 and 2010 (UN 2012)

1.1.3 Sanitation Coverage

Unlike water supply, the world is not on track to meet the sanitation MDG target (Figure 1.2) with only 63% of the global population using an improved sanitation facility in 2010. This proportion is estimated to improve by only four percentage points to 67% by the year 2015 (UN, 2012). This is 5 percentage points short of the 72% MDG target unless the pace of changes in the sanitation sector is accelerated. Again, it is the developing nations with the least improved sanitation coverage with many countries including those in SSA having less than 50% improved sanitation coverage (UN, 2012; WHO/UNICEF JMP, 2012). This translates to over 2.5 billion people in the developing world without access to improved sanitation facilities and 1.1 billion of these still practice open defecation in fields, forests, bushes and water bodies. Just like water access, the majority of those without access to sanitation are the poorest communities who live in rural areas.

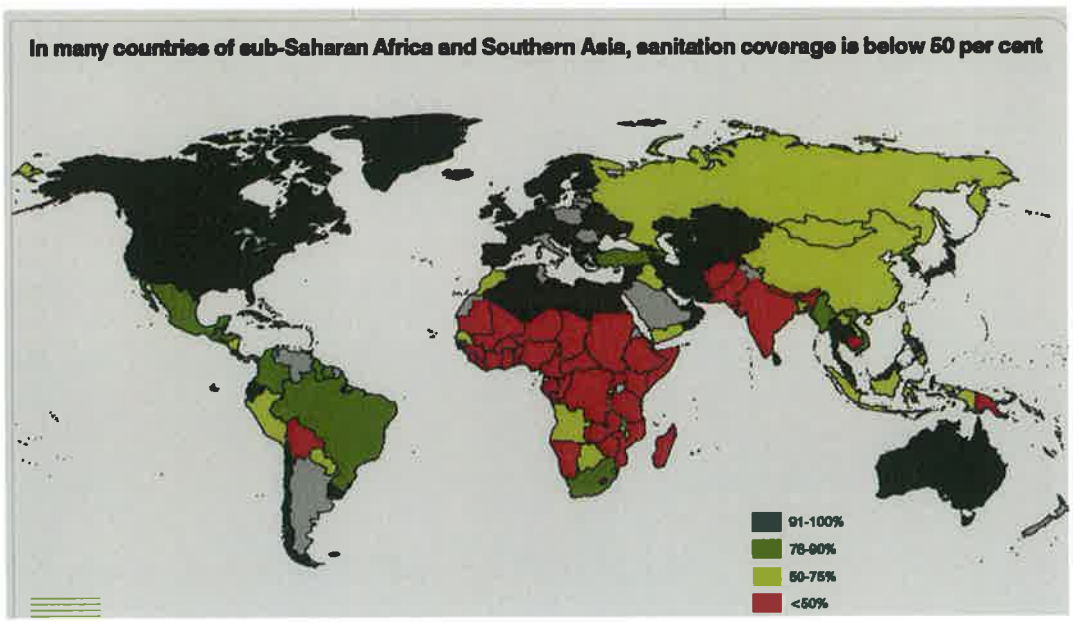


Figure 1.2: Proportion of population using improved sanitation in 2010 (WHO/UNICEF 2012)

1.2 Water, Sanitation and Health

Unsafe water, poor sanitation and hygiene (WASH) are associated with a range of diseases mostly diarrheal in nature, which contribute immensely to the global burden of disease (GBD). The global burden of disease is measured by use of the disability-adjusted life years (DALYs) and is defined as a measure of the gap between current health status of a population compared to an ideal situation where everyone lives to old age free of disease and disability (Lopez, Mathers, Ezzati, Jamison, & Murray, 2006; WHO, 2009a). DALYs are the sum total of years lost due to premature death (YLL) and years of healthy life lost due to poor health status or disability (YLD) in a population (Lopez, Mathers *et al.* 2006; WHO 2009). One DALY accounts for one year of healthy life lost and the sum of DALYs across a population accounts for the burden of disease in that population (WHO, 2009a).

As a global risk factor for burden of disease, unsafe water, sanitation and hygiene, is ranked fourth after under-weight, unsafe sex and use of alcohol, contributing 4% of all global DALYs (WHO, 2009a). However, in low income countries (LICs), unsafe water, sanitation and hygiene is second only to underweight as a leading risk factor for DALYs accounting for 53 million (6.3 %) of all DALYS. It is only in LICs that unsafe water, sanitation and hygiene is still ranked among the 10 leading risk factors for mortality, accounting for 1.6 million annual deaths (Table 1.2)

Table 1.2: The leading risk factors of death by income group in 2004

	Risk factor	Deaths (millions)	Percentage of total		Risk factor	Deaths (millions)	Percentage of total
	World				*Low-income countries*[a]		
1	High blood pressure	7.5	12.8	1	Childhood underweight	2.0	7.8
2	Tobacco use	5.1	8.7	2	High blood pressure	2.0	7.5
3	High blood glucose	3.4	5.8	3	Unsafe sex	1.7	6.6
4	Physical inactivity	3.2	5.5	4	Unsafe water, sanitation, hygiene	1.6	6.1
5	Overweight and obesity	2.8	4.8	5	High blood glucose	1.3	4.9
6	High cholesterol	2.6	4.5	6	Indoor smoke from solid fuels	1.3	4.8
7	Unsafe sex	2.4	4.0	7	Tobacco use	1.0	3.9
8	Alcohol use	2.3	3.8	8	Physical inactivity	1.0	3.8
9	Childhood underweight	2.2	3.8	9	Suboptimal breastfeeding	1.0	3.7
10	Indoor smoke from solid fuels	2.0	3.3	10	High cholesterol	0.9	3.4
	Middle-income countries[a]				*High-income countries*[a]		
1	High blood pressure	4.2	17.2	1	Tobacco use	1.5	17.9
2	Tobacco use	2.6	10.8	2	High blood pressure	1.4	16.8
3	Overweight and obesity	1.6	6.7	3	Overweight and obesity	0.7	8.4
4	Physical inactivity	1.6	6.6	4	Physical inactivity	0.6	7.7
5	Alcohol use	1.6	6.4	5	High blood glucose	0.6	7.0
6	High blood glucose	1.5	6.3	6	High cholesterol	0.5	5.8
7	High cholesterol	1.3	5.2	7	Low fruit and vegetable intake	0.2	2.5
8	Low fruit and vegetable intake	0.9	3.9	8	Urban outdoor air pollution	0.2	2.5
9	Indoor smoke from solid fuels	0.7	2.8	9	Alcohol use	0.1	1.6
10	Urban outdoor air pollution	0.7	2.8	10	Occupational risks	0.1	1.1

[a] Countries grouped by gross national income per capita – low income (US$ 825 or less), high income (US$ 10 066 or more).

Source: WHO 2009

1.2.1 Water Quality and Health

Water quality encompasses the physical, biological and chemical characteristic of water with respect to the purpose for which that water is intended such as drinking, swimming, fishing and other ecosystems (Johnson *et al.*, 1997). Drinking water quality can be affected by numerous factors including but not limited to pH, temperature, turbidity, dissolved solids and electrical

conductivity. Water can also be contaminated by micro-organisms such as bacteria of faecal origin, protozoa and viruses. In this thesis we shall concentrate on the physical and biological aspects that affect the quality of drinking water. Physical aspects discussed include pH, temperature, turbidity and total dissolved solids while biological aspects are bacterial indicators of water quality i.e. *E. coli* and *E. faecalis*.

1.2.2 pH

The pH of water is the indicator for acidity or alkalinity of water. It can also be termed as negative common logarithm of the hydrogen ion activity, ($pH= -\log (H^+)$) (WHO, 2007). Pure water has a neutral pH of 7, and a lower or higher value from neutral pH indicates acidity or alkalinity respectively (APHA, 1992; Manahan, 2005). Although pH of drinking water is not usually a health concern, it can be an indicator of the presence of certain effluents particularly when continuously measured and recorded together with conductivity of water (Chapman, 1996). Ideally drinking water should be at a pH range of 6.5-8.5; however, natural water may have lower values due to environmental factors such as acidic rain or presence of limestone in the ground. The lower the acidity of water, the higher the potential of corrosiveness leading to high levels of metal ions such as iron, zinc, manganese, copper which may have negative health impacts on humans (Manahan, 2005). The metal ions can also cause damage to metal piping leading to metallic taste of water and shortening pipe life span (Manahan, 2005). Low pH in water can be treated with the use of a neutraliser such as soda ash although this may increase the sodium content of water. Alkaline water usually indicates hardness of water but does not pose a health risk apart from affecting the aesthetic characteristics of water such as taste. Although pH 6.5-8.5 is ideal for drinking water, the human body maintains pH equilibrium and is not harmed

by consumption of waters out of this range (Opio, 2012). In fact some evidence suggests that hardness in drinking water may be protective with respect to cardiovascular disease although data is inadequate to provide a causal association (UNICEF, 2008b).

1.2.3 Temperature

Simply, temperature measured in degrees Celsius (°C) is a measure of the hotness or coldness of water (Adams & Moss, 2009). Temperature is an important measure of water quality as it affects the growth of micro-organisms with a growth range of -8100°C. Bacterial growth is optimum at about 35°C (Adams & Moss, 2009). Temperature is also important for regulation of gases and minerals in water with the solubility of gases such as oxygen and carbon dioxide increasing with decrease in temperature whereas dissolved minerals increase with increase in temperature (UNICEF, 2008b).

1.2.4 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) is a measure of the salinity of water. A TDS of less than 600mg/L is generally considered to be acceptable while that of 1000mg/L or higher increases salinity of water and therefore affects its palatability. The major ions associated with TDS in water are sodium and chloride but no guideline values (GV) have been given for either of the ions (UNICEF, 2008b). Electronic conductivity (EC) is sometimes used as a surrogate for TDS. It is a measure of the capacity of water conduct electrical charge and is directly related to the concentration of dissolved ions in water also known as total dissolved solids (TDS). Conductivity and TDS are both positively correlated to temperature (APHA, 1992; USEPA, 2011).

1.2.5 Turbidity

Measured in Nephelometric Turbidity Units (NTU), turbidity is the degree of cloudiness or haziness of water i.e. a measure of the degree to which water loses its transparency (Lenntech, 2010). Turbidity is caused by suspended solids/ particulates generally invisible to the naked eye which may get into water bodies due to runoff of storm waters, growth of phytoplankton and waste disposal into water bodies (UNICEF, 2008b). Many countries have set standards for allowable turbidity for drinking water and in Uganda the standards body Uganda National Bureau of Standards (UNBS) has set the turbidity for class II potable water to not more than 10 NTU (UNBS, 2008). The main effect of turbidity on humans is aesthetic since no one likes the look of "dirty water"(Lenntech, 2010). Microorganisms including bacteria, protozoa and viruses are typically attached to particulates in water and therefore reduction or removal of turbidity from water will greatly improve its microbial quality (WHO, 2011).Water turbidity in water can be reduced by simple cloth filtration to remove suspended particulates. Alum and *Moringa oleifera* seed extracts have also been cited as coagulants used to aid in removal of particulates in water hence reduction of turbidity (Muyibi & Alfugara, 2003) . However suspended particles may enhance the attachment of heavy metals, toxic organic compounds and pesticides thus decreasing the risk of exposure to such toxins (Opio, 2012).

1.2.6 Microbial Indicators of Water Quality

The commonest and deadliest pollutants of water drinking water in the developing countries are of biological origin including bacteria, protozoa, viruses and parasites. Since it is expensive to test for each of the mentioned micro-organisms in water, it has been suggested that indicator organisms be used to suggest presence or absence of each class of micro-organisms (Sobsey & Brown, 2011). An ideal indicator organism of water quality should:

- Be easily isolated and enumerated.
- Be present in large numbers in normal faecal matter of humans and other warm blooded animals.
- Be more resistant to disinfection than the pathogen.
- Must not multiply in water and its persistence in water must be comparable to that of faecal pathogens.
- Must generally be absent from other sources of bacteria coming into contact with water (Bonde, 1977; Gadgil, 1998).

Although it is hard to find an organism that meets all the above criteria, the WHO guidelines for drinking water quality (WHO, 2011) have established *Campylobacter jejuni, Cryptosporidium parvum* and rotavirus as indicator organisms of choice to test microbial drinking water quality. These are representative of bacteria, protozoa and viruses respectively. However, in cases where facilities or resources do not exist or are limited for using the recommended indicator organisms, alternative or surrogate indicators (Table 1.3), have also been suggested.

For purposes of this research, faecal bacteria *E. coli,* and *E. faecalis* were chosen as the indictor organisms of interest to test for faecal pollution of drinking water. *C. jejuni* was also considered but due to the disadvantage of being quickly inactivated by solar disinfection (SODIS) (Boyle *et al.*, 2008) it was not suitable for study settings i.e. tropical climate. Initial trial analyses of water did not reveal presence of *C. perfringens* prompting us to drop this organism from subsequent tests. It was also not possible, to test for Rotavirus or its surrogates due to resource limited settings in which the study took place. There were no laboratory facilities to test for viruses microbes.

Table 1.3: Key test pathogens and alternative indictor microbes for use in the laboratory verification of HWT technology

Target pathogen	Recommended alternatives	Comments/special considerations
Campylobacter jejuni	*E. coli* spp., *Enterococcus* spp. (e.g. *E. faecalis* and *E. faecium*), *Salmonella* spp., *V. cholerae*	*C. jejuni* is associated with a relatively high DALY; *Salmonella* spp. and *C. jejuni* are common enteric pathogens. *E. coli* resembles them (Gram-negative, rod-shaped) and has non-pathogenic strains. *Enterococcus* spp., especially *E. faecium* and *E. faecalis*, are abundant in faeces, prevalent and persistent in faecally contaminated water and utilized as faecal indicators of recreational water quality.
Rotavirus	Echovirus 12, MS2, φX-174, other bacteriophages	Rotavirus is highly infectious and causes high disease burdens in children; echovirus 12, a human picornavirus, resembles other enteroviruses, has low pathogenicity and is superficially similar to hepatitis A and E viruses, noroviruses and astroviruses. MS2 and φX-174 are coliphages superficially resembling human enteric viruses, and they respond similarly to them in many water treatment processes.
Cryptosporidium or *Giardia*	*Clostridium perfringens* spores, other spore-forming bacteria (e.g. naturally occurring aerobic spores in natural waters or added as *Bacillus* spp. spores), inert particles, *Entamoeba histolytica or Entamoeba* spp.	*Cryptosporidium* and *Giardia* are prevalent waterborne protozoa causing major disease burdens. As there are no established non-pathogenic protozoa resembling them, *C. perfringens* (or sulfite-reducing clostridia) spores, *Bacillus* spp. spores or naturally occurring aerobic spores in natural waters are suggested as surrogates or indicators. Because chlorine-based technologies are not effective against *Cryptosporidium*, *C. perfringens* (sulfite-reducing clostridia) spores would not be an adequate indicator organism because they are inactivated by chlorine. *E. histolytica* or other human *Entamoeba* species (e.g. *E. dispar* or *Entamoeba coli*) are acceptable for use in challenge tests as well. For technologies relying on physical straining only, inert particles 4–6 μm in diameter may be used. Manufactured fluorescent microspheres have been successfully used for this purpose.

Source: Sobsey and Brown, 2011

1.2.7 Escherichia coli (*E. coli*)

These gram-negative rod shaped bacteria are commonly found in the gut of humans and other warm blooded animals. *E. coli* has for long been widely accepted as indicator organism of choice for assessing faecal contamination in water especially in the temperate climate (Adams & Moss, 2009; Fisher & Phillips, 2009; Hazen & Toranzos, 1990) since it can easily be distinguished from other total coliforms. Most common strains of *E. coli* are harmless but some can cause serious illnesses including diarrhoea. These pathogenic strains are generally ingested through contaminated water or food and can be categorised into various groups depending on the way in which they cause disease (UNICEF, 2008b). Enterotoxigenic *E. coli* (ETEC) is the most frequently isolated pathogen in children with diarrheal disease although other strains including enteropathogenic *E. coli* (EPEC), entroaggregative *E. coli* (EAEC) and enteroinvasive *E. coli* (EIEC) are also common causes of diarrhoea.

1.2.8 Enteroccus faecalis (*E. faecalis)*

These are, gram-positive bacteria often occurring in pairs or as short chains and are commonly found living commensally in human intestines. They have the ability to tolerate a wide range of temperatures (10-45°C), pH (4.5-10) and high sodium chloride concentrations making them an ideal indicator of faecal water contamination compared to *E. coli* especially in tropical waters (Fisher & Phillips, 2009; Jin, Englande, Bradford, & Jeng, 2004). In addition, *E. faecalis* being of faecal origin from warm blooded animals is also a clearer indicator of water faecal contamination than *E. coli* in tropical waters where *E. coli* can easily multiply. *E. feacalis* is also resistant to drying (Gleeson & Gray, 1997; Cara Gleeson, 1996) and would still be an ideal indicator especially in dry weather conditions.

1.3 Water-related Diseases

Diarrheal diseases normally attributed to unsafe water, sanitation and hygiene forms a sub-set part of water related diseases. According to Gleick (2002), water related diseases can be classified into four subsets according to mode of transmission i.e. water borne, water-washed, water-based and water-related diseases (Table 1.4).

Table 1.4: Classification of water-related diseases.

Mode of Transmission	Description	Examples
Water-borne	Caused by ingestion of water contaminated by human or animal faeces or urine containing pathogenic bacteria or viruses	Cholera, typhoid, amoebic and bacillary dysentery and other diarrheal diseases
Water-washed	Caused by poor personal hygiene and skin or eye contact with contaminated water	Scabies, trachoma, flea, lice and tick-borne disease. dysentery
Water-based	Caused by parasites found in intermediate organisms living in contaminated water	Schitosomiasis, dracunculiasis and other helminths
Water-related	Caused by insect vectors especially mosquitoes that breed in water.	Malaria, dengue, filariasis, yellow fever, trypanosomiasis, onchocerciasis

Source: Gleick (2002)

Water washed diseases may be reduced by increasing water quantity regardless of quality while water based diseases caused by parasitic infections can be reduced upon by improvement in water supply. Water related insect vector diseases such as malaria are not necessarily influenced by domestic water quality and sanitation. However, they may be improved upon by improving infrastructure such prevention of water stagnation which is a breeding ground for mosquitoes. Water borne diseases including diarrhoea, typhoid and cholera are the major causes of water related morbidity and mortality globally. For purposes of this research, we shall focus on water-

borne diseases, with particular interest on diarrheal and gastro-intestinal diseases that may be prevented through the improvement of water quality.

1.3.1 Water Borne Diseases

A wide range of diseases are associated with use of unsafe water. Although mainly transmitted through the ingestion of faecally contaminated water, water-borne diseases can also be transmitted in a variety of others ways (Figure 1.3) in what is often referred to as the complex faecal-oral transmission pathways (Prüss, Kay, Fewtrell, & Bartram, 2002). These pathways include disease transmission through unsafe hygiene practices such as improper washing of hands or food either due to lack of sufficient water or use of faecal contaminated water. Flies may also transmit disease causing organisms directly from faeces to food. These diseases may therefore be reduced primarily through improvement of water quality and through other interventions such as increasing water quantity and provision of sanitation/hygiene education. Unlike other water-related diseases, ingestion of faecally contaminated water may expose large numbers of people to epidemics such as cholera which kill within a short period of time (Montgomery & Elimelech, 2007; Prüss *et al.*, 2002). Efforts to reduce such diseases are of paramount importance.

1.3.1.1 Diarrheal Diseases

Infectious diarrhoeal disease is a leading cause of morbidity and mortality worldwide and is probably the greatest contributor to the global burden of disease due to unsafe water, sanitation and hygiene (Prüss *et al.*, 2002). Diarrhoea is ranked third amongst all infectious diseases and annually accounts for over two million global deaths most of which occur in developing countries. The disease is predominant among children and is estimated to cause over 1.5 million

deaths of children under five years of age (Kosek, Bern, & Guerrant, 2003; WHO, 2004, 2009a). Sub- Saharan Africa bears the brunt of diarrheal disease with a reported 17% of all deaths in children under 5 years occurring due to diarrhoea. It is also estimated that 85% of all disease burden in the region is due to diarrhoea (Rosen & Vincent, 1999). Although children seem to be highly affected, diarrhoea still poses a threat even to older children and adults in SSA not only due to lack of safe water and proper sanitation but also the high prevalence of HIV and AIDS this region (Lule *et al.*, 2005).

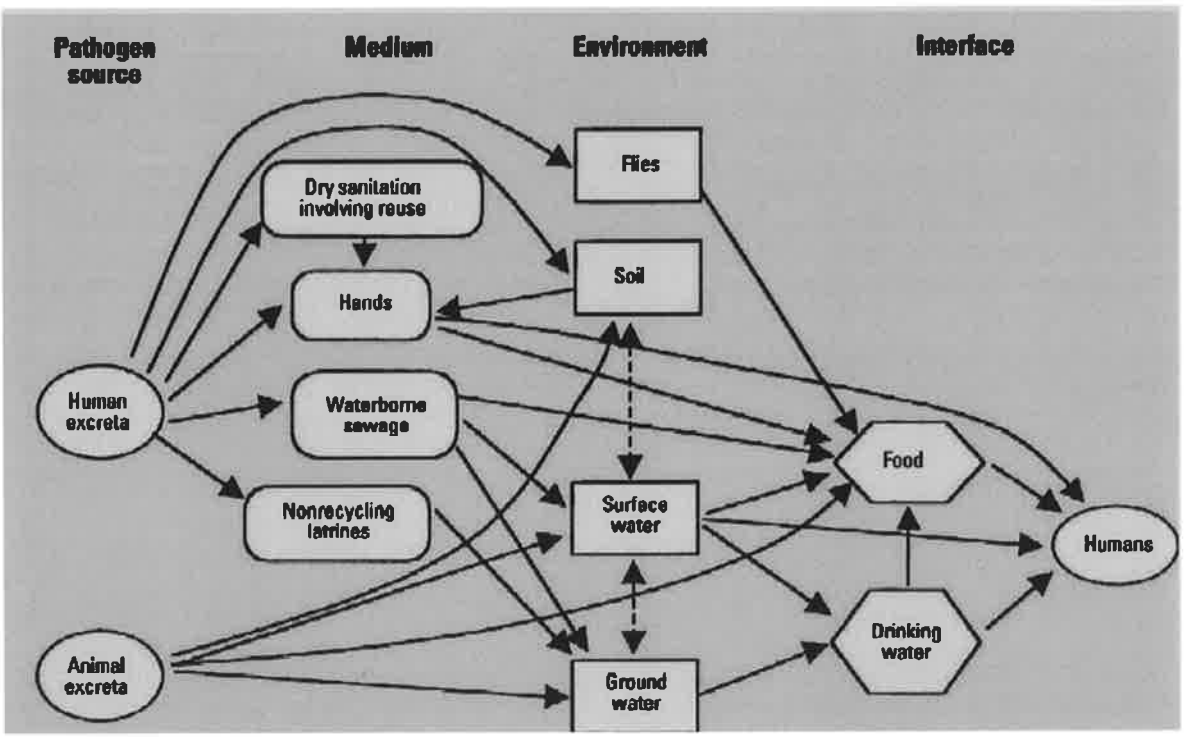


Figure 1.3: Transmission pathways of fecal-oral disease (Pruss *et al* 2002).

Diarrhoeal disease accounts for the loss of over 62 million DALYs annually which is much higher than the 47 million and 35 million DALYs attributed to malaria and tuberculosis

respectively (WELL, 2005; WHO, 2004). The average morbidity incidence of diarrhoea in children is reported to be 3.2 episodes per year, although in some developing countries, even up to 12 episodes are reported (WHO, 2004).

Diarrheal disease does not only cause morbidity and mortality but is also a predisposing factor for malnutrition i.e. under nutrition (Figure1.4) which brings with it not only a multitude of complications but also death. The complications include poor cognitive development, poor immunity against a variety of diseases and long term gastro-intestinal disorders (Clasen, Schmidt, Rabie, Roberts, & Cairncross, 2007; Guerrant, Oriá, Moore, Oriá, & Lima, 2008; Pollitt, 1995; Prüss-Üstün, Kay, Fewtrell, & Bartram, 2004; Prüss *et al.*, 2002; Solsona & Fuertes, 2003). These long term adverse effects on the mental and physical development of children may lead to poor productivity in their adulthood years (Guerrant *et al.*, 2002). Guerrant and colleagues (2002) suggest that a substantial proportion of global malnutrition is due to impaired intestinal absorptive functions caused by repeated enteric infections especially diarrhoea. The relationship between diarrheal disease and malnutrition is a vicious cycle (Figure 1.5) where diarrhoea disrupts intestinal absorptive capacity hence causing malnutrition and malnourished children not being able to fight off infections, have more incidences, longer duration, and increased severity of diarrheal illnesses (Bairagi, Chowdhury, Kim, T Curlin, & Gray, 1987; El Fatih, Willet, & Ware, 1988; Guerrant *et al.*, 2008; Sepu'lveda, Willet, & Munoz, 1988; Tomkins, Dunn, & Hayes, 1989).

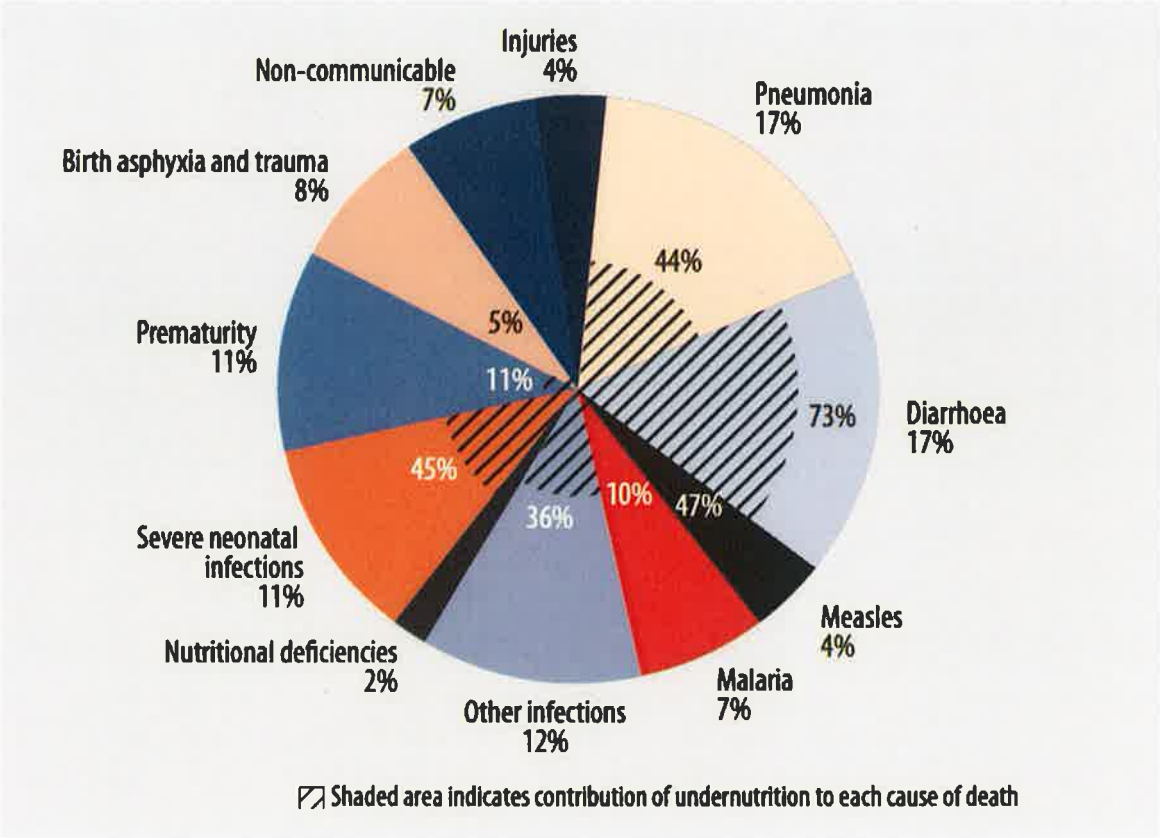


Figure 1.4: Major causes of death in children under 5 years of age with disease specific contribution of under nutrition. (WHO 2009)

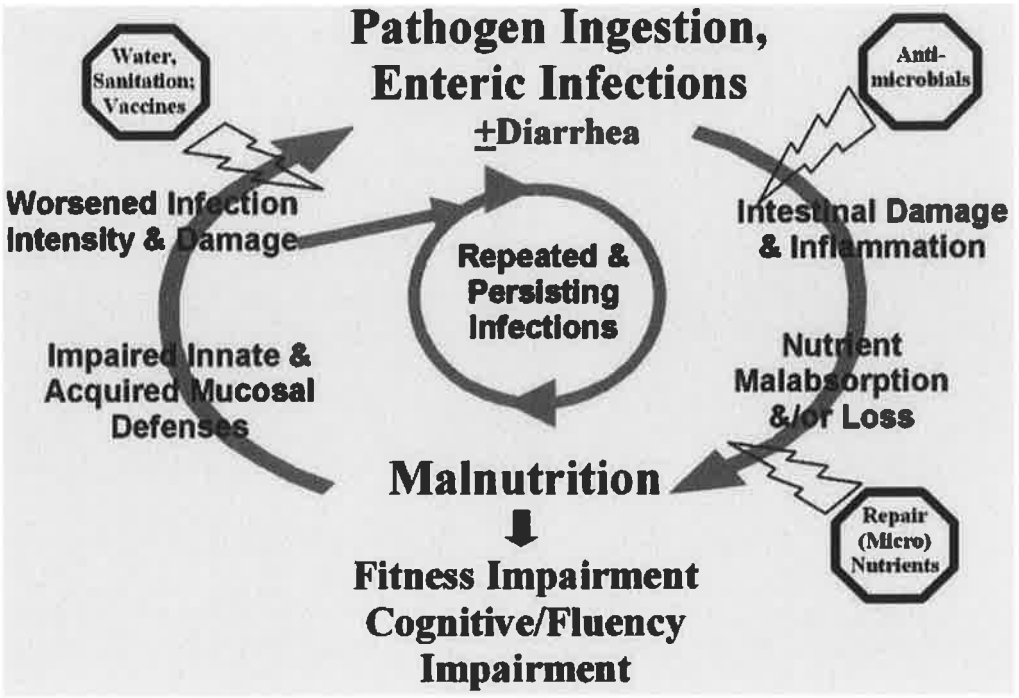


Figure 1.5: The vicious cycle between diarrhea and malnutrition (Guerrent *et al* 2008).

Diarrhoea is caused by a wide variety of bacterial, viral and parasitic infections including *Escherichia coli*, *Salmonella sp.*, *Shigella sp.*, *Campylobacter jejuni*, *Vibrio cholerae*, rotavirus, norovirus, *Giardia lamblia*, *Cryptosporidium sp.*, *and Entamoebahistolytica* (Clasen *et al.*, 2007; Girard, Steele, Chaignat, & Kieny, 2006). Rotavirus, the leading cause of diarrheal disease amongst children world-wide is estimated to cause the annual death of 527, 000 children in developing countries alone.

The disease can be classified according to the number of days of duration or acuteness:

- Acute watery diarrhoea lasts several hours a day and is mainly caused by *V. cholerae* and usually occurs during outbreaks.
- Acute bloody diarrhoea also known as dysentery has blood stains in the stool.

- Persistent diarrhoea lasts for over 14 days. This type of diarrhoea can cause malnutrition and results in greater morbidity and mortality compared to acute diarrhoea.

1.3.1.2 Diarrhoeal Disease Prevention Interventions

The WHO (2007) estimated that 94% of all diarrheal diseases are preventable through modifications including interventions to improve water quality, sanitation and hygiene. If MDG 7c were to be met, $7.3 billion per year would be saved through avoidance of health related costs alone (Bartram, Lewis, Lenton, & Wright, 2005).

Diarrheal diseases are potentially water borne, contracted through the ingestion of microbiologically contaminated water. However, diarrheal disease can also be transmitted through the consumption of contaminated food/beverages, through direct or indirect contact with faeces or though person to person contact in what has been termed as the complex faecal-oral route (Clasen *et al.*, 2007; Mara & Feachem, 1999; Prüss *et al.*, 2002).

Because of the various routes through which diarrheal causing-pathogens are transmitted, studies suggest that prevention should not only include improved water quality but also water supply, sanitation and other hygiene practices need to be improved upon (Cairncross *et al.*, 2010; Montgomery & Elimelech, 2007). For example improved sanitation through safe disposal of faecal matter can reduce diseases transmission via flies and the environment. Supply of water in sufficient quantities enables hand washing and food preparation both of which are good hygiene practices that could further minimise transmission through food and hands. However, in a review of more than 46 articles on the effect of improved water supply, water quality, hygiene and sanitation on diarrheal disease, Fewtrell and colleagues (2005), found that most interventions had a similar degree of impact on diarrheal illness with relative risk estimates ranging between 0.63

and 0.75 (Table 1.5). The review revealed that single interventions to prevent water diarrheal disease were just as effective as multiple interventions and that improvement of water quality through point-of-use (POU) water treatment was more effective than had previously been thought. Just like Fewtrell *et al* (2005), another meta-analysis review by Clasen *et al* (2007) on interventions to improve microbial quality of water to reduce morbidity due to diarrhoea concluded that interventions to improve water quality were effective for preventing diarrhoea in all ages and under-fives. Effectiveness did not depend on the presence of improved water supplies or sanitation in the study settings and was not enhanced by combining with other common interventions intended to prevent diarrhoea such as instructions on basic hygiene, water storage vessels, improved sanitation or water supplies.

Table 1.5: Studies of different interventions and diarrheal health effects.

Reference	Intervention	Country (location)	Study quality*	Health outcome	Age group	Measure	Estimate (95% CI)
Ghannoum et al,[31] 1981	Reservoirs and chlorination	Libya (unstated)	Poor	Dysentery	All	RR†	0·41 (0·39–0·44)‡
				Giardia	All	RR†	1·43 (0·98–2·08)
Kirchhoff et al,[32] 1985	Point-of-use water treatment (hypochlorite)	Brazil (rural)	Good	Diarrhoea	<2 years	RR†	1·07 (0·88–1·30)‡
					2–4 years	RR†	1·16 (0·90–1·51)
					5–9 years	RR†	0·71 (0·48–1·07)
					≥10 years	RR†	1·80 (1·02–3·16)
Mahfouz et al,[33] 1995	Point-of-use water treatment (chlorination)	Saudi Arabia (rural)	Good	Diarrhoea	0–60 months	RR†	0·54 (0·30–0·99)‡
Conroy et al,[34] 1996	Point-of-use water treatment (solar disinfection)	Kenya (rural)	Good	Diarrhoea	5–16 years	OR	0·66 (0·50–0·87)‡
				Severe diarrhoea	5–16 years	OR	0·65 (0·50–0·86)
Sathe et al,[35] 1996	Point-of-use water treatment (boiling)§	India (urban)	Poor	Diarrhoea	All	RR†	2·15 (1·57–2·73)‡
Xiao et al,[36] 1997	Point-of-use water treatment (boiling) and source improvements	China (rural)	Insufficient data to judge quality	Diarrhoea	All	RR†	0·38 (0·35–0·40)‡
Semenza et al,[37] 1998	Point-of-use water treatment (disinfection and safe storage)	Uzbekistan (unstated)	Good	Diarrhoea	All	RR	0·15 (0·07–0·31)‡
					<5 years	RR	0·33 (0·19–0·57)
Quick et al,[38] 1999; Sobsey et al,[39] 2003	Point-of-use water treatment (disinfection and safe storage)	Bolivia (peri-urban)	Good	Diarrhoea	All	OR	0·57 (0·39–0·84)‡
Iijima et al,[40] 2001	Point-of-use water treatment (pasteurisation)	Kenya (rural)	Poor	Severe diarrhoea	All	RR†	0·56 (0·39–0·81)‡
Roberts et al,[41] 2001	Safe household storage	Malawi (refugee camp)	Good	Diarrhoea	All	RR†	0·79 (0·62–1·03)‡
					<5 years	RR†	0·68 (0·45–1·01)
Gasana et al,[42] 2002	Source protection and source treatment	Rwanda (unstated)	Poor	Diarrhoea	0–60 months	RR†	1·00 (0·90–1·12)‡
Quick et al,[43] 2002	Point-of-use treatment (disinfection and safe storage)	Zambia (peri-urban)	Good	Diarrhoea	All	RR	0·53 (0·30–0·93)‡
Colwell et al,[44] 2003	Point-of-use treatment (simple filtration)	Bangladesh (rural)	Good	Cholera	0–60 months	RR†	0·62 (0·46–0·83)‡
Jensen et al,[45] 2003	Source water treatment (chlorination)	Pakistan (rural)	Good	Diarrhoea	0–60 months	OR	1·99 (1·10–3·61)‡
Sobsey et al,[39] 2003	Point-of-use water treatment (disinfection and safe storage)	Bangladesh (urban)	Poor	Diarrhoea	0–60 months	IDR	0·78 (0·73–0·83)‡

Results of the meta-analyses: fixed-effects estimate of relative risk (RR) 0·56 (95% CI 0·54–0·58); heterogeneity p<0·01; random-effects estimate of RR 0·69 (95% CI 0·53–0·89); Begg's test p=0·09. *For definition of quality see main text. †Calculated. ‡Result used for the overall meta-analysis, which provided a pooled estimate of relative risk. §Various treatment types studied, boiling chosen to compare against no treatment. IDR=Incidence density ratio; OR=odds ratio.

Source: Fewtrell et al., 2005

This thesis will review water quality improvement through use of POU household treatment interventions with a particular focus on solar water disinfection (SODIS) for the prevention of diarrhoeal disease.

1.4 Household Water Treatment and Safe Storage Technologies (HWTs)

Household water treatment has been in existence since ancient times. Greek and Sanskrit record writings over 4000 years BC describes a method of boiling and filtering drinking water to better its taste and smell as well as reducing visible particles and turbidity (Barry & Hughes, 2008). However, it was the ancient Greek physician Hippocrates who in 500 BC first believed that filtering water made it healthful for the human body. He invented the cloth filter known as the Hippocratic sleeve for filtering water which he believed to have healing powers. Centuries later, John Snow a British scientist, was able to prove that the seemingly odourless and clear water from a pump was the cause of the 1854 cholera epidemic in Soho, England and that chlorination and sand filtration of the water could effectively prevent the disease. This later paved the way for modern water disinfection using chlorine (Barry & Hughes, 2008). Since then many technologies have been developed to treat water at the household level to make it safe for drinking. With an estimated 2 million diarrheal deaths world-wide especially in the developing world, it is believed that if used consistently, HWTS could reduce the global disease burden by 4 % (WHO-UNICEF, 2010). The WHO generally groups the recommended technologies into four categories:

Physical removal of pathogens (filtration, adsorption, sedimentation). This method involves removal of microbes from water by physical means. In the case of filtration, microbes are removed by straining the water through filters of defined pore sizes. These include fibre/cloth filters, carbon block filters, polymeric membranes and porous ceramics containing colloidal

silver reactive membranes. Some filter such as those with chemical or colloidal coatings may also cause microbes to adsorb onto the filter media surface or be inactivated or prevent multiplication of the microbes. Sedimentation on the other hand involves removal of suspended particles in the water either by simply letting water stand and decanting off afterward or by use of natural or chemical coagulants. These coagulate or precipitate coagulants suspended particles including microbes. The water may be decanted off leaving the floc or may be filtered through a cloth or fibre membrane filter. Normally three vessels are used in series over a period of approximately two days as settled water is decanted from one vessel to the next (Sobsey & Brown, 2011).

Chemical treatment to deactivate pathogens (chlorination, iodisation). This is one of the most commonly used HWT in developing countries. The method employs the use ozone and other chemicals such as iodine, bromine and chlorine for microbial inactivation in water. With the exception of ozone, proper dosing of bromine, iodine and chlorine is critical so as to provide sufficient residuals in the water to provide protection from post-treatment contamination (WHO, 2011). The most commonly used forms of chlorine include hypochlorous acid (common household bleach), calcium hypochlorate or sodium dichloroisocyanurate. These forms of chlorine are inexpensive, convenient, relatively safe and easy to dose (Sobsey & Brown, 2011; WHO, 2011). For proper dosing 2mg/L of chorine is recommended for water with a turbidity of <10NTU, and double the concentration for turbid water.

Disinfection by heat (boiling, pasteurisation) and ultra-violet radiation either by use of the sun (SODIS) or by artificial UV sources. In boiling or pasteurisation of water disinfection is achieved by heating water to temperatures where a rolling boil is reached. The water is then

allowed to cool and is stored in an appropriate container to prevent re-contamination. In the case of UV lamps, water flowing through a reactor is exposed to sufficient doses of UV germicidal wavelength of 254nm. During this process the microbes become inactivated and the water is safe to drink. However this method is not considered appropriate for developing countries because of the high cost, the need for reliable electricity and maintenance requirements (Sobsey & Brown, 2011). Water disinfection can also be achieved by solar heating whereby heat from sunlight is used to kill microbes in water stored in dark or opaque containers. Disinfection can also be achieved by solar water disinfection (SODIS). In this technology, water in UV penetrable containers is exposed to the sun during which process disinfection is achieved by a synergy of heat and UV from the sun (WHO, 2011).

Combined approaches (filtration and boiling, filtration with disinfection). The use of any two or more of the above mentioned technologies simultaneously or sequentially is sometimes used to achieve water disinfection. For example coagulation in combination with filtration, filtration and then disinfection, etc.

Numerous reviews and studies have since been conducted to gauge the effectiveness of these water treatment technologies especially with regard to health and the potential to reduce diarrheal diseases amongst the affected populations (Clasen *et al.*, 2007; Conroy, Elmore-Meegan, Joyce, McGuigan, & Barnes, 1996; Fewtrell *et al.*, 2005; Graf *et al.*, 2010; Rose *et al.*, 2006). All these studies and reviews have shown evidence that HWTS have the potential to improve the health of people without access to safe drinking water. With these promising results, the WHO sponsored International Network for the Promotion of Safe Household Water Treatment and Storage consisting of a global collaborations of the United Nations and bilateral

agencies, Non-Governmental Organisations (NGO's), research institutions and/or organisations and companies from the private sector committed to promote Point-of Use HWTS and to review these methods in order to identify the most promising technologies (Sobsey, 2002). Accordingly, the criteria for selecting an appropriate POU-HWT for use included:

- High effectiveness in improving and maintaining microbial water quality.
- Significantly reducing water-borne diseases.
- Simple and accessible to the target population
- Cost effective for the beneficially and provider
- Socio-culturally acceptable, sustainable and with potential for large scale promotion.

Basing on these criteria, a number of POU-HWTS were found to be promising and recommended for further development, characterisation, implementation and dissemination (Sobsey, 2002). They included:

- Solar disinfection by the combined action of heat and UV radiation (SODIS)
- Solar disinfection by heat alone ("solar cooking")
- Chlorination plus storage in an appropriate vessel
- Combined systems of chemical coagulation-filtration and chlorine disinfection

In a subsequent review of HWTS, Sobsey *et al.*, (2008) indicate that SODIS still remains one of the simplest technologies to apply since it is virtually cost-free to start and maintain.

1.4.1 Solar Disinfection (SODIS) of Drinking Water

Solar water disinfection was approved by the WHO in 2005 as one of the recommended HWTS (WHO, 2009b). The basic SODIS technique demonstrated in (Figure 1.6) involves filling a clear plastic, glass or even plastic bag with contaminated water, exposing it to un-obscured sunlight for a minimum of 6 hours in strong sunny conditions or longer (usually 48hours) under cloudy weather (Lantagne, Quick, & Mintz, 2006) for pathogenic inactivation, making water safe to drink (Dejung *et al.*, 2007; Walker, Len, & Sheehan, 2004)). Polyethylene-terephthalate (PET) plastic bottles are usually preferred for SODIS since PET is generally considered inert and therefore a suitable material for food packaging (EAWAG/SANDEC, 2009) in comparison to other plastic materials. In addition plastic is more robust compared to glass bottles and would not easily break making it more durable for SODIS use (McGuigan *et al.*, 2012).

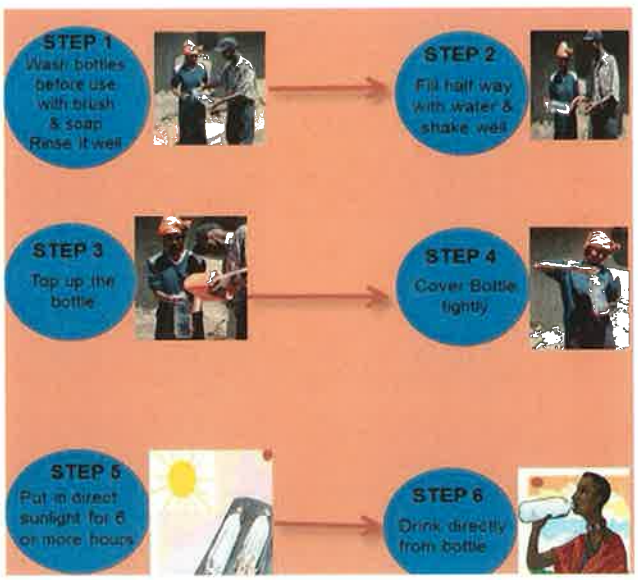


Figure 1.6: A 6-step demonstration of using SODIS for treatment of drinking water.

It is also recommended that where possible, turbidity of water should be less than 30 NTU since suspended particles in turbid water may block UV light penetration through the water. Preliminary treatment of turbid water including sedimentation and filtration is recommended for effective SODIS treatment (Sommer *et al.*, 1997). Turbidity can be reduced by use of a cloth filter or use of *Moringa oleifera* seed extract which acts as a coagulant for organic matter (Okuda, Baes, Nishijima, & Okada, 2001). It is recommended that SODIS treated water be used within 48 hours and where possible drunk from the cup to minimise risks of recontamination that may occur if the container used for drinking is not clean.

1.4.1.1 SODIS Inactivation Mechanisms.

The sun emits energy in the form of electromagnetic radiation that covers the ultraviolet (UV), visible light and infrared range (Figure 1.7)

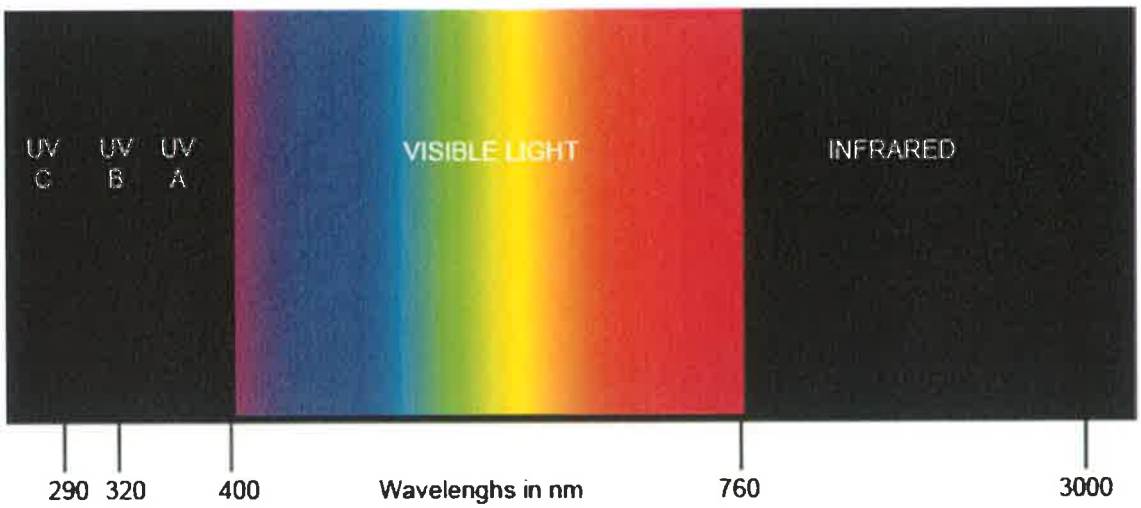


Figure 1.7: Important Components of the Electromagnetic Spectrum (www.uvabcs.com)

All ultraviolet light (UVA, UVB and UVC) has bactericidal properties; however it is UVA and infra-red light that are most critical during the SODIS process (Kramer & Ames, 1987; Oates,

2001). The result of UV radiation on the DNA molecule is the formation of pyrimidine dimers including cyclobutene pyrimidine dimers (CPDS) and 6-4 photoproducts (6-4PPs) and their Dewar Isomers (Sinha & Häder, 2002). These DNA conformational changes are attributed mainly to UVB since DNA strongly absorbs UV at 320nm or lower and most of the UVC is absorbed by the ozone layer and oxygen in the atmosphere (Kaiser, Kleiner, Beisswenger, & Batschauer, 2009).

The formation of these dimers prevents base pairing with complimentary purines on the other strand of DNA hence changing the shape of the DNA molecule in the dimer. This makes it difficult for DNA polymerase the enzyme responsible for copying DNA to move through the dimer or form base pairs. The result is the misreading of the genetic code and therefore interference in the DNA transcription and replication processes causing cell mutations and death (Sinha & Häder, 2002). However, bacteria have several repair mechanisms in response to UV damage. The repair mechanisms have been classified into photo reactivation and dark repair (DR) (Zenoff, Sineriz, & Farías, 2006). Photo reactivation occurs in the presence of blue-light (345-400nm), where the enzyme photolyase binds to CPDs and 6-4PPs and reverses DNA damage (McGuigan *et al.*, 2012; Sinha & Häder, 2002). This is the simplest and oldest DNA repair mechanism. In contrast, dark repair mechanisms are more complex and do not directly reverse DNA damage but rather replace the damaged DNA. The cells can remove affected bases (base excision repair) or the damages nucleotides (nucleotide excision repair) allowing the gaps in either case to be filled by DNA polymerase hence repair (Sinha & Häder, 2002).

UV-A light on the other hand causes indirect damage to DNA, proteins and lipids through formation of reactive oxygen species (ROS). On UV- A irradiation, endogenous photosensitizers

such as porphyrins, flavins and quinones are transformed into an excited state and hence are able to transfer energy (Eisenstark, 1998; Kramer & Ames, 1987). In the absence of an energy acceptor, the energetic photons cause a conformational change of the chromophores leading to loss of biological activity hence inactivation. Alternatively, the excited photosensitizers transmit energy to singlet oxygen, hydrogen peroxide, super oxides and hydroxyl radicals in water to form ROS. These ROS are free radicals which are then able to react with all cell components to damage cell membranes hence causing DNA strand breakage and base changes, leading to inactivation (Chamberlain & Moss, 2008). It should however be noted that since solubility of oxygen is inversely proportional to temperature (UNICEF, 2008b) formation of ROS due to singlet oxygen occurs early on during the SODIS process when temperatures are still low and oxygen concentration high. For this particular reason, it has been advisable to aerate water in the transparent containers before exposing water to the sun by vigorously shaking the containers half way before filling the container with water to incorporate oxygen so as enable creation of ROS leading to faster inactivation during the SODIS process (Kehoe *et al.*, 2001; R. H. Reed, 1997; R. Reed, 2003). Apart from the action of UVA, the high temperatures created by the infra-red part of the spectrum also cause bacterial inactivation through pasteurisation. McGuigan *et al.*,(1998) report a strong synergistic effect between thermal and optical inactivation at temperatures $\geq$ 45°C. They suggest that in addition to slow pasteurisation, high water temperatures also inhibit DNA repair mechanisms. In fact Wegelin, and colleagues (Wegelin *et al.*, 1994), showed that at temperatures $\geq$ 50°C the rate of bacterial inactivation in SODIS treated water was three times faster than at lower temperatures.

1.4.1.2: Organisms Susceptible to SODIS

The use of sunlight to disinfect drinking water is not a new phenomenon. Literature indicates that over 2000 years ago, Indian communities placed drinking water in open trays outside in the sun to be blessed. However, it was not until after 1984 when Acra and colleagues at the American University of Beirut demonstrated that that exposure of water in clear plastic containers to sunlight caused the death of enteric bacteria such as *E. coli* and *Salmonella* spp that renewed interest in solar disinfection increased. These findings subsequently led to numerous studies which have since shown SODIS to be effective in inactivation of bacteria, viruses, protozoa, fungi and helminths (Kehoe, Barer, Devlin, & McGuigan, 2004; Mackenzie, Ellison, & Mostow, 1992; F. Méndez-Hermida, Castro-Hermida, Ares-Mazas, Kehoe, & McGuigan, 2005; Smith, Kehoe, McGuigan, & Barer, 2001; Vidal & Diaz, 2000). The current microbial species known to be inactivated by the SODIS process are summarised in Table 1.6.

Table 1.6: Current waterborne microbial species known to be inactivated by SODIS.

Microbe	Species	Microbe	Species
Bacteria	*Campylobacter jejuni* *Enterococcus sp.* *Enteropathogenic E. coli* *Mycobacterium avium* *Mycobacterium intracellulare* *P. aeruginosa* *Salmonella typhi* *S. typhimurium* *Shigella dysenteriae* Type I *Shigella flexneri* *Streptococcus faecalis* *Staphylococcus epidermidis* *Vibrio cholerae* *Yersinia enterocolitica*	Fungi Helminths	*C. albicans* *Fusarium sp.* *Ascaris sp* (ova)
Viruses	Bacteriophage f2 Encephalomyocarditis virus Polio virus Rotavirus Norovirus	Protozoa	*A. polyphaga* (cyst) *C. parvum* (oocyst) *Entamoeba sp.* (cysts) *Giardia sp* (cysts)

Adapted from McGuigan et al., 2012

1.4.1.3 Regions Best Suited for SODIS

SODIS works best in geographical latitude areas between 15-35°N&S where most developing countries lie. These areas receive sunshine almost throughout the year (EAWAG/SANDEC, 2009) and are therefore suitable for SODIS. Figure 1.8 shows the geographical areas suitable for SODIS.

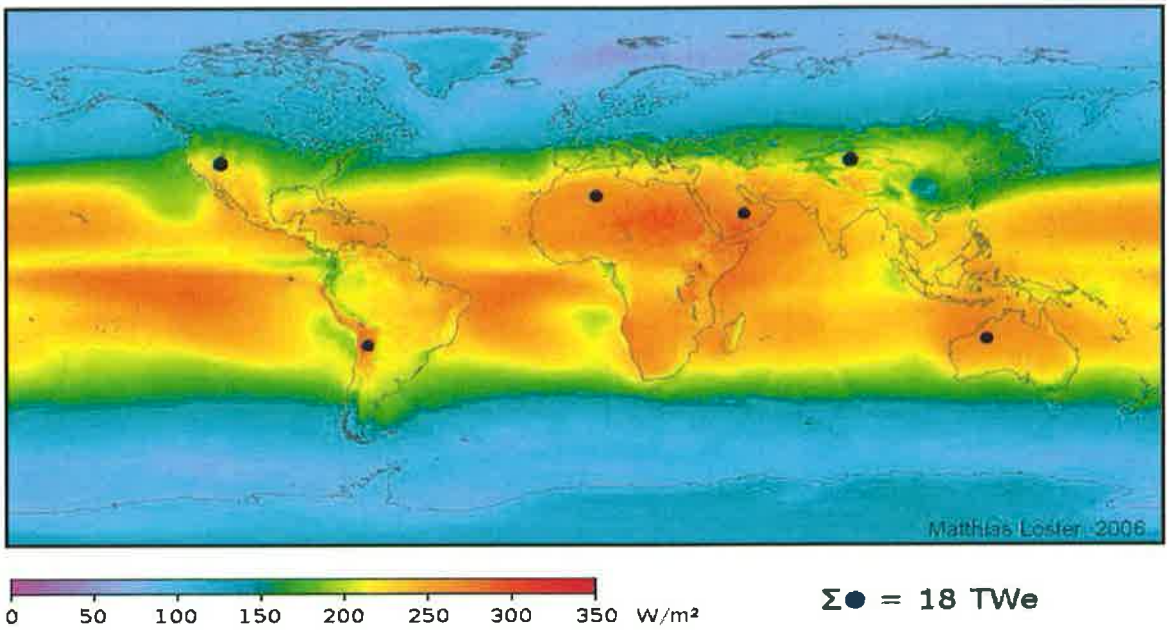


Figure 1.8: Geographical regions suitable for SODIS.. (*Dark spotted areas could provide more than the world's total primary energy demand (assuming a conversion efficiency of 8%)* Source; http://en.wikipedia.org/wiki/File:Solar_land_area.png

1.4.1.4: Health Impact of SODIS

So far, the Swiss Water Federation (EAWAG) estimates that currently, over 5 million people in more than 55 countries worldwide inclusive of Uganda (Figure 1.9), regularly use SODIS for drinking water treatment. In Uganda however, the technology only accounts for 0.2% of all house hold water treatment technologies in the country (UBOS, 2011).

A number of SODIS health impact assessment studies have shown that the technology combined with improved hygiene behaviour, can significantly reduce diarrhoea incidences among users. A controlled field trial (Conroy *et al.*, 1996) among Maasai children 5-16 years reduced diarrheal

episodes (odds ratio 0.66 CI 0.50-0.87) among children using SODIS compared to control group. A further study to assess the effect of SODIS on diarrhoea incidences amongst Maasai children less than less 6 years of age in Kenya also revealed a 16% reduction in diarrheal diseases in children that were using SODIS water compared to the control group (Conroy, Elmore, Joyce, McGuigan, & Barnes, 1999). In India a 40% diarrhoea reduction in children less than 5 years drinking SODIS treated water (Rose *et al.*, 2006) was reported despite 86% of the children drinking water from untreated sources. Another three year study conducted by the Joint Development Associates (JDA) International Incorporation in Uzbekistan in 2004 revealed a 55.5% reduction in diarrheal incidences amongst children (0-5 years) in the participating villages. In those villages that were not part of the study, there was an average increase of 28.4% in diarrheal incidences amongst the same age group of children (JDA International & EAWAG, 2004). A more recent study (Graf *et al.*, 2010), revealed that SODIS reduced diarrheal prevalence amongst children under 5 years to 22.5% for those who sometimes used SODIS for treating water and to 18.3% in the intervention group that completely used SODIS for water treatment down from 34.3% prevalence before introduction of SODIS. The same study also showed that regular use of SODIS could reduce the risk of contracting diarrhoea by 42.5%. In Sakkim, India, SODIS was also associated with a 76% diarrhoea reduction in children (<5years) who were drinking SODIS treated water compared to the control group where there was no reduction noticed (Rai, Pal, Kar, & Tsering, 2010). SODIS has not only been associated with reduction in diarrheal episodes among users but has also been associated with improved anthropometric outcomes in children under 5 years (du Preez *et al.*, 2011). This is further confirmed by a Cochrane review in which the technology has been specifically singled out as one of those WASH interventions that have a benefit in improvement of height for age outcomes

for children under 5 years (Dangour *et al.*, 2013). However not all studies conducted have revealed successful reductions in diarrheal incidences. A cluster randomized controlled SODIS trial in Bolivia (Mäusezahl *et al.*, 2009), did not show a statistically significant reduction in diarrheal disease incidents between children in the SODIS intervention group and the control. However, children in the intervention group had fewer mean diarrheal episodes (3.6) compared to 4.3 mean episodes per child in the control group. Du Preez, and colleagues (Du Preez, McGuigan, & Conroy, 2010) too did not find a statistically significant difference in dysentery episodes between control and intervention group children in study carried out in South Africa. It should be noted that in both these cases, compliance was low and therefore could have affected the results. In the South African study, only participants with higher motivation (at least 75% compliance with the study protocol) had a significant reduction in dysentery (IRR 0.36, 95%CI, 0.16-0.81, P=0.014) compared to the control while the study by Mausezahl and colleagues (Mäusezahl *et al.*, 2009) reported a low compliance of 32% in their study. Participant motivation/compliance is therefore a vital component in translating the bactericidal effect of SODIS into health gains as evidenced by these two studies.

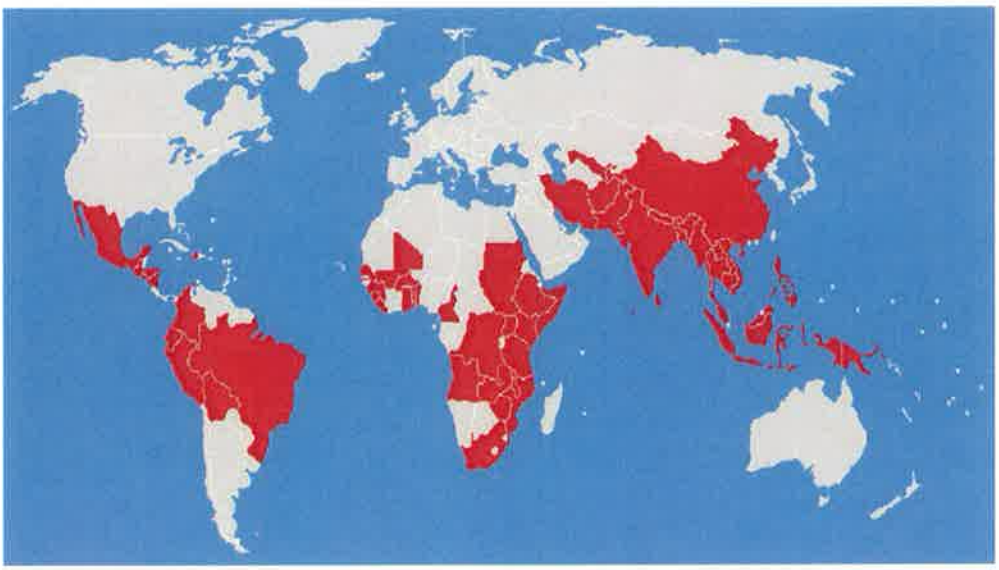


Figure 1.9: Map indicating the 55 countries where SODIS is in daily use. (McGuigan *et al.*, 2012)

1.4.1.5: Barriers to SODIS Uptake

Despite the obvious advantages associated with SODIS, the technology still has limited uptake amongst users. There is a large variation (20-80%) in adoption and sustained use of the technologies in communities where it has been introduced and promoted (Meierhofer & Landolt, 2009), it is therefore imperative to understand the factors that limit or increase the uptake and sustained us of SODIS. SODIS compliance implies the need for behavioural changes amongst the users who have to collect and clean bottles, fill them with water and expose them to the sun and collect them afterwards (McGuigan *et al.*, 2012). Behavioural factors including personal, social-cultural and environmental have been identified as those that may affect an individual's intention to adopt SODIS and sustain use of the same. Numerous scientific studies have investigated these behavioural factors to explain their effect on SODIS uptake.

In Nicaragua (Altherr, Mosler, Tobias, & Butera, 2008) , 81 families from two communities were interviewed in regard to their SODIS use or non-use. Researchers found that intention to use and actual use of the technology was related to a positive attitude towards the technology. In this case well designed promotional activities with highly motivated promoters were important in imparting confidence among users and positively influenced the uptake of the technology.

Rainey and Harding (2005) used the health belief model (HBM) to identify factors that were affecting SODIS uptake in Kathmandu, Nepal. They used perceived barriers, perceived risk, perceived benefits, self-efficacy and cues to action as some of the factor that were affecting SODIS uptake. The major perceived barrier was the workload of women who were responsible for water treatment in the home. Consequently treating water with SODIS was not a priority in relation to other chores they had to perform. Those who did not view diarrhoea as being caused by faecally contaminated water (lower perceived risk) were unlikely to treat their water with SODIS compared to those who believed that treating water with SODIS would lead to reduced stomach-related illnesses in the home (perceived benefit). Rainey and Harding suggested the promotion of SODIS through schools i.e. including it in the school syllabus and practically teaching pupils to treat water with SODIS (Rainey & Harding, 2005). This would relieve women's workload which was indicated as the leading barrier to SODIS uptake. Other factors including good taste of SODIS treated water; cost savings, compatibility of the method with daily household chores, perceived reductions in diarrheal episodes and participation at campaign events were positively related to SODIS use (Heri & Mosler, 2008).

Patterns influencing the adoption of SODIS were also studied by Moser and Mosler (2008). They found that early adoption of SODIS was predicted by increased involvement in the topic of

drinking water, middle adoption by the recognition that the majority supported the technology and late adoption was predicted by the recognition that the majority had already adopted the technology. Meierhofer and Landolt (2009) in their evaluation study of factors affecting SODIS uptake and sustained use identified numerous barriers to uptake including availability of bottle (PET and/or glass), single information events versus long-term interventions, motivated promoters, education level and economic status of users and social pressure. Availability of bottles leads to increased uptake of SODIS in comparison to situations where bottles were not easily available. Long term interventions with regular visits by promoters to trained users were more likely to increase uptake and sustained use of the technology than single interventions. It was also revealed that the more educated and economically well-off, the harder it was to convince one to use SODIS. However, once doubts about the SODIS technology were dispelled, such people were more likely to adopt SODIS and sustain its use over a long period of time (Graf, Meierhofer, Wegelin, & Mosler, 2008). SODIS was more acceptable in areas where it was clearly visible in the community and used by numerous people including community leaders.

INTRODUCTION PART 2: UGANDA

In this section, a brief overview of Uganda's current water and sanitation situation is discussed.. Particular emphasis is put on the water and sanitation situation in rural Uganda where our study took place.

1.5 Country Over-view

Uganda (Figure 1.10) is an East African land-locked country lying across the Equator, about 800km inland from the Indian Ocean. The country is bordered by the Democratic Republic of Congo (DRC) to the West, Kenya to the East, Sudan to the North, Tanzania to the South and

Rwanda to the South-West (UBOS, 2002). Uganda's population was estimated to be 34.5 million people in 2011 (World Bank, 2011). The country has one of the fastest world-wide population growth rate at just over 3% per annum, putting enormous strain on adequate provision of not only water and sanitation needs but also other sectors such as health and education (World Bank, 2009).

Figure 1.10: Map of Uganda showing the current district status in 2011. (UBOS 2011)

The country enjoys an equatorial climate with plenty of rain, sunshine and mean annual temperatures ranging between 16°C- 30°C. The east, central and western regions of the country experience two distinct rainy seasons (March- May and September to November) while the northern region experiences one rainy season (April to October). The rest of the seasons are dry

with minimal rain. Annually, the country receives an estimated amount of 750-2100mm of rainfall (UBOS, 2002).

The Human Development Index (HDI) which compares life expectancy at birth, adult literacy rate and per capita incomes of different UN countries ranked Uganda at position 161 out of 186 countries in 2011 (UNDP, 2011). Uganda's HDI trends (Table 1.7) show an improvement in the country's HDI indicators over the years. However, the country's latest HDI value of 0.456 for 2012 is still below the Sub-Saharan value of 0.475 (UNDP, 2013) and has not impacted on the country's ranking which still stands at position 161 just like in 2011. With the country still facing high infant mortality rate of 128 deaths per 1000 live births, much still needs to be done in terms of poverty alleviation to improve the population livelihood and hence HDI rankings. Absolute poverty in Uganda currently stands at 24.5% but the Ugandan government aims at reducing this to less than 10% of the population by the year 2017 (MoFPED, 2012).

Table 1.7: Uganda's HDI trends based on consistent time series data, new component indicators and new methodology.

	Life expectancy at birth	Expected years of schooling	Means years of schooling	GNI per capita (2005 PPP$)	HDI value
1980	50.1	3.9	1.9	..	..
1985	49.6	5.7	2.3	0,484	0.294
1990	47.4	5.6	2.8	0,517	0.299
1995	44.9	7.0	3.4	0,614	0.321
2000	46.1	10.7	3.9	0,770	0.372
2005	50.2	10.0	4.3	0,880	0.401
2010	53.7	10.8	4.7	1,099	0.442
2011	54.1	10.8	4.7	1,124	0.446

Source UNDP 2011

As a guiding framework for the achievement of poverty reduction to less than 10% of the population by the year 2017, the government of Uganda launched the Poverty Eradication Action

Plan (PEAP) in 1997. Implementation of the PEAP was to be achieved through five pillars/components that respond to key challenges of poverty reduction and development i.e.

Economic Management

Production, competitiveness and incomes

Security, conflict resolution and disaster management

Governance

Human development.

Ill health was identified in the PEAP as one of the main causes of poverty and overall human underdevelopment rather than economic growth at the macro-levels. Therefore, improving population health outcomes was one of the key priorities under the human development pillar of the PEAP. One of those strategies identified in the PEAP to improve on population health outcomes and therefore reduction in poverty levels was through improvement of access to safe water and sanitation.

1.6 Water Access and Sanitation Coverage in Uganda

1.6.1 Water Access

In Uganda, safe water is defined as that which is free from disease causing organisms, toxic chemicals, colour, smell, and unpleasant taste (MWE, 2008). Water supply from a tap and piped water system, boreholes, protected wells or springs, rain water and gravity flow schemes is considered safe while that from open sources including ponds, streams, rivers, lakes, swamps, water holes, unprotected springs, shallow wells, and water trucks are considered unsafe (UBOS,2002). Although the WHO-UNICEF JMP (2012) report indicates that at a 77% safe water coverage by the year 2010, the country is one of those that have met their MDG targets for

improved water access (Figure 1.11), the statistics from the MWE paint a different picture with about 66% access to safe water coverage by 2011 (MWE, 2012). This makes it hard to pin-point the exact improved water access coverage for the country. What is true from both reports however is that the rural areas remain under-served compared to urban areas.

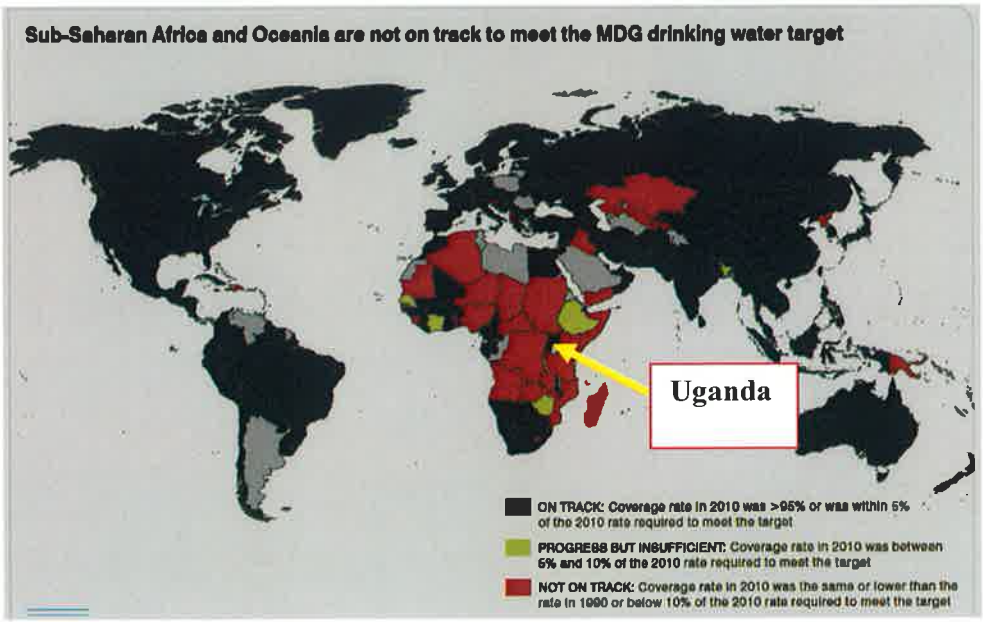


Figure 1.11: Progress towards the MDG drinking water target, 2010. (WHO/UNICEF JMP 2012)

According to the UBOS (2002) census report, the challenge of providing safe water to the rural population is largely due to scattered settlement patterns which make it hard to provide centralised supply unlike in the urban centres where the settlements are more centralised and easily be served. These disparities in water access between the rural and urban areas, have led the Ugandan government to set different targets for urban and rural areas with regard to improved water supply and accessibility (UBOS, 2002).

1.6.2 Urban Safe Water Coverage

Safe water access for urban dwellers is defined as having an improved/safe water source within 0.2 km of the household. The National Water and Sewerage Cooperation (NWSC) government parastatal body is responsible for provision of piped water to urban cities and larger towns in Uganda. Even then, safe water accessibility in these towns and cities is still only at 69% leaving other urban dwellers with no access to safe water (MWE, 2012).

1.6.3 Rural Access to Safe Water

In rural areas, access to safe drinking water is determined by the walking distance from the household to the water source, time spent to and from the water source and the volume of water used per person per day in each household. A distance of 1.5km or less; a time of less than 30 minutes round trip to water source from home and use of 20 litres per person per day is considered as access to sufficient water for the rural population (Rugumayo, 2008; UBOS, 2002) . The MWE (2012) indicates that safe water access in rural areas declined from 65% in 2010 to 64% in 2011. The decline was mainly attributed to general cuts in government funding to the water sector and the creation of new districts which meant that some resources for water services were diverted to cater for other district infrastructure development (MWE, 2012).

With an estimated 85% (29.09 million) Ugandans living in rural areas, this implies that approximately 36% (7.2 million) people in the rural areas are still without access to safe drinking water. According to Godfrey, (2012), 60% of rural households in Uganda reported travelling a distance of 1.5km or more to access safe water. The Directorate of Water Development (DWD) in the MWE indicates unprotected open water sources as the most frequently used by the rural population. These account for over 40% (Table1.8) of all the water supply in rural Uganda

(UBOS 2002). Other studies (Mellor, 2009) have shown that in some rural areas unprotected water sources can account for over 82% of domestic water supply. With the rapid population growth, more investments in safe water supply which can outpace the rapid population growth are needed.

Table 1.8: Percentage distribution of households by source of drinking water in Uganda.

Selected Water Indicators	Residence		
	Urban	Rural	Total
Source of Drinking Water			
Tap/piped water	58.5	3.9	11.5
Borehole	12.4	26.0	24.1
Protected well/spring	20.7	22.7	22.5
Gravity flow scheme	1.4	3.0	2.8
Open water sources/rain water	6.8	44.4	39.1
Total	**100**	**100**	**100**

Source: UBOS 2002

1.6.4 Sanitation Coverage

Although Uganda has made tremendous steps in improving water supply and coverage, the country still lags behind and is not on track to meet the MDG target for sanitation by 2015 (Figure 1.12). Just like safe water supply, the official government statistics for sanitation coverage differ from those estimated by the WHO-UNICEF JMP report on Uganda. While the MWE (2012) water and sanitation sector performance report indicates a 76% access to improved sanitation, the JMP reports only 34% coverage of improved sanitation country wide. Again, the rural population is still the most adversely affected with an estimated 30% of the population without access to improved sanitation (MWE, 2012). Another estimated 10% of Ugandans in rural settings are still practicing open defecation and only one in four Ugandans washes their

hands with soap and water (Kasirye & Barungi, 2011; MWE, 2012; UBOS, 2007). However with this alarming sanitation state, the provision of sanitary facilities such as improved pit latrines still remains largely a private initiative unlike water which is publicly provided and yet the reality is that the cost of constructing a private latrine is out of reach for majority of rural households (Kasirye, 2010; MWE, 2012; UBOS, 2007).

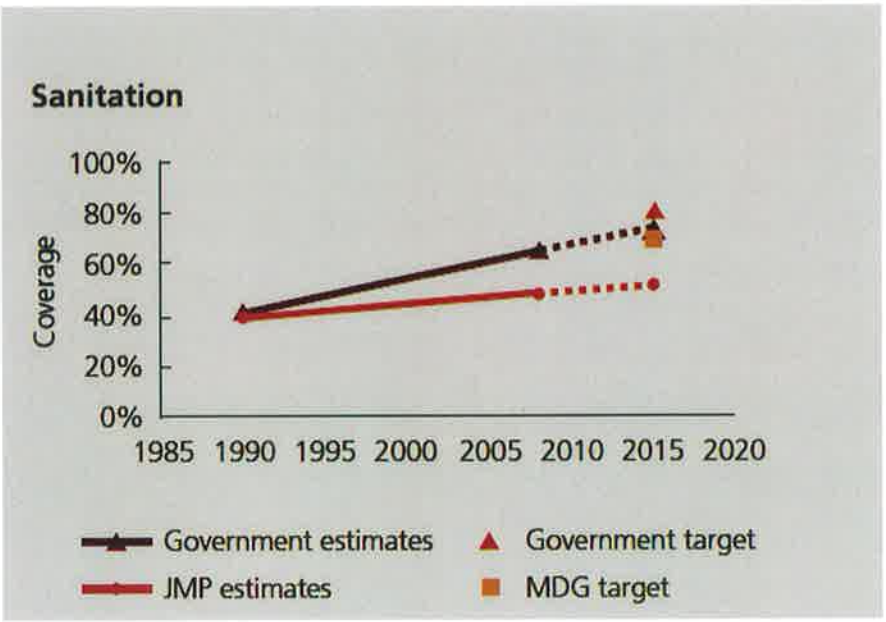


Figure 1.12: Progress in sanitation coverage in Uganda. (MWE 2009 and UNICEF JMP 2010)

1.7 Water Policy and Legal Framework

Since water is a finite resource and vital for the sustenance of life there is a clear need for resource management and development through which priorities can be established and the protection and optimal use of the nation's water resources are planned and assured (MWE 1995).

The main goal of the Ugandan water sector therefore is to "Manage and develop the water resources of Uganda in an integrated and sustainable manner so as to secure and provide water of adequate quantity and quality for all social and economic needs for the present and future generations with the full participation of all stakeholders" (MWE, 1995). The government aims to achieve 100 % safe water and sanitation coverage for the urban areas and 77% and 95% safe water and sanitation coverage respectively for the rural areas by the year 2015 with an 80-90% effective use and functionality of facilities. To achieve this, a number of comprehensive policies and legal frameworks have been instituted by the Ugandan government for both the rural and urban populations.

1.8 Drinking Water Quality

Water quality problems in Uganda are mainly due to poor/lack of sanitation with fecal coliforms routinely found in drinking water (DWD, 1994; UN-World Water, 2006; UN-WWAP, 2006). Water quality, regulation and monitoring in Uganda are the responsibility of the DWD, but due to financial constraints, there is little or work done especially with respect to rural water quality. In urban areas the NWSC monitors water quality internally often with no external monitoring (UBOS, 2002). A report on the water and sanitation situation in Uganda indicated that 90% and 95% of all water samples taken from protected and treated water supplies met the national standards for drinking water quality (Water Aid Uganda, 2006). However it is worthwhile to note that these sources account for a small percentage of water sources especially in the rural areas. In addition, these sources are usually located long distances away from the homesteads and the risk of recontamination during transportation and storage is real and high (UN-WWAP, 2006). In contrast to the WaterAid report, studies around the capital city Kampala (Howard, Pedley,

Barrett, Nalubega, & Johal, 2003; Rukia, Francis, & Kabagambe, 2005) have found the water from these sources to be highly contaminated with faecal coliforms, with over 90% of water tested for total coliforms not meeting the WHO recommended standards. Worse still, all the tested samples did not meet WHO standards for faecal coliforms hence water was unfit for human consumption.

Due to limited research on the bacteriological and other quality parameters, rural water quality remains largely unknown. The latest study (Opio, 2010; Parker *et al.*, 2010) carried out in the North and North-Eastern Uganda found that unprotect open hand dug wells had the worst microbial quality of all water sources tested and yet these make up the largest water supply source for the rural community (UBOS, 2002, 2007). This research is therefore a timely contribution to the knowledge base of rural water quality in the country.

1.9 WASH and Related Diseases in Uganda

Poor sanitation coupled with insufficient and unsafe water greatly increase the risk of water borne and related illnesses. Water, sanitation and hygiene related diseases contribute over 75% to the burden of disease in Uganda (Kagolo, 2012). It is estimated that the country loses over 389 billion Ugandan shilling annually due to WASH related disease (Kagolo, 2012). Diarrhoea, one of the common WASH related diseases was one of the top 10 outpatient diagnoses among patients of all ages and accounted for 19% of infant mortality in Uganda (Katende & Tumwesigye, 2002). Despite increased access to improved water supplies, national prevalence of diarrheal increased from 3.9% in 2002 to 4.7% in 2010 amongst the general population. The disease had also increased by three percentage points to 9% in the same time period among children below six years of age (Kasirye & Barungi, 2011). This is attributed not only to the poor

sanitation situation in the country but also cultural practices and low awareness of hygiene and sanitation importance among the general population, especially in the rural areas (UBOS, 2010; UN-WWAP, 2006). The long distances travelled to collect water also contribute to the high WASH disease since in most cases the water collected is inadequate to meet all the household general needs. The average water usage per person in rural Uganda is estimated at 13L/day compared to the recommended 20L/day (UN-WWAP, 2006).

Table 1.9: The Uganda Diarrhea Prevalence per 1000, 2009/10

		Region			
	All	Central	Eastern	Northern	Western
All Households	47.2	27.2	56.0	74.5	34.5
Urban	23.9	18.1	26.7	50.7	18.3
Rural	51.1	31.1	58.3	77.0	35.1
By age category					
Infants 0-5 years	91.5	62.0	98.5	128.8	76.6
Children 6-14 years	36.0	13.6	44.9	53.5	30.3
Adults 15+ years	26.8	15.2	33.3	49.7	13.8

Source: Kasirye and Barungi 2011

Despite the worrying situation, Uganda seems more comfortable with treatment rather than prevention of the WASH diseases. Sanitation has largely been left as a private affair with limited assistance from the state and yet the costs of constructing even a simple pit-latrine are out of the common man's reach (UBOS, 2002).

1.10 Primary School Water Supply and Sanitation

Water supply to primary schools the majority of which are located in rural areas is one of the key challenges in the water sector. Of 12,230 primary schools surveyed, only 40% had access to pipe or borehole water. Considering that these two sources are the most protected and therefore

have considerably safe water, the majority of pupils in schools are left without access to clean water (UN-WWAP, 2006). Even for those that have access to safe water, the sources are usually further than the recommended 0.5km from school and often shared with the community (Jitta, 2006; UWASNET, 2010). Due to the long distance and waiting time at these sources, pupils are more often than not forced to use water from other unprotected sources. The most recent survey on the water situation in Ugandan primary schools revealed that less than 1 in 5 schools provided the recommended 5 litres of water per pupil in day primary schools (Jitta, 2006)

Table 1.10: Water supply in Ugandan primary schools.

Source type	No. of schools	% no. of schools
Piped water	1,133	9.2
Borehole	3,587	29.2
Spring/well	4,718	38.4
Rain water tanks	902	7.3
Lake/river	731	6.0
Other	556	4.5
Unknown	653	5.3
Total	**12,280**	**100**

Source: UBOS (2003)

The government of Uganda is also still finding it a challenge to provide proper and adequate sanitation in primary schools. Of the 334 surveyed primary schools from the five major regions of the country (North, South, East, West and Central), the average pupil per latrine ratio was 69:1, much higher than the recommended 40:1 (Jitta, 2006) with only 33 % of schools having separate latrines for girls (Jitta 2006). The high pupil per latrine ratio is attributed to the increased enrolment of pupils since the introduction of Universal Primary Education (UPE) by the government in 1996 (Jitta, 2006; UN-WWAP, 2006). Often pupils are forced to resort to open defecation which exacerbates the already appalling sanitary situation leading to frequent illness, absenteeism and poor academic performance (UWASNET, 2010). Almost 2.7 % of

absenteeism by pupils in Ugandan primary schools is due to diarrhoeal and other water-related diseases including but not limited to gastro intestinal complaints.

1.11 Household Water Treatment in Uganda

Despite the fact that drinking water in rural Uganda is of poor bacteriological quality, very few people seem to be doing anything to treat water in order to make it safe. Most people who get water from improved sources feel that it is safe and therefore find no need to treat it but studies have shown that quality of these sources is questionable. However, even when the water from these sources is safe, recontamination during collection, transportation and storage does occur (Kasirye & Barungi, 2011; Parker *et al.*, 2010). The 2006 UDHS study (Table 1.11) shows that only 32.5% of the rural population boiled their water before drinking, 65.2% did not treat their water at all before drinking.

Table 1.11:Percentage methods of household water treatment in Uganda

Treatment prior to drinking	Urban	Rural	Total population
Boiling	67.8	32.5	37.1
Bleach/chlorine	1.6	0.7	0.8
Strained through cloth	2.1	1.6	1.6
Ceramic/sand or other filter	1.4	0.5	0.6
Other	3.2	2.0	2.1
No treatment	29.9	65.2	60.7
%using appropriate treatment method	69.9	34.4	38.9

Source: (UDHS 2006).

1.12 Study Aims and Objectives

The main objective of this study was to introduce SODIS as an alternative point-of use household water treatment technology to the Ndagwe Sub County community using a school based trial protocol.

1.12.1 Specific Objectives

1. Assess the effect of SODIS on microbial quality of water used by pupils while at school and hence their health in terms of water-related diseases with particular emphasis on occurrence of diarrhea and gastro-intestinal complaints.

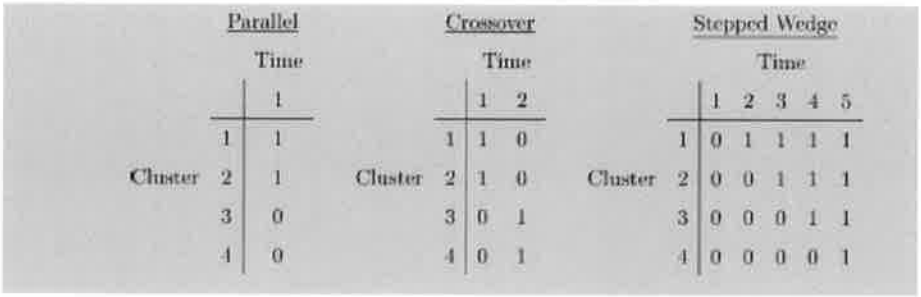
2. Assess effect of SODIS on attendance patterns of pupils and the extent to which diarrhea and gastro-intestinal complaints contributed to pupil absenteeism.

3. Assess effectiveness of pupils in the transfer of the SODIS knowledge back to their care-givers/community through interview-based survey of community members

4. Assess efficacy of SODIS between Glass and PET reactors under real field conditions for purposes of promoting either or both reactors to the Ndagwe community.

The cluster randomized stepped wedge design (Figure 1.13, Table 2.1) was used in the implementation of this study for the first three objectives. Unlike other cluster randomize trials (CRTs) such as the parallel and the standard cross-over designs the stepped wedge cluster design is a type of crossover design in which subjects are randomized to clusters or groups that start treatment or intervention at different time points (Hussey & Hughes, 2007; Woertman *et al.*, 2013). The cross over in the clusters is unidirectional and starts from control to intervention with

the first time point typically a baseline period where none of the clusters receive intervention. The rational for use of this design is further discussed in Chapter Four, section 4.2.



Parallel		
		Time
		1
Cluster	1	1
	2	1
	3	0
	4	0

Crossover			
		Time	
		1	2
Cluster	1	1	0
	2	1	0
	3	0	1
	4	0	1

Stepped Wedge					
		Time			
		1	2	3	4	5
Cluster	1	0	1	1	1	1
	2	0	0	1	1	1
	3	0	0	0	1	1
	4	0	0	0	0	1

Figure 1.13: Treatment schedules for parallel, crossover, and stepped wedge designs. "0" represents control or existing treatment; "1" represents an intervention (Hussey and Hughes 2007).

CHAPTER TWO: METHODOLOGY

2.1 Study Location

This was a project funded study and the location had already been chosen by the project managers as Makondo parish in Ndagwe Sub County. However, after initial field visits to Makondo to ascertain the number of primary schools in the parish, it was necessary that the geographical area be expanded to include other parishes since the Makondo parish had only four primary schools which were not enough to meet our major objective stated above. It was agreed that the study area be increased to include the whole of Ndagwe sub-county (Figure 2.1).

Ndagwe sub-county (Latitude 00^{o} 24'S, longitude 31^{o} 25'E and Altitude 1300m) is located about 50 km west of Masaka town in Bukoto-west constituency, Lwengo District. Lwengo district was formally part of Masaka district until July 2011 and as such not much demographic data and other administrative data has been compiled for the new district. In this research, the information obtained by the researcher was from the Masaka District Administration. The sub-county lies 250km from Kampala, the capital city of Uganda.

In the Ugandan system of local government administration a district is sub-divided into counties which are then sub-divided into sub-counties. The sub-counties are further sub-divided into parishes (MOL, 2010). Ndagwe sub-county is composed of six parishes and they include: Makondo, Ndagwe, Nanywa, Kityo, Mpumudee and Kiwangala. The parishes are finally divided into villages which form the smallest entity of political administration (MOL, 2010).

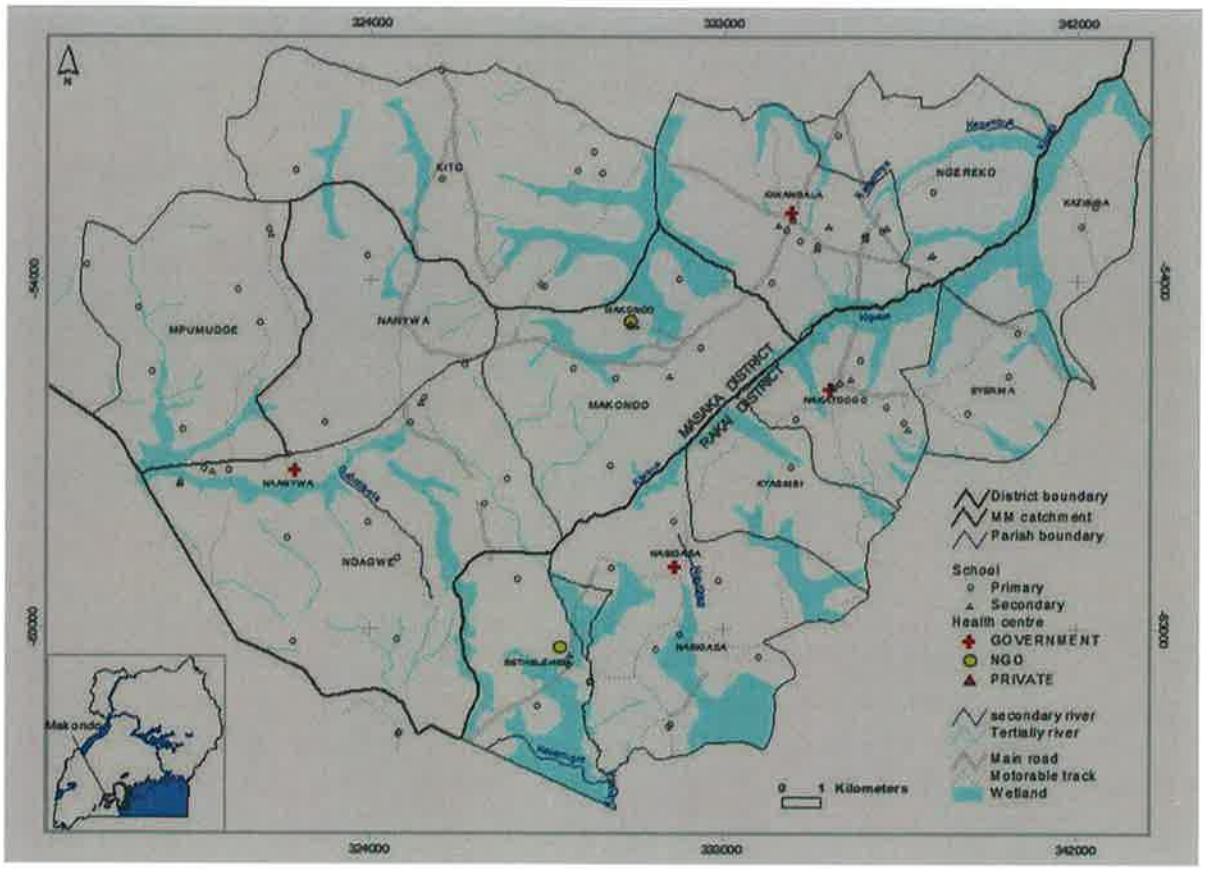


Figure 2.1: The different parishes of Ndagwe Sub-county. (Water is Life Project GIS data).

2.1.1 Culture and Economic Activity

The population in the sub county is tribal and a multicultural with the Baganda being the dominant tribe. Other tribes include but are not limited to Banyankole, Banyarwanda and Tanzanians. Luganda is the main language of communication (UBOS, 2002). Subsistence agriculture is the main economic activity. Households grow foods such as sweet potatoes, bananas, beans, cassava and vegetables for home consumption and sell the surplus for additional income. Coffee and vanilla are the main traditional cash-crops of the area. Upland rice, aloe-vera

and chillies have recently been introduced as additional cash-crops to supplement traditional cash-crops (MWE, 2004).

2.1.2 Health

Water borne diseases such as diarrhoea, gastro-intestinal complaints, and other water-related diseases including malaria and skin diseases were reported to be very common amongst the population, especially in infants and children less than five years (MWE, 2004). These health data statistics are further collaborated by the year-long health data-base on common childhood water borne diseases in the sub-county created by the charity organisation, Medical Missionaries of Mary (MMMs) during the course of this study (Figure 2.2 and Appendix G). Most of the of these diseases are those caused by or related to consumption and use of unclean water (WHO-UNICEF, 2008).

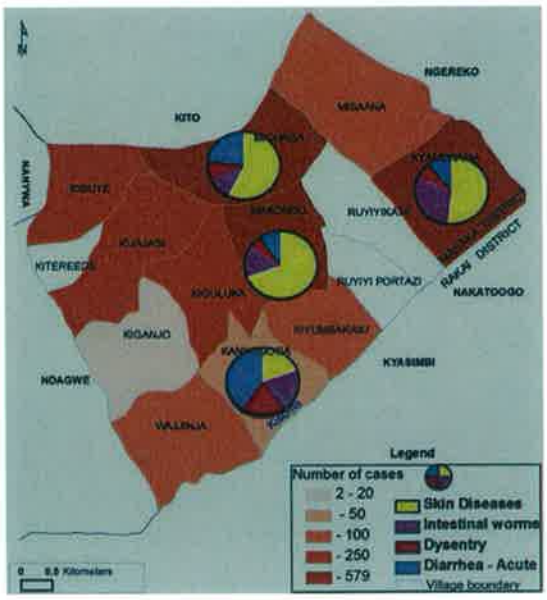


Figure 2.2: Common childhood water-borne diseases recorded in four different villages in Makondo parish in 2011. (*MMM Clinic in Makondo)*

2.1.3 Community and School Water Supply

Access to improved water source coverage in Ndagwe sub county increased from 40.6% in 2004 (MWE, 2004) and is currently estimated to be 58% (Mutebi & Victor, 2011). The commonest improved water sources include shallow wells, a few protected springs and rainwater harvesting systems. The sub-county receives about 1100-1200 mm of rainfall per annum with an average of 100-110 rainy days, making this area rather dry compared to other parts of the country (Mutebi & Victor, 2011). Rainwater harvesting therefore becomes seasonal and most people run out of water during prolonged dry seasons and resort to nearby unprotected open dug wells. This is because the shallow pumps are either far from the homesteads or have stopped functioning, according to the Makondo village Local Council (LC) 1 chairman (Gerald Ssemakula). However in severe drought even the open dug wells dry up and people have to walk distances of up to 5km or more in search of water (MWE, 2004). There was no official information about school water and sanitation facilities either from the ministry of Education or from the Masaka District Education Officer (DEO) for the sub county. However from observation in this study, school pupils share the same water sources with the surrounding communities.

2.2: Study Implementation

The study was conducted in four phases. First, a baseline cross-sectional study was carried out to assess microbial water quality and the types of water sources that were being used by the pupils while at school. Baseline absenteeism of subject pupils from the selected schools was also assessed. This was mainly to gauge the occurrence of diarrheal disease/gastro-intestinal complaints and to what extent these were contributing to the absenteeism of subject pupils from school.

In the second phase, pupils were supplied with 1.5 litre PET plastic bottles to treat their drinking water using SODIS. Monitoring of pupil absenteeism and water quality testing of raw water was also continued. In addition, SODIS treated water quality when applicable was also assessed.

In the third phase, an in-depth interview based questionnaire survey was conducted amongst selected care-givers of participating pupils. This was to gauge the extent to which SODIS knowledge had been transferred to the general community and if the technology was being practiced.

Lastly the efficacy of SODIS in glass and PET plastic bottles under dissimilar weather conditions in real field conditions was assessed. Results from this experiment would be used as a basis on which to promote use of glass or PET bottles to the community in Ndagwe sub-county.

2.2.1 Phase 1: Cross-sectional Study

This phase of the study had the following specific objectives:

- To build rapport with the local community so as to gain better understanding of the study area as well as support from the community leaders and school teachers for the study.
- To select the primary schools and pupils that would participate in the study
- To find out the type of drinking water sources used by pupils in the selected schools and whether there was any form of drinking water treatment carried out at these schools prior to this research.

- To assess the microbial quality of drinking water used by the pupils in the selected primary schools using total bacteria, *E. coli*, *E. faecalis* and *C. perfringens* as indicators of water quality.

- To examine the absenteeism rate amongst participant pupils and to what extent diarrheal disease and gastro-intestinal complaints were responsible for pupil absenteeism. Other causes of absenteeism were also monitored.

2.2.2 Phase 2: Introduction of SODIS Water Treatment

This phase was to specifically achieve the following objectives.

- Provide bottles to subject pupils for SODIS water treatment of their drinking water both at school and at home. This was the water they were to drink for the duration of this study.

- Assess microbial quality of drinking water before and after SODIS treatment.

- Assess the effect of seasonal variations on water quality and efficacy of SODIS.

- Assess the effect of water source type on efficacy of SODIS

- Continue assessment of absenteeism amongst the subject pupils and find out the rate to which diarrheal disease, gastro-intestinal complaints and other causes were contributing to absenteeism.

2.2.3 Phase 3: Community SODIS Survey questionnaire

In this phase, in-depth face -to-face questionnaire-led interviews with Ndagwe Sub county community members were carried out to:

- Assess the extent to which SODIS knowledge had been transferred to the general community of Ndagwe Sub County and how acceptable it was to the community.
- Gather or obtain information on the general household drinking water quality and treatment in the community
- Assess acceptability of glass and PET bottles for the purposes of SODIS water treatment promotion.

2.2.4 Phase 4: SODIS efficacy in sub-Saharan field conditions (Glass vs. PET reactors)

In this phase, an efficacy assessment of SODIS in both glass and PET bottles under a variety of weather conditions in the field was carried out. This would help to promote either or both of the two reactors to the community for SODIS water treatment. It would also be useful in understanding under which weather conditions either of the reactors works best so as to impart this knowledge to the community accordingly for better water treatment efficiency.

2.3 Ethics

Before commencement of this research, ethical approval was sought from the Research Ethics Committee (REC) of the Royal College of Surgeons in Ireland. This approval required that all the participants i.e. school head teachers, pupils, parents and guardians of the participating pupils sign a consent form indicating that they were willing to participate in the study. The researcher was required to thoroughly explain the purposes of the research, risks and benefits associated with the research and the fact that subjects could decide to drop out of the study at any time without any consequences whatsoever to them. Approval (REC601) was granted in November 2010 after which field work began. Copies of the participant information sheet, consent forms

and research ethical approval are attached as Appendices A, B, and C respectively. Research clearance was also sought from the Uganda National Council of Science and Technology. This is the body approved by the Ugandan Government to coordinate and approve all research based in Uganda. The letter of clearance is attached as Appendix D.

2.4 Sample size determination

Since the absenteeism rates or causes of the same amongst pupils in the study area were unknown before the study, the worst case scenario of 50% absenteeism rate was assumed. A sample of 319 pupils from a population of 7000 would have been enough to give 95% power to detect a 10% difference in absenteeism of pupils after intervention (Conroy, 2004). However, previous SODIS studies in Kenya and Zimbabwe had suffered a significant loss of participants (up to as much as 40%) through circumstances such as post-election violence and/or economic hyperinflation crises which were unforeseen at the recruitment phase of these studies (du Preez *et al.*, 2011). With Ugandan elections having been scheduled for February and March 2011 it was deemed prudent to recruit significantly more pupils than the figure calculated. Furthermore, due to scanty data on school attendance and causes of pupil absenteeism in the study area in addition to high school dropout rates (almost 80%), in Ugandan primary schools (Mubatsi, 2009), a larger sample was thought to be necessary to cover for such short-comings. Therefore a sample size of 750 pupils (50 pupils per school) was decided upon to cater for the above mentioned short falls. This number was easy to achieve due to the fact that all the schools selected for the study were eager to participate.

2.5 Study Design

Phases I and II of the study took place in primary schools which had to meet the following criteria:

- Be located in Ndagwe sub-county and have at least 50 pupils in the lower primary classes (Primary one to primary three).
- Have a water source from which the school collected water for pupils to use while at school.
- Willingness by the school administrators and teachers to allow for this study to take place in their schools and participate actively in the SODIS project.
- Willingness of parents/primary care givers to allow their children to participate in this study.
- Lastly, the willingness of the local council (LCs) leaders to allow this study to take place within their jurisdiction.

A total of fifteen primary schools met the above criteria. However, one school (Nanywa Primary school) was dropped from the study after the teachers responsible for the SODIS project were uncooperative in recording of data and making sure that participant pupils were exposing their drinking water to the sun for SODIS treatment. The remaining schools included Kabuyoya, Kyaterekera, Kijjajasi, St. Agatha, Arise and Shine, Misenyi, Miremebe, Bunjjako, Misana, Ndagwe, Ndeeba, Living Hope, King Godfrey and Nakatete primary school. Figure 2.3 shows the location of the selected schools and their respective water sources.

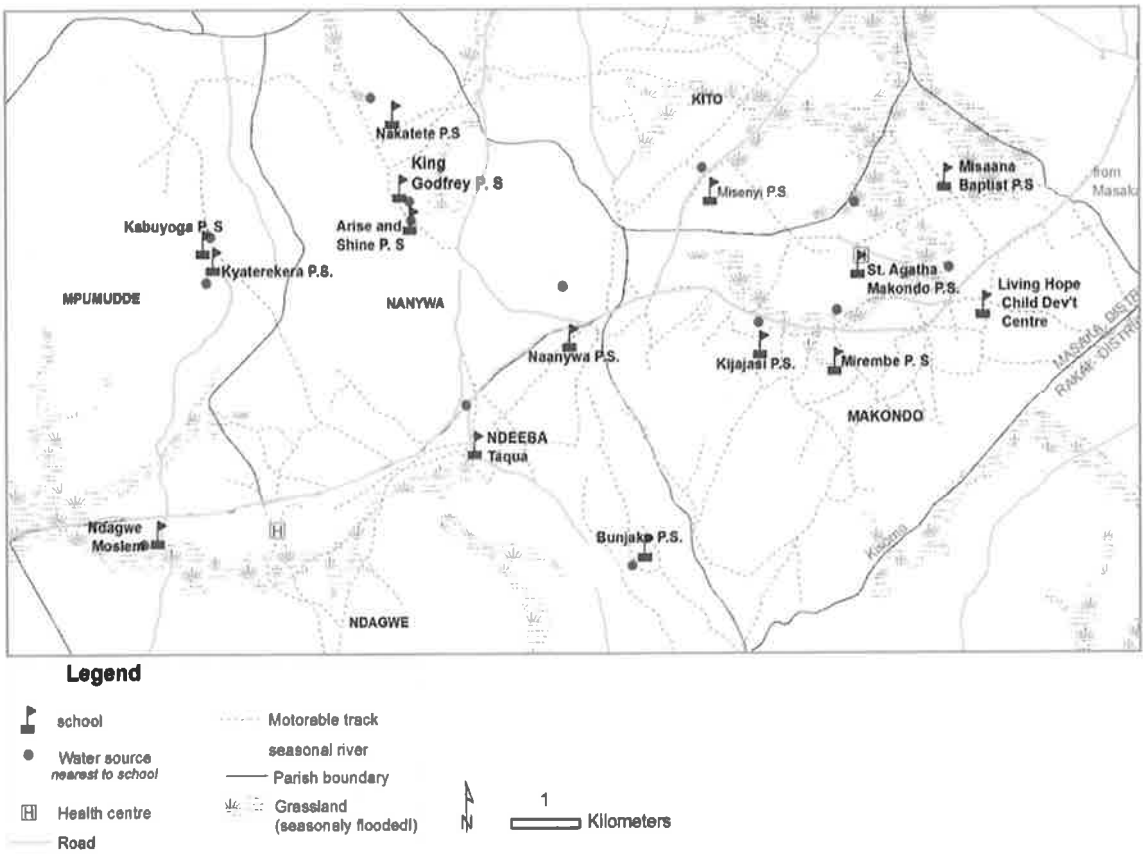


Figure 2.3 : Location of study primary schools and their water sources.

2.5.1 Phase 1: Baseline Cross-sectional Survey

The cross-sectional baseline survey was carried out to increase researcher understanding of the study location /area. Particular interest was in finding out the number of schools in the area that met the above criteria and the type of drinking water sources pupils in these schools used. Assessment of drinking water treatment practices if any, carried out to make drinking water safe for pupils while at school was also of interest during this baseline study. The survey also intended to ascertain the rate of absenteeism and major causes of the same amongst pupils. All this information was largely unknown prior to this study. There was barely any published data

from relevant government institutions with regard to the above sought information for the study area. Therefore this baseline was crucial since it was basing on the attained information that the study would proceed to the next phase.

2.5.2 Phase 2: SODIS Water Treatment

This phase began after attainment of the baseline cross-sectional survey information described above. The phase was mainly to assess the impact of SODIS water treatment on the health of participant pupils with particular interest in the prevalence of diarrheal disease and gastro-intestinal complaints, diseases usually associated with poor water quality. Pupil absenteeism due to these particular diseases was used as an indicator to assess the impact of SODIS on water quality and therefore disease outcomes. A clustered stepped wedge study design (Table 2.1) was used in this study phase. The fourteen remaining schools were grouped into two clusters of four schools and one cluster of six schools. SODIS was then introduced on a cluster by cluster basis at different time periods corresponding with the start of school terms. The first cluster of schools stared SODIS in June 2011, the second cluster of schools started SODIS in September 2011 and the last cluster implemented the technology in February 2012. This design was used for ethical purposes, such that all the subjects would be able to use the technology by the end of the study. The clusters that were not yet practicing SODIS, acted as a control for those that were, hence eliminating the need for a control as is the norm in randomised controlled studies. The design was also helpful in mitigating some unanticipated financial constraints and other field hurdles. For example, the initial intention was to use a 5:5:4 cluster system but by the time bottle distribution commenced, only bottles enough for four schools were available for purchase hence the 4:4:6 system.

Table 2.1: Cluster Stepped Wedge Design

CLUSTER	Term III (2010)	Term 1 (2011) (Step 1)	Term II (2011) (Step 2)	Term III (2011) (Step3)	Term I (2012) (Step4)
1	Baseline data, no treatment	Baseline data, no treatment	Treatment	Treatment	Treatment
2	Baseline data, no treatment	Baseline data, no treatment	Control	Treatment	Treatment
3	Baseline data, no treatment	Baseline data, no treatment	Control	Control	Treatment

2.6 Participant Eligibility and Recruitment

In the Ugandan school curriculum pupils start school at the age of 6. Pupils within the age range of 6-9 years were chosen as eligible participants in this study. These were pupils in the lower classes (primary 1-3). The eligible pupils were randomly selected as follows: All pupils from lower primary section (P1-P3) from each of the selected schools were asked to pick from a pool of papers on which numbers 1-200 were written. Two hundred was the highest total number of pupils in lower primary section recorded during baseline. Pupils who picked numbers 1-50 were selected to participate in the study and retained their number for identification and record keeping purposes. Pupils in primary one and two study half day (8:00am-12:00 Mid-day) and were responsible for SODIS water treatment early morning. The P3 pupils who study up to 5:00pm were responsible for storage of treated water at the end of the day.

2.7 Training of School Teachers

Before introduction of SODIS, all teachers from the participating schools had one-day training in January 2011 at the Medical Missionaries of Mary (MMM) medical centre in Makondo on the

basics of SODIS and attendance/ record keeping. After this, training was repeated at the start of every school term according to the schedule in Table 2.2. To minimise information cross contamination, only teachers whose schools were practicing SODIS and those in whose schools SODIS was to commence next were given SODIS training at the start of each term. In all these trainings, the teachers were given a practical demonstration of the SODIS process as well as good attendance monitoring and record keeping practices. A participatory approach during training was used. Each participant had to demonstrate to fellow participants the SODIS technique and how attendance records would be kept during the course of the school term (Figure 2.4). This mode of training made it easier for the researcher since teachers who were trained previously were able to assist in the training of the new trainees. They were also able to note any difficulties that may have been encountered during implementation of SODIS in their schools and how such were overcome. This would in turn help the new trainees to avoid such difficulties.

Table 2.2: Training schedule for teachers in the different clusters

Time of Training	Teachers Trained
Jan 2011	All teachers from selected primary schools trained in attendance monitoring and record keeping
May 2011	Teachers from cluster1, given training on the SODIS technique and refresher on monitoring of attendance
Sept 2011	Training of teachers from clusters 1 and 2 on the SODIS technique and attendance monitoring
Jan 2012	Training of teachers from all the three clusters in the SODIS technique and attendance monitoring

Figure 2.4: Teachers Demonstrating the SODIS process to colleagues during a training session at the MMM clinic

2.7.1 Training of Pupils

Pupils were trained through practical demonstrations of the SODIS process by the teachers and researcher. The participatory approach mentioned above was also used in these trainings. Pupils were encouraged to demonstrate the SODIS process to fellow pupils and teachers after initial demonstration by the researcher/teachers. The teachers were encouraged to form SODIS clubs in their schools such that other pupils could practice SODIS although only participant pupils were followed for purposes of this study. In addition each school was provided with SODIS posters (Appendix E) to act as reinforcements to SODIS knowledge. These posters were pinned in

various locations around the schools so that pupils could easily access and read them. The main focus of this research was to assess the efficacy of SODIS on water from the different sources based on an as-is situation. For this reason, filtration of turbid water before SODIS treatment was not included during training sessions. Besides, filtration was not a common water treatment practice study area and may not have been adhered to.

2.8 Distribution of PET Bottles

Participant pupils were provided with four new, clean empty 1.5 litre PET bottles for SODIS treatment of drinking water. Introduction of SODIS was on a cluster-by-cluster and term-by-term basis. Pupils in the first cluster of schools received bottles in June 2011 (2nd Term, 2011 academic year), the second cluster received bottles in September 2011 (3rd Term, 2011 academic year) and the third cluster received bottles in February 2012. (1st Term, 2012 academic year). Two bottles were to be used for SODIS water treatment while at school and the other two were to be used while at home. Pupils were instructed to fill one bottle with water and place it in full un-obscured sunshine on a raised stand (Figure 2.5). Bottles were exposed first thing in the morning (about 8:00am) before classes began and were left out in the sun until evening when they would be put in a designated storage area (Figure 2.6) by responsible pupils before close of school usually at about 5:00pm. Pupils in primary three were responsible for collection and storage of treated water at the end of the school day. As one bottle was being exposed to the sun, the other contained treated water. Pupils were to drink "today" the water that was exposed the previous day. On Fridays, pupils were to go home with one bottle in which they were to expose water on Sunday. This would be the water that they would drink on Monday when they returned to school as they exposed more for the next day's consumption. Treated water was never allowed

to stay in the container for more than 48 hours so as to minimize the possibility of re-growth of partially inactivated bacteria. The pupils were also encouraged to drink directly from bottles instead of transferring the drinking water container to minimise the risks of recontamination of treated water both at school and at home. But because of water scarcity and long distances to collect water, pupils sometimes shared water and therefore drinking directly from the bottle was not always adhered to. The pupils were instructed to wash the bottles with soapy water and rinse thoroughly before filling with water for treatment.

Figure 2.5 : SODIS water treatment on a stand at Misenyi Primary School

Figure 2.6: Ready to drink SODIS water in a common storage area at Arise and Shine primary school

2.9 Attendance Monitoring

All teachers were provided with A4 hard cover note books in which they were to keep records (Figure 2.7) of absent pupils along with reasons why pupils did not come to school. In order to avoid a bias towards diarrhoea and gastro-intestinal diseases, a list of reasons from which to choose when a pupil was absent was given to the teachers. All causes of absenteeism were self-reported by the pupils. If a child was absent due to sickness, a teacher was supposed to probe further until a specific type of illness was identified. These reasons were coded (Table 2.3) such that teachers just recorded the code instead of the full name of cause. This was to make it easier and quicker for the teachers to keep records.

Table 2.3: Causes of school pupil absenteeism in Ndagwe sub county

Absenteeism Code	Full Name of cause
D	Diarrhoea
GI	Gastro-intestinal Complaints
M	Malaria
W	Work at home
S	Lack of school fees or scholastic material
O	Any other reason

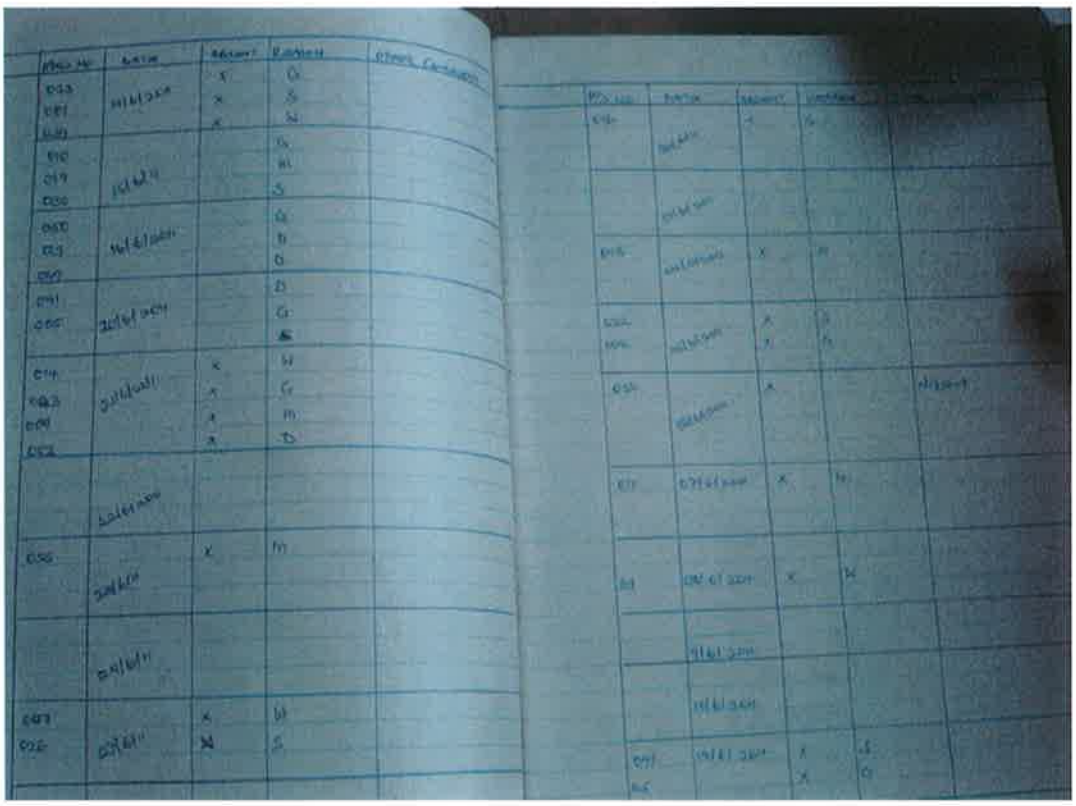


Figure 2.7: Sample of an attendance record book from Kabuyoga Primary school

2.10 Water Quality Analysis

2.10.1 Sampling

A one litre sample of raw water and another of treated water (where applicable) were collected every month from each school. The raw water samples were collected directly from the water source while a bottle of treated water was picked randomly from the ready to drink water exposed by the pupils at the schools. The raw samples were aseptically collected in clean sterile high density polyethylene plastic bottles (Nalgene Labware, USA). All samples were transported on ice in a cooler box over a four hour journey from the field to the Makerere University School of Food Technology, Nutrition and Bio-engineering for microbial analysis. Samples were usually processed within 8 hours after collection. Occasionally when samples arrived late from the field, they would be kept overnight at refrigeration temperatures (<2°C) and analysed as soon as possible the following day.

2.10.2 Physical Water Characteristics

Water physical parameters including total dissolved solids (TDS), pH, turbidity and temperature were measured onsite during sampling before transportation of samples for microbiological analyses.

The Primo 2 family microprocessor conductivity and TDS with temperature compensation meter (Hanna Instruments) was used for on-site assessment of the total dissolved solids and temperature of the water. The meter was calibrated according to the manufacturer's instructions by switching it on and then pressing the ON/OFF button for approximately three seconds till a blinking display of "1382" showed on the screen to confirm entrance into calibration mode. The meter was then without exceeding the maximum level, immersed into the HI 70032P calibration

solution supplied with the meter for approximately 20 seconds. Once the display on the screen stopped blinking, the Primo 2 was calibrated and ready for use. The meter was calibrated on a monthly basis.

pH was measured using the Clerks pocket meter (Hanna Instruments). The meter was calibrated with pH7 and pH4 solutions on a monthly basis. During sampling, the electrode was washed with distilled water between samples and always immersed in a pH7 solution after every use.

Turbidity of the water was measured in nephelometric turbidity units (NTU) using a turbidity tube (Del Agua, Robens Institute, Guildford, United Kingdom, Range 5-2000NTU). Water was poured into the tube to a level where the dark ring at the bottom of the tube was no longer visible to the naked eye. Turbidity was then read off the tube as marked (Figure 2.8).

Figure 2.8: Measuring turbidity at an open dug well (Bunjako Primary school)

2.10.3 Bacteriological Examination of Water

Water samples were analysed for *E. coli, E. faecalis,* total bacterial contamination, and *C. perfringens. E. coli* and *E. feacalis were* assayed by use of the standard membrane filtration method while the heterotrophic plate count (HPC) and ISO (7937) methods were used for the enumeration of total bacteria and *C. perfringens* respectively.

Membrane Filtration Technique

The standard membrane filtration method (USEPA, 2005) was used. Samples were filtered using a stainless steel membrane filtration manifold system (Sartorius Stedim 16842) connected to a vacuum pump (Innovac –Charles Austen Pumps Ltd). The filtration system and other equipment used during analysis were flame sterilised with ethanol between each sample to avoid cross-contamination.

Water samples were filtered through sterile cellulose nitrate membrane filters (0.45µm pore-size and 47-mm-diameter, Gelman Sciences Inc. USA). Filters were then placed on appropriate media and incubated at appropriate temperatures and duration. Colonies were counted using an electronic colony counter (Stuart SC6, Germany).

E. coli

Chromogenic medium (Conda Pronadisa 1340) was used for the enumeration of *E. coli.* The filters were placed in an upright position onto the media and incubated at $37^{\circ}C$ for 24 hours. All violet-dark blue colonies due to β-glucuronidase cleavage of salmon-galactoside and X-glucuronide were counted as *E. coli.* Although the medium already contained tryptophan which allowed for the indole reaction hence confirmation of *E. coli,* further confirmatory tests for *E. coli* were carried out by streaking *E. coli* colonies from the chromogenic media filters onto Les Endo agar base (Conda Pronadisa 1137) and the plates incubated at $35^{\circ}C$ for 24 hours. The

red/pink colonies with a metallic sheen confirmed the presence of *E. coli.* The ATCC 25922 *E. coli strain* obtained from the school of veterinary medicine, Makerere University was used as positive control.

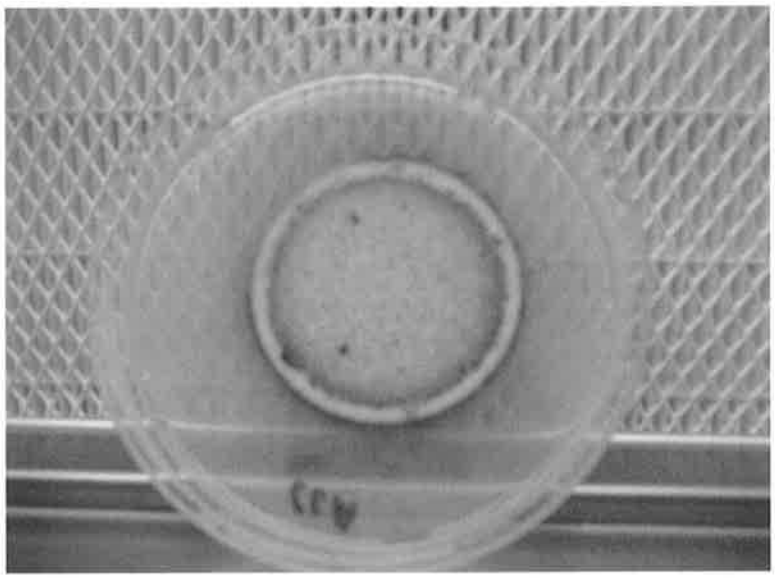


Figure 2.9: A plate of *E. coli* colonies (dark-blue-colour)

E. faecalis

Slanetz and Bartley medium (Conda Pronadisa 1109) was used for the determination of *E. faecalis.* The filters were placed on agar plates and pre-incubated at 37°C for 4 hours to aid bacterial resuscitation. They were then incubated at 36±2°C for a further 44±4 hours. After incubation all red, maroon and pink colonies that were smooth and convex were counted and recorded as presumptive faecal streptococci. All membranes with positive presumptive results were transferred to a pre-warmed dish (44°C) of Bile Esculin Azide Agar (Conda Pronadisa Cat. 1005). The plates were incubated at 44 ± 0.5°C for 2 hours. After incubation, all colonies with a brown-black surrounding medium were counted and confirmed as *E. faecalis*. *E. faecalis* strain NC08132 from the Uganda National Bureau of Standards Nakawa, Kampala was used as positive control

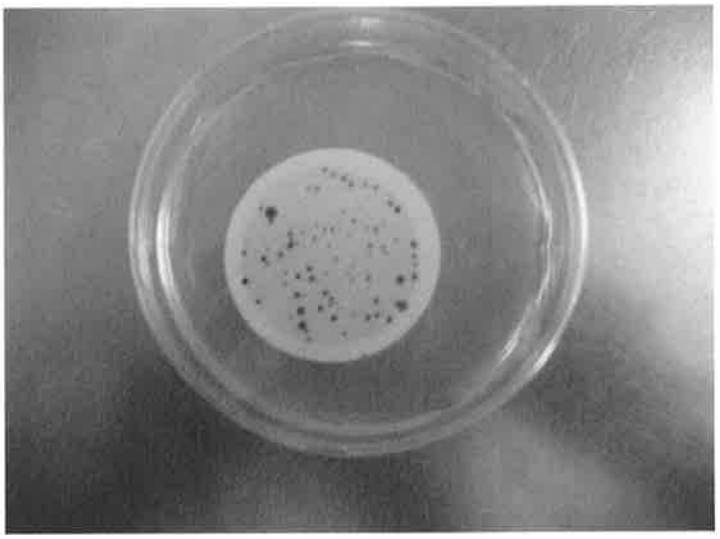


Figure 2.10: A plate of *E. faecalis* colonies

Total bacteria

These were enumerated using the plate count technique. Samples were thinly spread onto yeast extract agar (Conda Pronadisa 1049). The samples were left at room temperature (usually 22±2°C) for 24 hours before counting number of colonies.

C. perfringens

The ISO (7937) method was used for presumptive identification and enumeration of *C. perfringens*. To eliminate vegetative cells leaving only spores, 100ml of water sample was heated to 80°C in a water bath and held at this temperature for 15 minutes. 1 mL of sample was then inoculated into Tryptose- Sulphite- Cycloserine (TSC) agar (Conda Pronadisa 1029) enriched with egg yolk emulsion (Conda Pronadisa 5152). The plates were incubated anaerobically in jars (BBL Gaspak 100™ UK) at 37°C for 20±2hrs. All black colonies with a halo due to production of hydrogen sulfide and degradation of egg yolk lecithin were to be presumed as *C. perfringens*. In the absence of presumptive colonies, no further confirmatory

tests were carried out. A wild strain isolated from soil (UG-MUKVET1) from the school of veterinary medicine, Makerere University was used as appositive control for *C. perfringens.*

All analyses for each bacterium were carried out in triplicate and the average of these taken as the final bacteriological concentration in each sample. The results were expressed as colony forming units per 100ml of water sample (CFU/100 mL). For plates that had colony growths that were too numerous to count (TNTC), a value of 300CFU/100 mL was assigned as the upper limit of detection. All negative controls were run using de-ionised sterile water for each sample. Total bacteria and *C. perfringens* analyses were only carried during the trial/baseline phase of the study.

2.11 Interview- based questionnaire

An interview-based questionnaire survey was carried out from June to July 2012 at the end of the school SODIS project to gauge the effectiveness of school pupils in the transfer of the SODIS treatment technology to their care-givers at home and the general Ndagwe Sub County community. Only care-givers who had at least one child in the SODIS-participating schools were interviewed.

The questionnaire (Appendix F) was developed by the researcher and approved by the research ethics committee of the Royal College of Surgeons in Ireland (RCSI). It was piloted in Michunda village in Makondo parish among some of the care givers and revised accordingly. The care givers in Michunda village did not participate in the final interviews. The questionnaire was in English although during interviews, questions were verbally translated into the main local languages (Luganda and Runyankole) where necessary. For comparability to Uganda national

surveys and other international surveys, the questionnaire included six WHO/UNICEF core questions on drinking water and sanitation for household surveys (WHO/UNICEF, 2006). The interviews were conducted in the homesteads of the interviewees and usually lasted about 20-30 minutes. To avoid courtesy bias from respondents, interviews were un-announced. If the care-giver at a particular homestead was not available for interviews, the caregiver in the next eligible household was interviewed.

2.12 Phase IV: Efficacy of SODIS in Glass vs. PET bottles in Real Field Conditions

A wild strain of *E. coli* (NL-UGA) isolated from water from Ndagwe sub-county, Lwengo district, Uganda was used as the test organism. The organism was isolated using membrane filtration onto chromogenic media (Conda Pronadisa 1340) in earlier experiments (June-Dec 2011) by the authors to ascertain drinking water quality from the Sub-county. The indole test for confirmation of the organism was used. The *E. coli* isolate was maintained on nutrient agar slants at 4°C for later spiking of test water.

2.12.1 Sampling

Ten-litre samples of turbid water from open dug wells and clear water from shallow wells were obtained on a weekly basis from the study area. Just like samples from the various school water sources, these samples were also transported on ice over a four hour journey to the Department of Food Technology and Nutrition, Makerere University, in Kampala, Uganda. SODIS treatment of samples was done at the university as well as subsequent microbial analysis. Unsterilized natural raw water was used to provide a realistic nutrient environment which would not have been possible using distilled and sterilised water as observed in other studies (Joyce, McGuigan, Elmore-Meegan, & Conroy, 1996; Ubomba-Jaswa, Navntoft, Polo-López, Fernandez-Ibáñez, &

McGuigan, 2009). Turbidity at the sample collection point was measured in nepholometric turbidity units (NTU) as described before (section 2.10.2). Two turbidity levels of 5NTU for clear (shallow well) water and 150NTU for turbid (open dug well) water were used. Sampling was done early in the morning (7:00-8:00am) before water collection by the community commenced. At this time, open dug well water was un-agitated, clear and had an average turbidity of 70NTU. To obtain a turbidity of 150 NTU, water in the well was agitated to increase turbidity and then mixed with the collected 70NTU water until a turbidity of 150 was achieved. Samples from the shallow well were always at 5NTU. Sampling was carried out from the same open dug well and shallow well for the duration of this study.

2.12.2 Inoculum Preparation

E. coli was grown on nutrient broth (Conda Pronadisa 1216) at 37°C for 18 hours to obtain a stationary phase culture. The cells were harvested by centrifugation (Eppendorf AG 22221, Germany) at 2000rpm (570x*g*) for 10 minutes and washed with phosphate-buffered saline (PBS). Test water was inoculated aseptically with *E. coli* to give an initial bacterial concentration of 10^6CFU/100 mL for turbid water and 10^8CFU/100 mL for clear water. Trial tests had shown that a 10^6 CFU/100 mL starting concentration for clear water would yield undetectable bacterial counts as early as the second hour of bottle exposure. A 10^8 CFU/100 mL concentration was therefore chosen to give more time points of detection for clearer results. The seeded water was asceptically poured into clear 1-litre swing top borosilicate glass or PET bottles for SODIS treatment. For each sample, two glass and two PET bottles were filled. Before filling, bottles were cleaned with warm soapy water and rinsed twice, first with sterile water and finally with test water.

The sample bottles were then laid horizontally on a raised corrugated iron sheet stand and exposed un-obscured, in both sunny and overcast weather conditions for a period of seven hours. Control samples in similar containers were stored at room temperature in a dark cupboard in the laboratory. Solar exposure usually started at 9:00 am in the morning till 4:00pm in the afternoon. Samples (10 mL) for the first three hours of exposure and 100 mL thereafter were taken for analysis at hourly intervals. The temperature of the water in both test and control samples was measured using a standard mercury thermometer. To prevent cross-contamination, separate thermometers for each sample were used. Ultra-violet light (UVA+ UVB) in W/m^2 was recorded using a UVA+UVB digital UV meter (Solarmeter model 5.0, Solartech Inc, USA) which was sensitive over a UVA-UVB range of 280-400nm (0-199.9mW/cm^2). Both temperature and UV measurements were taken at hourly intervals.

2.12.3 Bacterial Enumeration

E. coli was enumerated on chromogenic medium (Conda Pronadisa 1340) using the standard membrane filtration technique (section 2.10.3). Appropriate 10-fold serial dilutions from the 10-mL samples were made. A 1-mL sample from an appropriated dilution was then made up to 100 mL using sterile ringer's solution and filtered. Where dilutions were not made, 100 mL of sample was filtered. Following incubation at 37°C for 24hrs, all violet-dark blue colonies were counted as *E. coli*. Counts were expressed as numbers of *E. coli* /100 mL of water. The detection limit was 1CFU/100 mL for all water samples.

2.13 Data Handling

Baseline, water quality and attendance/absenteeism data was entered and summarised with Microsoft excel. Household survey questionnaire data was cleaned, coded, entered and

summarised using Epi-data 3.1. All data were exported to and analysed using STATA Release (12.1) and/or SPSS (18.0).

2.13.1 School Water Quality Analysis.

Bacterial loads in the water samples followed a skewed distribution. In some samples especially the SODIS treated ones, there was undetectable bacterial growth (0 CFU/100 mL) while others usually raw samples, bacterial growth loads were too numerous to count (TNTC) and these were assigned a value of 300 CFU/100 mL. Due to this skewed data, bacterial counts were categorised and compared using the the non-parametric chi-squared tests. This is a commonly applied approach within the water resources community and shows no loss of power compared to parametric tests (Helsel & Hirsch, 1992).

Furthermore, water quality data was also analysed using interval regression (du Preez *et al.*, 2011) for comparability with the χ^2 tests used above. Interval regression allows the analysis of data in which some or all values are not known precisely but are known to lie within a defined interval. In the case of our water quality data, a reading of 300 indicated a bacterial concentration of 300CFU/100mL or more. Likewise, a reading of zero did not mean that the water contained no bacteria, but rather that none was detected in the sample. In analysis, these values are taken as ≥300 CFU/100mL and <1CFU/100mL respectively. Data were converted to a $\log_{10}$ scale for analysis, as interval regression assumes that values are normally distributed, and previous work on water quality data has shown that this assumption holds broadly true when data are expressed on a logarithm scale (Williams, 2000). The Huber-White robust variance estimates were used to correct the calculation of standard errors for clustering effects. Huber-White standard errors have the advantage that, even where the covariates associated with the clustering effect cannot be

specified in full, confidence intervals have ≤ 95% coverage i.e., they are never narrower than the true confidence interval (Williams, 2000).

2.13.2 Pupil Absenteeism Analysis

Days of absence and cause were entered and summarised in Excel and exported to STATA 12 for analysis. The students' two sample t-test was used to compare absenteeism before and after introduction of SODIS treatment. Statistical analysis tested whether absence declined between follow-up 1 and baseline, and thereafter tested whether absence at a later follow-up was lower than the follow-up prior to it. Thus the null hypothesis test for follow-up 2 is that the rate of absence does not differ from the rate at follow-up 1

Furthermore, a model using generalised negative binomial regression analysis was also used. The model was stratified by cluster with the school identified as the primary sampling unit. The Huber-White variance estimation was used to correct standard errors for the clustering effect. The model included a dummy term for step i.e. time period during the study as well as term for SODIS i.e. period of SODIS intervention. Also included in the model was a term for whether or not the school had a protected water supply. In the model, only data from step 2 and step 3 study periods where we had both control and SODIS treatment data was used. In step 1 (baseline) only control data was available since SODIS treatment had not commenced while in step 4 (last phase of SODIS treatment) only data after SODIS treatment was available since all the subject pupils were using SODIS for treatment of their drinking water both at home and at school.

2.13.3 SODIS Dissemination (Survey Data) Analysis

Survey data were double entered into Epi-data 3.1 and analysed using SPSS (Version 18.0). Cross-tabulations, frequencies and percentages were run to analyse the data

2.13.4 Glass vs. PET Reactors Analysis

All samples were analysed in duplicate. Since weather conditions could not be controlled, the best set of results obtained on both predominantly sunny and overcast days are reported. The data were statistically analysed using paired sample t-tests (SPSS for windows version 18.0) and graphs were created using Sigmaplot 2000 graphing software.

CHAPTER THREE: RESULTS

3.1 Water Quality of Raw and SODIS Treated Water

Of the 14 primary schools that participated in this study, six used open dug wells, one used a bore-hole, four used shallow wells and three used harvested rain water. However, in schools that had rain harvesting water systems, water was usually reserved for teachers especially during dry spells and pupils had to resort to nearby open dug wells for their water needs during such periods. None of the schools had any water treatment plan for pupils while at school prior to introduction of SODIS. Table 3.2 shows the different schools with corresponding GPS coordinates followed by a brief description of each water source type.

Table 3.1: GPS locations and type of water sources used by schools in the study

School name	Longitude (degrees)	Latitude (degrees)	Water source type
Ndagwe Moslem	31.386441	S 0.536013	Open dug well
Misenyi P.S.	31.459121	S 0.492843	Harvested rain water
Ndeeba Taqua	31.428161	S 0.524783	Bore hole
Living Hope Child Dev't Centre	31.494781	S 0.507233	Shallow well
St. Agatha Makondo P.S.	31.478391	S 0.502133	Shallow well/ rain harvested water
Misaana Baptist P.S	31.489771	S 0.491133	Shallow well
Kijajasi P.S.	31.465578	S 0.512229	Rain harvested water
Mirembe	31.475298	S 0.514321	Shallow well
Kyaterekera P.S.	31.393809	S 0.501468	Rain harvested water
Naanywa P.S.	31.440657	S 0.511301	Open dug well
Bunjako P.S.	31.450425	S 0.537865	Open dug well
Nakatete P.S	31.417387	S 0.482997	Open dug well
Arise and Shine P. S	31.419648	S 0.496382	Open dug well
Kabuyoga P. S	31.392507	S 0.499342	Open dug well
KIing Godfrey P. S	31.418316	S 0.492325	Open dug well

Open Dug well

Shallow (less 2m deep) hand-dug pits (Figure 3.1) almost always located in low-lying areas (valleys) and usually collect water runoff from uphill. They also include unprotected springs. The open dug wells were not only a source of water for the schools and surrounding communities but were also used as watering holes for animals especially cattle and goats (Figure 3.2.)

Figure 3.1: A small boy collecting water from an open dug-well at Ndagwe Primary School

Figure 3.2; Cattle being taken for watering at the open dug well in Figure 3.1 above.

Bore-hole

Small diameter (less than 300mm) machine drilled wells (Figure 3.3) usually 30-100 meters deep. They have 4-8inch PVC screenings/ casings and have a sanitary seal and drainage aprons. Water is pumped using a hand pump.

Figure 3.3: A bore hole at Ndeeba Primary School

Shallow Wells

They are machine drilled wells just like bore-holes (Figure 3.4) but have a shorter depth (10-30m). They are installed with concrete rings or lined with bricks. Water is pumped by use of a hand pump.

Figure 3.4: A shallow well located valley at Mirembe Primary School

Rain Harvested Water

Water harvested from corrugated iron-sheet roofs through guttering into a plastic water tank (Figure 3.5). The tank has a tap through which water is drawn. Concrete walls are often built around the tanks to prevent damage to the plastic tank.

Figure 3.5: Rain harvesting water tank at Kijajasi Primary school

3.1.1 Physicochemical Parameters of Water

A total of 138 raw water samples were analysed for both physical and microbiological quality over a 10 month period. Physical water parameters were compared to the Ugandan standards for potable drinking water (Table 3.2).

Table 3.2: Ugandan standard for physical water parameters

Parameter	Requirement levels
pH	6.5-8.5
Turbidity (NTU)	10 NTU
Total Dissolved Solids (TDS)	1500mg/L

Source:(UNBS 2008)

3.1.1.1 pH

Of all the tested samples, 48(34.8%) were below pH 6.5 while 84(60.9%) were within the Ugandan standard recommendation of pH 6.5-8.5 for drinking water. Only 6 (4.3%) samples had pH above 8.5. Borehole and open dug well water samples had 70% of all samples falling within the 6.5-8.5 pH range compared to 64.7% and 38.2% of samples from rain harvested water and shallow wells respectively (Table 3.3).

Table 3.3: Number of samples from the various water sources that fell in the different pH categories.

pH	Open dug well	Plastic tank	Shallow well	bore-hole	Total
<6.5	13	11	21	3	48
6.5-8.5	42	22	13	7	84
>8.5	5	1	0	0	6
Total	60	34	34	10	138

3.1.1.2 Turbidity

Only 52.2% of all samples met the Ugandan standard for turbidity of ≤10NTU. All the samples from bore holes met the Ugandan standard for turbidity followed by 97.1% of samples from harvested rain water and 67.7% of samples from shallow wells. Only 6(10%) of samples from open dug wells had a turbidity of ≤10NTU.

3.1.1.3 Total Dissolved Solids (TDS)

All the samples were well below the Ugandan maximum recommendation for TDS in drinking water of 1500ppm. On average, water from the bore hole had the highest TDS followed by open dug wells, shallow wells and finally rain harvested water.

3.1.1.4 Temperature

The Ugandan standards are silent on temperature of drinking water. However, the average temperatures of water from the different schools were measured and ranged from 20.7-27.1˚C. Table 3.4 shows the mean physical parameters of water from each of the schools for the duration of this study.

Table 3.4: Mean physical characteristics of raw water from different sources in Ndagwe Sub-county. Figures in parentheses indicate standard deviations.

School	Water source	Turbidity (NTU)	pH	TDS (ppm)	Temp (˚C)
Kabuyoga	ODW	119(116)	7.3(1.4)	73(35)	22(2)
Kyaterekera	RHW	5(N/A)	6.8(0.9)	13(6)	21(1)
Kijjajasi	RHW	15(30)	6.9(0.7)	335(45)	21(1)
St. Agatha	SW	7(2)	6.6(0.7)	165(164)	24(1)
Arise & shine	ODW	97 (68)	6.5(0.6)	287(29)	25(1)
Misenyi	RHW	6(1)	6.7(0.7)	19(9)	23(2)
Mirembe	SW	25(19)	6.1(0.5)	92(37)	24(1)
Bunjako	ODW	106(72)	7.3(0.9)	268(96)	22(2)
King Godfrey	ODW	41(38)	6.9(0.8)	275(39)	23(1)
Ndagwe	ODW	174(304)	7.2(0.9)	332(86)	22(2)
Living Hope	SW	7.(7)	6.5(0.8)	42(11)	24(2)
Misana	ODW	8(8)	6.6(0.5)	77(31)	27 (2)
Ndeeba	BH	5(1.)	6.4(0.4)	388(86)	24(1)
Nakatete	ODW	303(411)	7(0.5)	113(32)	25(2)

ODW=Open dug Well, RHW=Rain harvested water, SW=shallow well, BH=Borehole N/A No standard deviation

3.1.2 Microbial Quality

Of the water samples examined for microbial contamination, 138 were untreated /raw samples while 77 were SODIS treated samples. Results of water quality during the baseline/trial period are given in Appendix H while those for the intervention period (June 2011-April 2012) are given in tables 3.5-3.18. The results show the mean monthly bacterial counts and physical

quality of water samples from each school in the respective clusters. Water source types are indicated in parentheses.

Cluster 1

Table 3.5: Mean monthly microbial and physical water quality measurements for Kabuyoga Primary school (Open dug well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E. faecalis*(T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	115 (5.5)	16(2.1)	20 (2.5)	2 (0.6)	7.3	100	60	20.5
Jul	155(14.7)	5 (1.2)	300	30(1.0)	10.7	300	92	19
Aug	33 (6.1)	0	4	0	6.9	300	33	24
Sep	300	0	215 (7.2)	0	6.3	50	117	21.7
Oct	268(41.9)	1(0.6)	300	0	6.8	47	53	21.7
Nov	300	15(2.7)	300	0	6.1	250	42	20.2
Jan*	300	n/a	300	n/a	8.6	50	127	24
Feb	300	0	232(3.1)	15 (2.0)	6.8	28	62	22
Mar	300	0	223 (10.2)	0	7.1	30	98	22.6
Apr	300	41(1.0)	300	35(2.0)	6.3	35		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.6: Mean monthly microbial and physical water quality measurements for Kyaterekaka Primary School (Harvested rain water)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E. faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	55 (8)	0	195(4.6)	0	7.2	5	8	21.3
Jul	53 (5.8)	0	300	0	8.8	5	12	20.5
Aug	0	0	0	0	7.8	5	11	19.1
Sep	3 (0.6)	0	0	0	5.9	5	11	21.3
Oct	0	0	48 (13.9)	0	6.2	5	21	20.2
Nov	0	0	29 (8.1)	0	6.0	5	6	20.2
Jan*	0	n/a	0	n/a	6.6	5	10	22
Feb	16 (2.5)	0	300	0	6.2	5	22	19.8
Mar	0	0	300	0	6.9	5	25	21
Apr	12(2)	0	300	0	6.4	5		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.7: Mean monthly microbial and physical water quality measurements for St. Agatha Makondo (shallow well June-November 2011, Rain harvested water Feb-Apr 2012)

Month	*E. coli* (R) (CFU/100 mL	*E. coli* (T) (CFU/100 mL	*E. faecalis* (R) (CFU/100 mL	*E.faecalis* (T) (CFU/100 mL	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	175(4.4)	0	0	0	5.7	7	119	21.7
Jul	300	0	0	0	5.9	7	122	24.4
Aug	300	0	3 (1)	0	7.2	7	102	24.5
Sep	300	0	6 (2)	0	7.2	7	102	24.5
Oct*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Nov	300	0	300	0	6.1	5	4	25.1
Jan*	n/a	n/a	n/a	n/a	7.9	5	30	25.5
Feb	0	0	0	0	6.6	10	456	23.3
Mar	0	0	0	0	6.6	10	383	25.2
Apr	65 (4.2)	0	0	0	6.5	5		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Oct/Jan* well broken down, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.8: Mean monthly microbial and physical water quality measurements for Kijajjasi Primary school (Harvested rain water)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E.faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	0	0	300	0	8	5	7	20.6
Jul	0	0	300	0	7.9	5	13	19.4
Aug	9(1)	0	21 (2.3)	0	6.9	5	19	19.4
Sept	13 (3.1)	0	67 (7.6)	0	6.6	5	14	20.7
Oct	25 (1.2)	0	300	17 (3.1)	6.9	5	11	22.8
Nov	166(2)	0	300	0	6	5	8	20.3
Jan*	33 (12.2)	n/a	279 (15.1)	n/a	6.8	100	144	20.4
Feb	25 (1.5)	0	13 (1.2)	0	6.5	5	61	21
Mar	49 (3.1)	0	300	0	6.9	7	36	21.7
Apr	300	0	300	0	6	5		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Cluster 2

Table 3.9: Mean monthly microbial and physical water quality measurements for Arise and Shine Primary School (Open dug well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E.faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	300	No SODIS	295 (1)	No SODIS	6.1	100	270	24.5
Jul	300	No SODIS	300	No SODIS	7.6	200	270	25.4
Aug	300	No SODIS	40 (10)	No SODIS	6.4	205	254	24.4
Sept	300	16 (2.5)	162(28.4)	2 (0.6)	5.8	100	267	25.1
Oct	300	5(1.7)	300	2 (1.2)	6.7	105	262	24.2
Nov	300	86 (2)	300	23 (3.8)	6	60	289	26.1
Jan*	196 (12.1)	n/a	147 (16.5)	n/a	6	130	318	23
Feb	300	11(2.7)	300	26 (4.5)	6.7	20	328	23.5
Mar	300	29(2.1)	300	11 (0.6)	6.9	30	324	24.7
Apr	300	52(0.6)	300	0	5.8	15		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.10 : Mean monthly microbial and physical water quality measurements for Bunjako Primary School (Open dug well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E.faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	145 (8.2)	No SODIS	115 (7)	No SODIS	7.4	95	180	22.3
Jul	175(21.8)	No SODIS	95 (13.2)	No SODIS	9.7	100	176	20.3
Aug	110 (15)	No SODIS	143 (5.8)	No SODIS	7.6	155	259	20.3
Sep	300	54 (2.3)	300	15(2.5)	6.7	80	259	23.8
Oct	300	15(5.0)	300	3 (0.5)	6.7	85	129	22.8
Nov	300	0	300	0	6.6	5	285	24
Jan*	29 (7.2)	n/a	32 (11.5)	n/a	6.8	76	370	19.3
Feb	300	2 (1.5)	300	14 (2.1)	7.3	30	423	20.3
Mar	300	19 (2.5)	300	0	7.2	180	329	25
Apr	300	23(1.5)	300	8(1)	6.7	250		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.11: Mean monthly microbial and physical water quality measurements for Mirembe Day and Boarding Primary School (Shallow well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL	*E. faecalis* (R) (CFU/100 mL	*E. faecalis* (T) (CFU/100 mL	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	177 (7.6)	No SODIS	4 (0)	No SODIS	6.9	30	113	23.3
Jul	20 (1.5)	No SODIS	3 (0)	No SODIS	7.1	20	111	22.4
Aug	65(5.0)	No SODIS	23 (3.1)	No SODIS	6	15	88	24.4
Sep	68 (7.2)	15(2.0)	0	0	5.4	15	88	22.3
Oct	46(5.0)	16(3.0)	0	0	6.1	25	144	26.6
Nov	300	47(4.2)	5 (1.2)	0	6	25	134	24.3
Jan*	300	n/a	11(8.5)	n/a	5.7	15	48	23.5
Feb	12 (1.2)	0	0	0	6.2	10	44	22
Mar	300	7 (2)	0	0	6.2	20	54	25
Apr	300	30 (8)	7 (2.1)	0	5.8	75		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.12: Mean monthly microbial and physical water quality measurements for Misenyi Primary School (Harvested rain water)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E. faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	130 (5.3)	No SODIS	137(2.7)	No SODIS	6.5	5	13	19.6
Jul	13(5.8)	No SODIS	17(1.2)	No SODIS	6	5	20	23.8
Aug	17(3.1)	No SODIS	87(9.5)	No SODIS	6.92	5	25	23.8
Sep	237 (26.0)	0	83 (16.7)	0	5.9	5	25	23.1
Oct	7 (2.3)	0	300	0	6.5	5	11	21.8
Nov	6 (1.2)	0	51 (7.6)	0	6.4	5	5	21.8
Jan*	0	n/a	0	n/a	7.2	5	20	21.9
Feb	6 (1.5)	0	300	0	6.5	8	34	21
Mar	43 (1.7)	0	300	0	7.4	5	20	24
Apr	0	0	68 (8)	0	5	6.7		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Cluster 3

Table 3.13: Mean monthly microbial and physical water quality measurements for King Godfrey (Open dug well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E.faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	130(4.4)	No SODIS	300	No SODIS	6.6	80	358	21.9
Jul	42(12.6)	No SODIS	300	No SODIS	8.8	90	280	22.1
Aug	300	No SODIS	300	No SODIS	7.2	55	267	22
Sep	58(12.6)	No SODIS	240 (36.1)	No SODIS	6.6	7	291	23.2
Oct	300	No SODIS	300	No SODIS	6.4	7	286	22.3
Nov	300	No SODIS	300	No SODIS	6.5	20	247	23.7
Jan*	60 (4.4)	No SODIS	131(11.5)	No SODIS	6.8	100	240	24.2
Feb	300	44 (2)	300	26 (2.1)	6.7	30	255	23
Mar	300	43 (3.5)	300	13 (4.2)	7.2	30	246	24
Apr	300	55(3.1)	300	52 (1.2)	6.3	7		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.14: Mean monthly microbial and physical water quality measurements for Living Hope (Shallow well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E.faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	97 (5.6)	No SODIS	154(3.6)	No SODIS	6	5	44	23.7
Jul	300	No SODIS	12 (7.2)	No SODIS	6.8	5	36	22.4
Aug	36 (4)	No SODIS	7(1.2)	No SODIS	8.2	5	66	21.4
Sep	124 (8)	No SODIS	47(7.6)	No SODIS	6.6	5	34	25.9
Oct	121 (2.3)	No SODIS	12 (3.5)	No SODIS	6.7	5	29	26.7
Nov	79 (14.1)	No SODIS	53 (8.1)	No SODIS	5.7	25	52	24.3
Jan*	20 (4)	No SODIS	4 (2)	No SODIS	5.4	5	38	23.8
Feb	27(2.1)	0	6 (0.6)	0	6.7	5	38	23.9
Mar	26 (1.2)	0	0	0	6.2	5	44	25.4
Apr*								

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, Apr*Well broken down, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.15: Mean monthly microbial and physical water quality measurements for Misana Primary school (Shallow well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E. faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	80 (1.2)	No SODIS	74 (1.7)	No SODIS	6.4	30	103	25.5
Jul	4 (2)	No SODIS	5 (3.1)	No SODIS	5.9	5	79	27.2
Aug	11(3.1)	No SODIS	0	No SODIS	7.6	5	103	27.2
Sep	9(2.3)	No SODIS	1(0.6)	No SODIS	6.8	5	78	25.8
Oct	13(2.3)	No SODIS	57 (8.1)	No SODIS	6.4	5	77	29.2
Nov	17(5.0)	No SODIS	131 (8.0)	No SODIS	6.3	5	5	26
Jan*	7 (3.1)	No SODIS	7 (3.1)	No SODIS	5.5	5	90	24.5
Feb	1 (1)	0	30 (1.5)	0	6.9	5	87	24.4
Mar	10 (1.5)	0	21 (2.1)	0	7.2	5	84	28.9
Apr	300	0	4 (1.5)	0	6.1	5		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.16: Mean monthly microbial and physical water quality measurements for Nakatete Primary School (Open dug well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E. faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	120 (4.4)	No SODIS	175(0.6)	No SODIS	6.9	95	114	21.4
Jul	300	No SODIS	300	No SODIS	7.8	1000	162	24.2
Aug	300	No SODIS	300	No SODIS	7.3	50	70	21
Sep	220 (10)	No SODIS	300	No SODIS	7.1	37	111	26.1
Oct	300	No SODIS	300	No SODIS	6.9	40	94	24.3
Nov	300	No SODIS	300	No SODIS	5.9	1000	50	26.4
Jan*	24 (2.3)	No SODIS	60 (5.6)	No SODIS	7.2	60	114	25.5
Feb	300	26 (2.1)	300	14 (3.5)	7.1	22	137	22
Mar	300	30(2.1)	300	20 (0.6)	6.9	75	118	24.7
Apr	300	53(2.5)	300	31(1.5)	7.1	400		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.17: Mean monthly microbial and physical water quality measurements for Ndagwe Primary School (Open dug well)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E. faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	65	No SODIS	300	No SODIS	6.9	65	307	24.1
Jul	300	No SODIS	300	No SODIS	9.4	750	351	19.19
Aug	33(5.8)	No SODIS	60(10)	No SODIS	7.2	750	376	20.9
Sept	160(14)	No SODIS	76(4.0)	No SODIS	7.5	40	453	21.5
Oct	207(8.1)	No SODIS	300	No SODIS	7.1	45	414	21.5
Nov	207(15)	No SODIS	300	No SODIS	6.6	35	240	23.7
Jan*	22 (3.1)	No SODIS	247(6.5)	No SODIS	6.6	15	320	22.5
Feb	300	6(1)	45(1.2)	3(0)	7.0	20	195	20.7
Mar	250(10)	20(3.5)	26(2.5)	0	7.2	7	182	22
Apr	300	10 (1.7)	300	0	6.2	10		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

Table 3.18: Mean monthly microbial and physical water quality measurements for Ndeeba Takuwa (Bore-hole)

Month	*E. coli* (R) (CFU/100 mL)	*E. coli* (T) (CFU/100 mL)	*E. faecalis* (R) (CFU/100 mL)	*E. faecalis* (T) (CFU/100 mL)	pH	Turbidity (NTU)	TDS (ppm)	Temp (°C)
Jun	25 (6.1)	No SODIS	0	No SODIS	6.5	5	420	23.2
Jul	7 (3.1)	No SODIS	0	No SODIS	7.3	5	432	23.5
Aug	0	No SODIS	0	No SODIS	6.5	5	415	23.5
Sept	0	No SODIS	0	No SODIS	6.6	5	417	23.1
Oct	13 (1.2)	No SODIS	5 (1.2)	No SODIS	6.4	5	430	25.3
Nov	59 (4.6)	No SODIS	155(11.4)	No SODIS	6.3	8	433	23.9
Jan*	0	No SODIS	4 (2.3)	No SODIS	6.7	5	421	25.6
Feb	1(0.6)	0	3(1.5)	0	6.9	5	374	21
Mar	0	0	0	0	7.3	5	367	23.3
Apr	0	0	0	0	6.3	5		

(R)= Raw water, (T) =Treated water, TDS = total dissolved solids, Jan(n/a) No SODIS treatment, where applicable, standard deviations in parentheses, 300=≥300 CFU/100 mL, 0=Not detected*

3.1.2.1 Raw Water Quality

Of the 138 raw water samples anlysed for microbial quality, 10 were from borehole, 34 from rain harvested water, 34 from shallow wells and 60 from open-dug wells. With regard to *E. coli,* water from the bore holes had the least microbial contamination followed by rainwater, shallow

wells and open dug wells had the most contaminated water. For *E. faecalis,* bore hole water still had the least contamination, followed by shallow wells, rain harvested water and open dug wells.

A few samples of raw water from borehole, shallow wells and rain water tanks met the WHO/Ugandan standard (0CFU/100 mL) for drinking water while all water from open dug wells did not meet these standard for both indicator bacteria (Table 3.19).

Table 3.19: Number of raw water samples from each source that met the Ugandan microbial standard for drinking water (0CFU/100 mL).

Water source Type	Number of analysed Samples	*E. coli*	*E. feacalis*
Bore hole	10	5 (50%)	6 (60%)
Rain Harvested water	34	10 (30%)	5 (15%)
Shallow well	34	3 (9%)	11 (32%)
Open dug well	60	0 (0%)	0 (0%)

Figures in parentheses represent percentages.

Microbial quality of the water was also compared to the less stringent WHO public health risk categories (WHO, 2003b). These risk classifications are recommended in assessing microbial quality of drinking water in the developing world where it is usually hard to meet the strict standards of 0CFU/ mL. The conformity value (0CFU/100 mL) was combined with the low-risk catergory of 1-10 CFU/100 mL to give one category i.e. the conformity/low risk category (0-10CFU/100 mL). The three different WHO categories used for comparison were: conformity/low risk category (0-10CFU/100 mL), intermediate risk category (11-100CFU/100 mL) and the high risk category (101-1000CFU/100 mL).

Most of the raw water samples (70 and 69) fell within the high-risk public health category of 101-1000 CFU/100 mL for both *E. coli* and *E. faecalis* (Figure 3.6 a and b) respectively. Of the 70 samples in the high risk category for *E. coli,* 51 (73%) were from open dug wells, 15 (21%)

were from shallow wells and 4 (6%) were from rain harvested water. Seven (70%) and 3(30%) of samples from the bore hole fell within the conformity/low risk and intermediate risk categories respectively. Almost a similar trend was noted for *E. feacalis* contamination with 50 (73%) of high risk categoty samples coming from open dug wells. However, 16 (23%) of samples from rain harvested water fell in the high risk category for *E. faeacalis* compared to 3(4%) of samples from shallow wells. Again none of samples from bore holes fell within the high risk category. In fact all samples from boreholes were within the conformity/low risk category for *E. faecalis* (Table 3.20). Overall, open dug well water had signficantly higher microbial contamination χ^2=74.65, p< 0.001 and, χ^2=81.14, p<0.001 compared to other water sources for both *E. coli* and *E. faecalis* respectively.

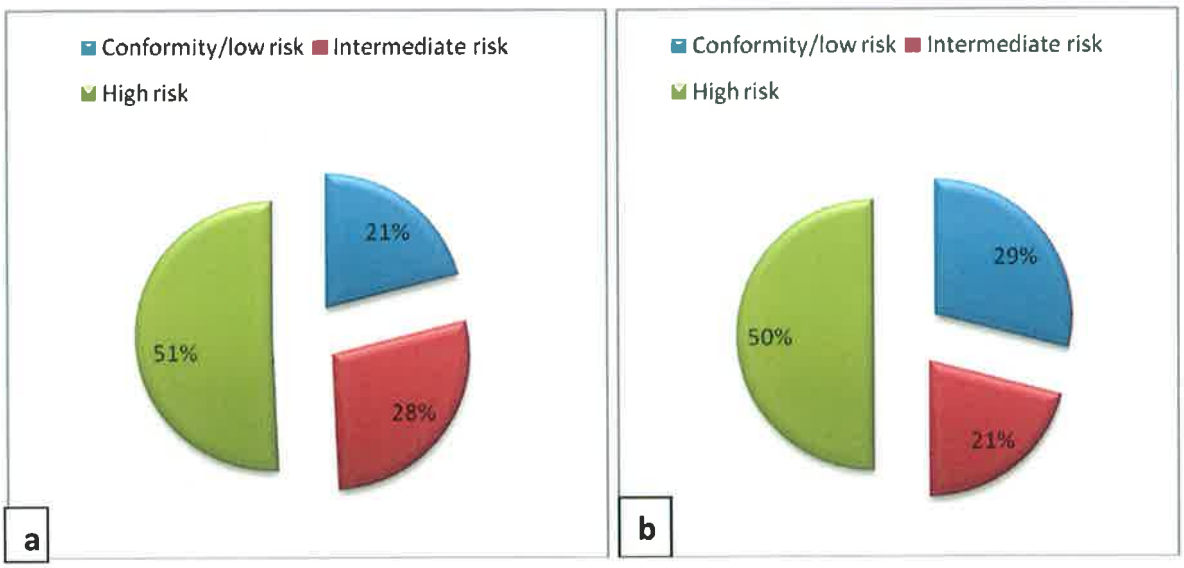


Figure 3.6: Percentage of raw water samples falling in the different WHO public health risk categories for drinking water. (a) *E. coli*, (b) *E. faecalis*

Table 3.20: Number of raw water samples from each source that fell in the different WHO public health drinking water risk categories for both *E. coli* and *E. faecalis*

E. coli	Open dug well	Shallow Well	Harvested rain water	Bore hole
Conformity/Low risk (0-10CFU/100 mL)	0	5	17	7
Intermediate risk (11-100CFU/100 mL)	9	14	13	3
High risk 101-1000CFU/100 mL)	51	15	4	0
Total number of samples	**60**	**34**	**34**	**10**
E. feacalis				
Conformity/Low risk (0-10CFU/100 mL)	1	21	8	10
Intermediate risk (11-100CFU/100 mL)	9	10	10	0
High risk 101-1000CFU/100 mL)	50	3	16	0
Total number of samples	**60**	**34**	**34**	**10**

3.1.2.2 Effect of SODIS Treatement on Microbial Water Quality

Seventy seven (77) samples were treated using SODIS. Of these 30 were from open dug wells, 27 fron harvested rain water, 17 from shallow wells and 3 from bore-holes. After SODIS treatement, 54 (70.1%) and 62 (80.5%) of all treated samples fell within the conformity/low risk category for *E. coli* and *E. feacalis* respectively. The rest of the samples fell within the intermediate risk category. None of the treated samples fell within the high risk category. All treated samples from the bore hole met the Ugandan/WHO standards for drinking water for both *E. coli* and E. *faecalis.* In comparison, 27 (100%) and 26(96.3%) of rain water samples met the drinking water standards for *E. coli* and *E. feacalis* respectively. Thirteen (76.5%) and 17 (100%) of samples from shallow wells met the Ugandan standards standards for both *E. coli* and *E. feacalis* respectively. Only 5 (16.7%) and 10 (33.3%) of samples from open dug wells met the Ugandan standard for drinking water after treatment (Table 3.21). Overall SODIS treatement was most effective in rain harvested water $\chi^2=29.14$, $p< 0.001$ and, $\chi^2=23.25$, $p<0.001$ compared to shallow well and open dug well water sources for both *E. coli* and *E. faecalis* respectively. The

three treated samples from the bore hole were not included in statistical analysis as they all had undetectable bacterial counts and were considered to have a neglible effect on analysis outcome. Table 3.22 shows the overall effect of SODIS treatment on quality of water throughout the entire period of intervention.

Table 3.21: Number of of SODIS treated water samples that met the Ugandan standard for drinking water (0CFU/100 mL) for *E. coli* and *E. faecalis*

Water source Type	Number of analysed Samples	*E. coli* (0CFU/100 mL)	*E. feacalis* (0CFU/100 mL)
Bore hole	3	3(100%)	3(100%)
Rain Harvested water	27	27 (100%)	26 (96.3)
Shallow well	17	12 (70.6%)	17 (100%)
Open dug well	30	5 (16.7%)	10 (33.3)

Numbers in parentheses are percentages

Table 3.22: Efficacy of SODIS treatment on mean bacterial contamination (CFU/100 mL) of water samples from the different sources

Water source	Raw water			SODIS treated water		
	No. of samples	*E. coli* (SD)	*E. faecalis* (SD)	No. of samples	*E. coli* (SD)	*E. faecalis* (SD)
ODW	60	227.2(104.3)	233.5(101.6)	30	26.9(32.8)	12.1(13.5)
SW	34	112.3(120.4)	24.9(55.9)	17	7.8(16.8)	0.1(0.2)
BH	10	5.4(8.345)	1.6(2.2)	3	0.0(n/a)	0.0(n/a)
HRW	34	115.0(71.5)	166.5(131.7)	27	0.0(n/a)	1.0(4.7)

ODW=Open dug Well, RHW=Rain harvested water, SW=shallow well, BH=Borehole, SD= standard deviation, n/a= No standard deviation

3.1.2 Interval Regression Analysis Results

In comparison to categorical data analysis for microbial quality of water, the interval regression model analysis also showed that SODIS had a significant effect on *E. coli* levels, with a reduction of 2.6 $\log_{10}$ units ($P<0.001$), and a similar effect on *E. faecalis*, with a reduction of 3.47 $\log_{10}$ units ($P<0.001$) for all water samples. (Table 3.23).

Table 3.23: Regression model for effect of SODIS treatment on microbial water quality.

Test bacteria	Treatment	log_{10} CFU/100ml	95% CI	Sig
E. coli	Control	2.14	1.30 to 2.99	<0.001
	SODIS	-0.49	-1.62 to 0.64	
	Difference	-2.63	-3.33 to -1.93	
E. faecalis	Control	2.16	1.24 to 3.08	<0.001
	SODIS	-1.31	-2.71 to 0.10	
	Difference	-3.47	-4.48 to -2.46	

3.1.2.1 Effect of Water Source Type on SODIS Efficacy

For *E. coli* SODIS treatment was most effective in rain harvested water with a 6.13 log unit reduction in treated samples compared to raw ones (P=<0.001). The effect of SODIS treatment between open dug well and bore-hole samples was not significantly different (P=0.986). In both water sources, SODIS treatment reduced *E. coli* contamination by 2.6 log units. In the case of *E. faecalis,* the effect of SODIS treatment was greater in both shallow well and harvested rain water than it was in open dug wells. SODIS treatement significantly reduced *E.faecalis* by 7.22 and 4.34 log_{10} units (P<0.001 and P=0.006) in shallow well and harvested rain water respectively. In comparison SODIS treament in open dug wells only achieved a 2.88 log unit reduction for *E. faecalis.*

3.1.2.2 Turbidity and SODIS Efficacy

Efficacy of SODIS was significantly affected by turbidity of the water. Samples that had turbidity of ≤30 NTU were more likely to be compeletely disinfected than those with a higher turbidity (χ^2=15.05, p<0.001 and χ^2 =21.79, p<0.001) for *E. faecalis* and *E. coli* respectively.

3.1.3 Seasonal Variations and Water Quality

Monthly rainfall data for Makondo was obtained from another Water is Life research student (Kagwisagye, 2012) and compared to the median microbial quality. Because of samples which were either undetectable bacterial growth or too numerous to count growths, the monthly log median of bacterial contamination per month instead of mean contamination was used to assess this relationship. Use of means would have exerted a significant influence on the values obtained (Howard *et al.*, 2003).

There was a weak positive Pearson's product moment correlation between bacterial quality and rainfall. However for both *E. coli* and *E. feacalis*, this was not significant r=0.516, p=0.127 and r=0.434, *p*=0.210 for *E. coli* and *E. feacalis* respectively.

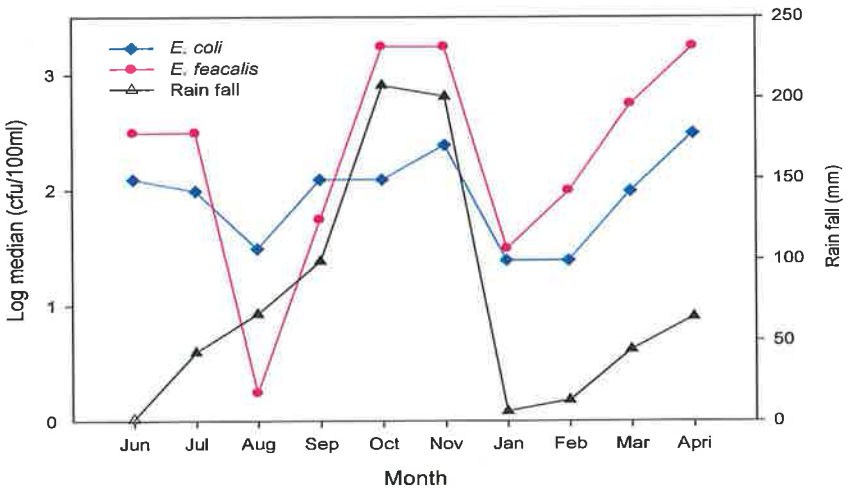


Figure 3.7: Relationship between rainfall and log median *E. coli* and *E. feacalis* water contamiation.

3.2 SODIS and Pupil School Attendance Patterns

Attendance data of pupils from Ndeeba and Nakatete primary schools was lost during the course of the study due to transfer of the collaborating teachers who moved with record books and could not be traced. Of the 600 pupils remaining, 24 had dropped out of school by the end of the study leaving 576 pupils.

Monthly cases and causes of pupil absenteeism recorded for each school term over the study period (February 2011-April 2012) are shown in Tables 3.25-3.36. Microbial contamination of both raw and treated water for the same time period are also included. The shaded rows indicate the rainy periods.

Cluster 1

Table 3.24: Monthly cases and causes of absenteeism recorded for Kabuyoga Primary School (Open dug well)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	56	11	4	10	n/a	n/a	n/a	n/a
	Mar	62	10	3	5	n/a	n/a	n/a	n/a
	Apr	76	14	4	5	300	No trt	300	No trt
2	Jun	32	4	6	5	115	16	20	2
	Jul	29	2	4	8	155	5	300	30
	Aug	28	2	2	3	33	0	4	0
3	Sep	5	5	1	3	300	0	215	0
	Oct	11	0	3	5	268	1	300	0
	Nov	10	4	0	6	300	15	300	0
4	Feb	1	4	1	5	300	0	232	15
	Mar	4	2	0	2	300	0	223	0
	Apr	6	6	0	4	300	41	300	35

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S=lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.25: Monthly cases and causes of absenteeism recorded for Kyaterekeka Primary School (Harvested Rain water)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	92	27	31	17	n/a	n/a	n/a	n/a
	Mar	93	27	9	13	n/a	n/a	n/a	n/a
	Apr	83	21	4	17	2	No trt	149	No trt
2	Jun	3	12	20	14	55	0	195	0
	Jul	4	13	1	15	53	0	300	0
	Aug	5	11	0	16	0	0	0	0
3	Sep	1	7	18	10	3	0	0	0
	Oct	3	9	2	9	0	0	48	0
	Nov	3	5	0	13	0	0	29	0
4	Feb	0	5	13	10	16	0	300	0
	Mar	1	10	1	8	0	0	300	0
	Apr	0	8	0	14	12	0	300	0

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.26 : Monthly cases and causes of absenteeism recorded for Kijajasi primary school (rain harvested water)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	12	39	56	31	n/a	n/a	n/a	n/a
	Mar	17	50	10	25	n/a	n/a	n/a	n/a
	Apr	10	38	3	34	84	No trt	300	No trt
2	Jun	19	40	45	35	0	0	300	0
	Jul	15	38	10	51	0	0	300	0
	Aug	10	18	1	34	9	0	21	0
3	Sep	5	27	24	37	13	0	67	0
	Oct	7	20	8	12	25	0	300	17
	Nov	5	22	4	8	1	0	300	0
4	Feb	1	10	23	16	25	0	12	0
	Mar	0	9	7	19	49	0	300	0
	Apr	0	2	0	12	300	0	300	0

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.27: Monthly cases and causes of absenteeism recorded for St. Agatha, Makondo (shallow well/rain harvested water)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	16	34	42	21	n/a	n/a	n/a	n/a
	Mar	13	22	16	18	n/a	n/a	n/a	n/a
	Apr	15	28	8	28	300	No trt	18	No trt
2	Jun	4	39	66	16	175	0	0	0
	Jul	1	25	9	21	300	0	0	0
	Aug	1	24	10	24	300	0	3	0
3	Sep	2	15	36	29	300	0	6	0
	Oct	3	12	2	12	n/a	n/a	n/a	n/a
	Nov	1	3	0	9	300	0	300	0
4	Feb	1	2	68	11	0	0	0	0
	Mar	4	2	2	24	0	0	0	0
	Apr	2	0	0	16	65	0	0	0

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S= lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Cluster 2

Table 3.28: Monthly cases and causes of absenteeism recorded for Arise and Shine Primary school (Open dug well)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	24	8	10	15	n/a	n/a	n/a	n/a
	Mar	26	8	5	8	n/a	n/a	n/a	n/a
	Apr	26	9	6	3	300	No trt	300	No trt
2	Jun	18	24	0	1	300	No trt	295	No trt
	Jul	19	16	0	0	300	No trt	300	No trt
	Aug	11	13	0	0	300	No trt	40	No trt
3	Sep	4	8	20	36	300	16	162	2
	Oct	2	16	18	23	300	5	300	2
	Nov	0	9	9	16	300	18	300	23
4	Feb	0	3	6	16	300	11	300	26
	Mar	0	5	4	12	300	29	300	11
	Apr	1	2	2	5	300	52	300	0

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S=lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.29 Monthly cases and causes of absenteeism recorded for for Misenyi Primary School (Harvested rain water)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	35	5	8	11	n/a	n/a	n/a	n/a
	Mar	48	2	1	3	n/a	n/a	n/a	n/a
	Apr	21	2	3	2	18	No trt	144	No trt
2	Jun	21	51	24	16	130	No trt	137	No trt
	Jul	12	48	20	22	13	No trt	17	No trt
	Aug	5	22	4	6	17	No trt	87	No trt
3	Sep	12	21	38	34	237	0	83	0
	Oct	10	18	42	33	7	0	300	0
	Nov	7	13	25	18	6	0	51	0
4	Feb	11	47	16	12	6	0	300	0
	Mar	5	32	23	19	43	0	300	0
	Apr	7	11	9	9	0	0	68	0

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S=lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.30: Monthly cases and causes of absenteeism recorded for Mirembe Primary school (Shallow well)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	41	10	6	2	n/a	n/a	n/a	n/a
	Mar	32	6	1	2	n/a	n/a	n/a	n/a
	Apr	27	7	0	3	300	No trt	97	No trt
2	Jun	12	10	16	22	117	No trt	4	No trt
	Jul	24	10	4	7	20	No trt	3	No trt
	Aug	5	3	1	3	65	No trt	23	No trt
3	Sep	9	8	29	18	68	15	0	0
	Oct	7	10	5	15	46	16	0	0
	Nov	5	8	4	12	300	47	5	0
4	Feb	4	12	12	22	12	0	0	0
	Mar	5	18	6	10	300	7	0	0
	Apr	2	10	2	3	300	30	7	0

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S=lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.31: Monthly cases and causes of absenteeism recorded for Bunjako Primary school (Open dug well)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	20	15	5	8	n/a	n/a	n/a	n/a
	Mar	28	6	1	7	n/a	n/a	n/a	n/a
	Apr	12	0	0	2	300	No trt	300	No trt
2	Jun	18	41	32	27	145	No trt	115	No trt
	Jul	13	30	20	23	175	No trt	95	No trt
	Aug	strike	strik e	Stri ke	Strik e	110	No trt	143	No trt
3	Sep	3	24	14	26	300	54	300	15
	Oct	6	8	31	43	300	15	300	3
	Nov	4	14	21	29	300	0	300	0
4	Feb	5	10	8	22	300	2	300	14
	Mar	0	4	3	12	300	19	300	0
	Apr	0	0	0	10	300	23	300	8

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S=lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Cluster 3

Table 3.32: Monthly cases and causes of absenteeism recorded for King Godfrey Primary school (Open dug well)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	22	12	4	12	n/a	n/a	n/a	n/a
	Mar	18	13	13	10	n/a	n/a	n/a	n/a
	Apr	16	10	10	10	300	No trt	300	No trt
2	Jun	26	16	9	7	130	No trt	300	No trt
	Jul	23	7	10	8	42	No trt	300	No trt
	Aug	11	3	12	11	300	No trt	300	No trt
3	Sep	22	3	0	19	58	No trt	240	No trt
	Oct	20	7	0	23	300	No trt	300	No trt
	Nov	15	5	0	14	300	No trt	300	No trt
4	Feb	5	7	3	10	300	44	300	26
	Mar	2	6	8	8	300	43	300	13
	Apr	1	6	0	2	300	55	300	52

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S=lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.33: Monthly cases and causes of absenteeism recorded for for Ndagwe Primary school (Open dug well)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	33	19	16	33	n/a	n/a	n/a	n/a
	Mar	19	16	14	40	n/a	n/a	n/a	n/a
	Apr	23	6	12	31	138	No trt	300	No trt
2	Jun	31	55	44	38	65	No trt	300	No trt
	Jul	28	55	36	48	300	No trt	300	No trt
	Aug	18	40	23	34	33	No trt	60	No trt
3	Sep	69	20	50	63	160	No trt	76	No trt
	Oct	68	4	52	66	207	No trt	300	No trt
	Nov	72	10	38	55	207	No trt	300	No trt
4	Feb	26	25	12	17	300	6	45	3
	Mar	17	34	15	10	250	20	26	0
	Apr	11	20	7	15	300	10	300	0

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S=lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.34: Monthly cases and causes of absenteeism recorded for Misana Primary school (Shallow well)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	16	15	4	8	n/a	n/a	n/a	n/a
	Mar	12	15	18	7	n/a	n/a	n/a	n/a
	Apr	10	12	10	10	20	No trt	80	No trt
2	Jun	19	16	12	12	80	No trt	74	No trt
	Jul	16	7	17	7	4	No trt	5	No trt
	Aug	8	2	15	11	11	No trt	0	No trt
3	Sep	28	9	12	12	9	No trt	1	No trt
	Oct	29	5	21	10	13	No trt	57	No trt
	Nov	21	3	18	11	17	No trt	131	No trt
4	Feb	8	4	11	5	1	0	7	0
	Mar	4	3	13	9	10	0	30	0
	Apr	4	4	10	3	300	0	21	0

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

Table 3.35: Monthly cases and causes of absenteeism recorded for Living Hope Primary School (Shallow well)

						Bacterial contamination (CFU/100 mL)			
Step	Month	D+G	M	S	W	*E.coli* (R)	*E.coli* (T)	*E. faecalis* (R)	*E.faecalis* (T)
1	Feb	12	6	2	5	n/a	n/a	n/a	n/a
	Mar	6	21	1	4	n/a	n/a	n/a	n/a
	Apr	5	4	1	1	168	No trt	178	No trt
2	Jun	10	4	1	3	97	No trt	154	No trt
	Jul	6	5	3	2	300	No trt	12	No trt
	Aug	7	3	4	3	36	No trt	7	No trt
3	Sep	5	0	3	0	124	No trt	47	No trt
	Oct	1	0	3	3	121	No trt	12	No trt
	Nov	4	0	1	2	79	No trt	53	No trt
4	Feb	0	1	1	2	27	0	6	0
	Mar	0	2	0	1	26	0	0	0
	Apr	0	1	0	2	Well broken	n/a	n/a	n/a

D+G=Diarrhoea and gastro-intestinal complaints, M=malaria, S lack of scholastic materials, W=work at home, (R)=Raw water, (T)= treated water, shaded rows indicate rainy periods

3.2.1 Inter-Cluster Absenteeism

Inter-cluster analysis results (Table 3.37) showed that at baseline, the average number of days a pupil was absent from school in a term due to all causes was 4.16±3.38 across all clusters. Although there was a decline in absenteeism across all clusters after step 2 and 3 SODIS treatment phases, this was not statistically significant ($p>0.05$). Significant decline (<0.001) in absenteeism due to all causes was only noted after step 4 when absenteeism fell from a mean of 3.8±4.2 days in the previous step to 1.9±2.5 days. Analysis of specific causes showed a significant decline ($p<0.001$) in absenteeism due to diarrhea for steps 2-4, while significant declines due to gastro-intestinal complaints (GI) was only noted at steps 2 and 4. At step 3, absenteeism due to GI significantly ($p<0.010$) increased from a previous average of 0.44(±0.84) days to an average of 0.63(±1.49) days. A significant decline ($p<0.001$) in absenteeism due to malaria and other/miscellaneous causes was only observed at follow ups 2 and 3 respectively.

Table 3.36: Inter-cluster mean number of days pupils were absent at different study phases before and after SODIS intervention

Treatment phase	Total absence	p-value	D+GI	p-value	D only	p-value	GI only	p-value	Malaria	p-value	Others	p-value
Baseline	4.16(±3.38)	Baseline	1.85 (±2.21)	Baseline	0.76 (±1.26)	Baseline	1.08 (±1.69)	Baseline	0.95 (±1.440	Baseline	1.37 (±1.87)	Baseline
Step 2	3.98(±4.33)	0.394	0.89 (±1.40)	<0.001	0.44 (±0.93)	<0.001	0.44 (±0.84)	<0.001	1.23 (±1.98)	0.005	1.87 (±2.92)	<0.001
Step 3	3.67(±4.21)	0.093	0.40 (±0.76)	<0.001	0.20 (±0.60)	<0.001	0.63 (±1.49)	0.010	0.61 (±1.11)	<0.001	2.23 (±2.77)	0.008
Step 4	1.98(±2.52)	<0.001	0.24 (±0.64)	<0.001	0.13 (±0.51)	<0.001	0.11 (±0.37)	<0.001	0.56 (±1.18)	0.439	1.18 (±1.74)	<0.001

D+GI=Diarrhoea and Gastro-intestinal complaints, D= Diarrhoea, GI= Gastro-intestinal complaints, Figures in parentheses indicate standard deviation

3.2.2 Intra-cluster Absenteeism

3.2.2.1 Cluster1

Cluster 1 had the longest phase of SODIS water treatment (June 2011-April2012). Average absenteeism had significantly dropped from an average of 6.32 (±3.37) days at baseline through to 1.67(±2.17) days in the last treatment phase (Step 4). Absenteeism due to diarrhoea, GI complaints and malaria also significantly reduced ($p<0.05$) from baseline and the subsequent follow-up treatment phases. There was no significant difference ($p=0.310$) in absenteeism due to other causes at baseline and step 2. Significant decline ($p<0.001$) was observed during step 3. Although there was an increase in absenteeism due to other causes in step 4 from a mean of 1.25(±1.6) days to 1.28(±1.97) days, this was not statistically significant ($p=0.815$).

3.2.2.2 Cluster 2

There were only two phases of SODIS water treatment for cluster 2 (September 2011-April 2012). Mean absenteeism due to all causes significantly increased ($p<0.05$) from a baseline of 3.0(±2.4) days to an average of 3.82(±3.70) days in step 2 and 4.46(±3.18) days in step 3. However, absenteeism significantly declined ($p<0.001$) to mean of a 2.59(±2.48) days during the next and last follow-up (Step 4).

Absenteeism due to diarrhea and malaria significantly ($p<0.05$) reduced in step 3. In the next follow-up (step 4) absenteeism due to these causes declined but this was not statistically significant. Absenteeism due to GI complaints significantly reduced ($p<0.05$) at both follow-ups (steps 3and 4) from baseline and step1. Significant decline due to other causes was only observed during step 4 of treatment.

3.2.2.3 Cluster 3

There was only one treatment phase for this cluster (February-April 2012). With the exception of malaria where absenteeism increased after SODIS treatment, there was a significant reduction ($p<0.05$) in absenteeism due to all and specific causes after follow-up. Details of absenteeism due to the different causes for each cluster are given in Table 3.38.

Table 3.37: Mean absenteeism days recorded for each cluster before and after the different SODIS treatment phases

Cluster 1	All absence (±SD)	p-value	D+GI (±SD)	p-value	M only (±SD)	p-value	O only (±SD)	p-value
Step 1 (Baseline)	6.3 (3.4)	n/a	2.7(2.8)	n/a	1.6(1.5)	n/a	2.0(1.8)	n/a
Step 2	4.2(4.7)	<.0.001	0.8(1.2)	<0.001	1.1(1.9)	0.003	2.3(3.8)	0.310
Step 3	2.2 (2.3)	<0.001	0.3(0.6)	<0.001	0.7(1.2)	0.001	1.3(1.6)	<0.001
Step 4	1.7(2.2)	0.006	0.1(0.3)	<0.001	0.3 (0.7)	<0.001	1.3(2.0)	<0.815
Cluster 2								
Step 1 (Baseline)	3.0 (2.4)	n/a	1.9(1.8)	n/a	0.5(0.9)	n/a	0.6(1.4)	n/a
Step 2	3.8(3.7)	0.006	0.9 (1.5)	<0.001	1.5(2.3)	<0.001	1.4(2.0)	<0.001
Step 3	4.5(3.2)	0.024	0.4(0.7)	<0.001	0.9(1.3)	0.001	3.2(2.7)	<0.001
Step 4	2.6(2.5)	<0.001	0.2(0.6)	<0.018	0.9 (1.5)	0.911	1.5(1.7)	<0.001
Cluster 3								
Step 1 (Baseline)	3.1(3.1)	n/a	1.0(1.3)	n/a	0.8(1.5)	n/a	1.4(2.1)	n/a
Step 2	3.9(4.5)	0.005	1.0(1.4)	0.578	1.1(1.8)	0.051	1.9(2.6)	0.006
Step 3	4.5(5.8)	0.074	1.8(2.8)	<0.001	0.3(0.7)	0.001	2.4(3.4)	0.003
Step 4	1.8(2.8)	<0.001	0.4(0.9)	<0.001	0.6(1.2)	0.002	0.8(1.5)	0.001

D+GI= Diarrhoea and gastro-intestinal complaints, M=Malaria, O=other causes of absenteeism, (SD)= Standard deviation

3.2.3 Absenteeism within Individual schools.

Statistical analysis for absence within individual schools was made for total absence due all causes i.e. D, GI, M, W,S O (Table 2.3), diarrhoea and gastro-intestinal complaints (D+GI). Absenteeism due to malaria (M) being one of the frequently mentioned causes of absenteeism was also analysed even though it was not one of the primary disease outcomes in this study.

When average cases of absenteeism recorded in each school during each step/ intervention phase of the trial were computed, there was no particularly consistent pattern that emerged coinciding with the introduction of SODIS treatment as indicated in Figures 3.6-3.14. These show the average number of absenteeism cases and confidence intervals for each school in the three clusters during each step of the trial.

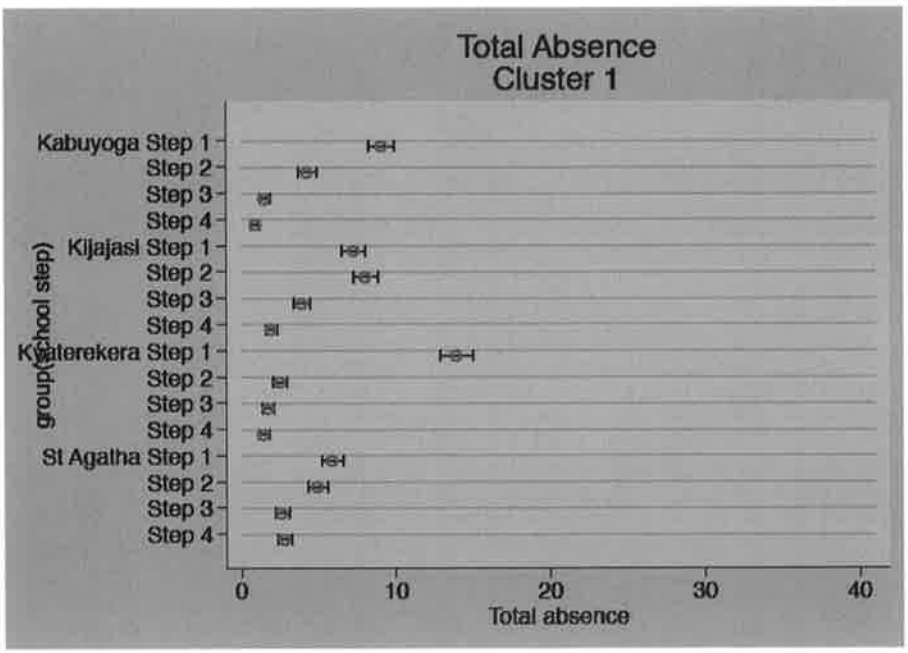


Figure 3.8: Average absenteeism due to all causes in cluster 1

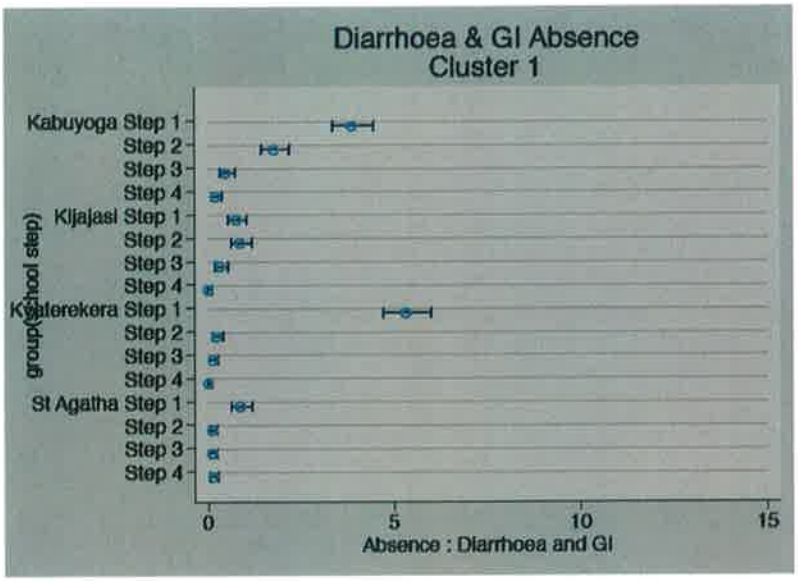


Figure 3.9: Mean absenteeism due to diarrhea and gastro-intestinal complaints in cluster 1

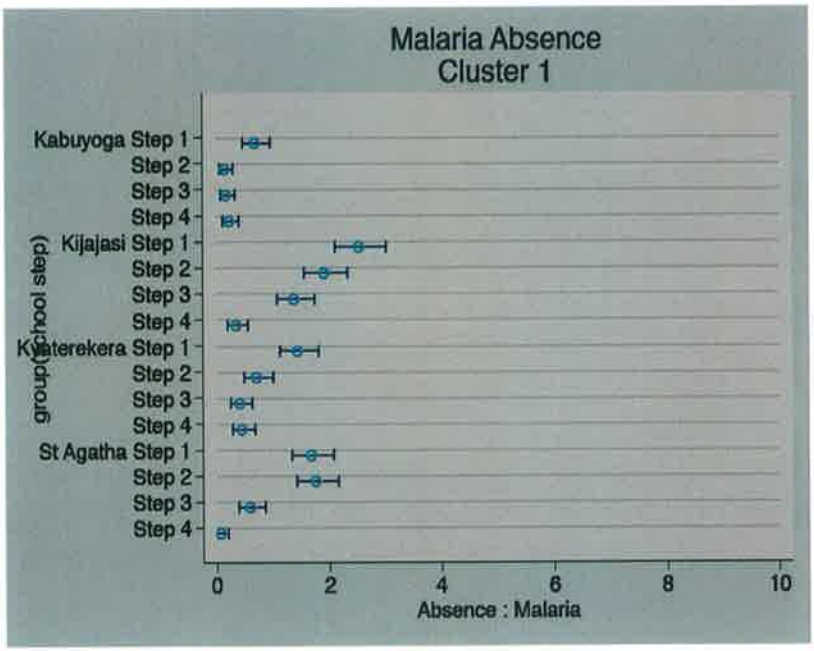


Figure 3.10: Mean absenteeism due to malaria in cluster 1

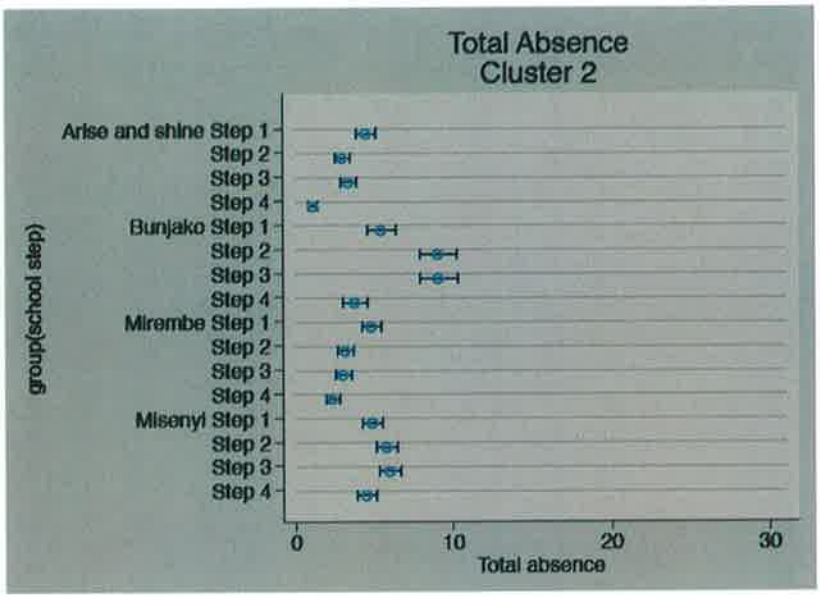


Figure 3.11: Mean absenteeism cases due to all causes in cluster 2

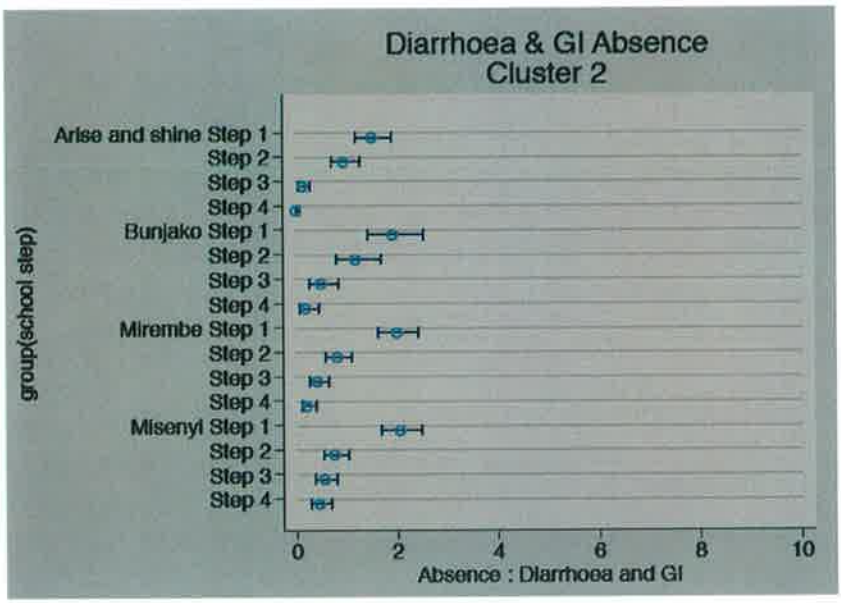


Figure 3.12: Mean absenteeism cases due to diarrhea and gastro-intestinal complaints in cluster 2

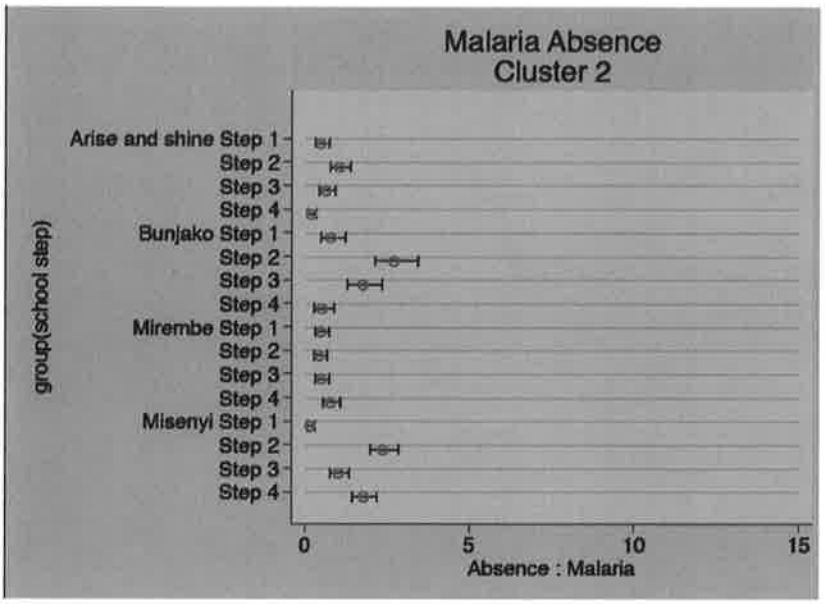


Figure 3.13: Mean absenteeism cases due to malaria in cluster 2

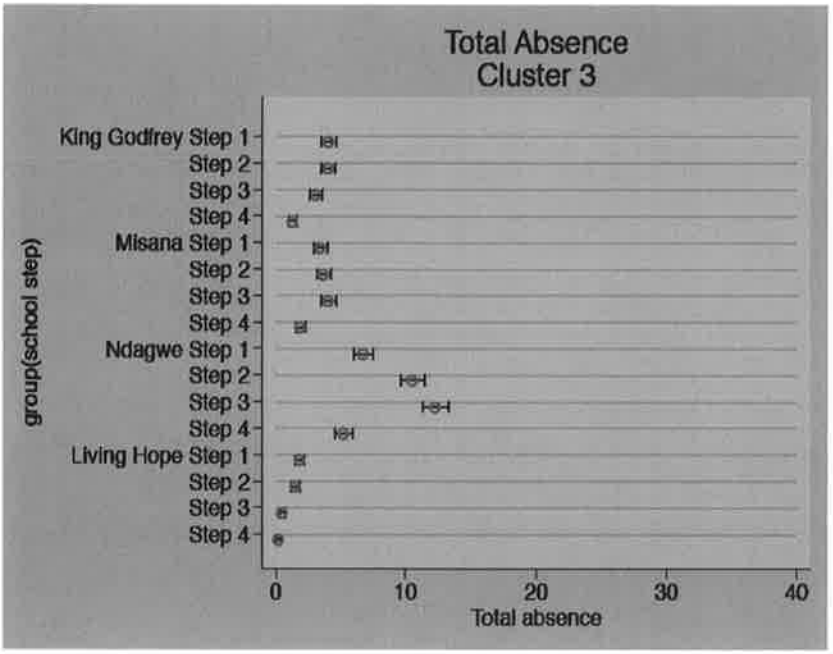


Figure 3.14: Mean absenteeism cases due to all causes in cluster 3

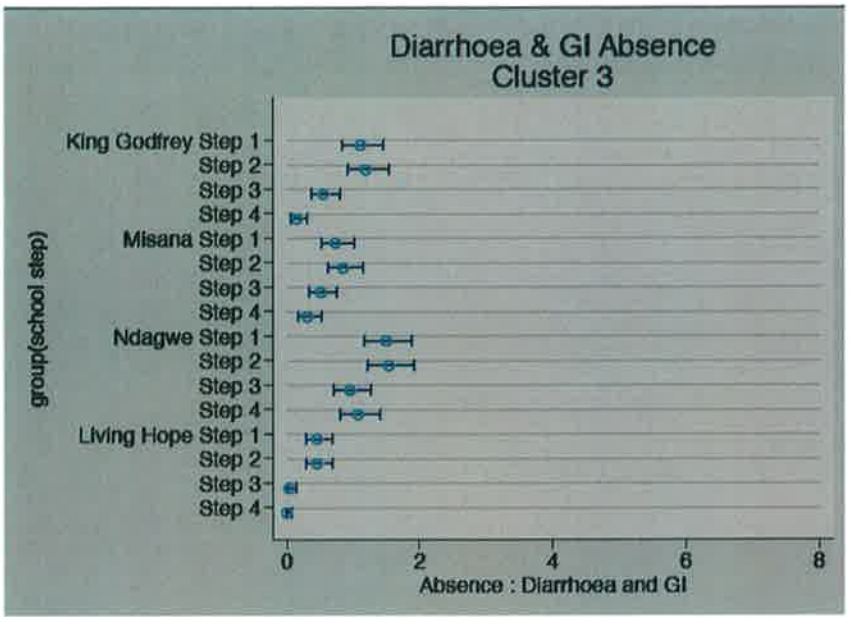


Figure 3.15 Mean absenteeism cases due to diarrhea and gastro-intestinal complaints in cluster3

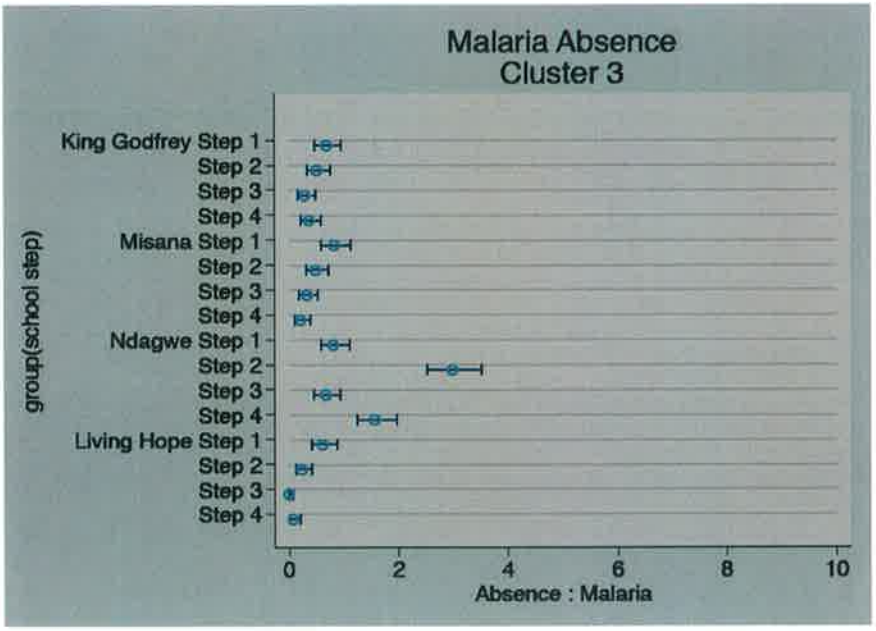


Figure 3.16: Mean absenteeism cases due malaria in cluster 3

3.2.4 Binomial Regression Analysis

Results of the regression model (Table 3.38) showed that overall; absenteeism incidences due to diarrhoea and gastrointestinal complaints were significantly lower in schools with a protected water supply. They also fell significantly (p=0.012) in step 4 when SODIS was being implemented in all schools. However, adjusted for these, SODIS was not associated with a significant reduction in absenteeism (IRR 0.63, p=0.222).

The model was also run for malaria and 'other' causes of absenteeism. The 'other' causes were a combination of lack of scholastic materials and work at home. In neither case was SODIS associated with level of absence (p=0.520 and p 0.832) respectively.

Table 3.38: Generalised Negative Binomial Regression Model for Absence due to Diarrhoea and Gastro-intestinal complaints.

Factor	Incidence rate ratio	95% CI	Sig
Protected water supply	0.51	0.26 to 0.99	0.048
Step	0.51	0.31 to 0.83	0.012
SODIS	0.63	0.29 to 1.39	0.222

3.3: SODIS Follow-up Survey

To assess pupils' effectiveness in the transfer of SODIS knowledge to their homes and communities, 175 (159 female and 16 male) primary care givers of pupils that were participating in the school SODIS trial project were interviewed. The majority of the respondents 96 (54.9%) had female children in the school SODIS project whilst 79 (45.1%) had males. The average age

of pupils whose care givers were interviewed was 8.3±1.7 years with a range of 6-12 years (Table 3.39).

Table 3.39: Age Frequency distribution of pupils whose care-givers were interviewed

Pupil age	Frequency	Percentage
6	35	20.0
7	30	17.1
8	25	14.3
9	25	14.3
10	48	27.4
11	10	5.7
12	2	1.1
Total	**175**	**100.0**

The majority of respondents 74.3% (130), stated use of open dug surface wells as their main source of water for drinking and other domestic purposes.

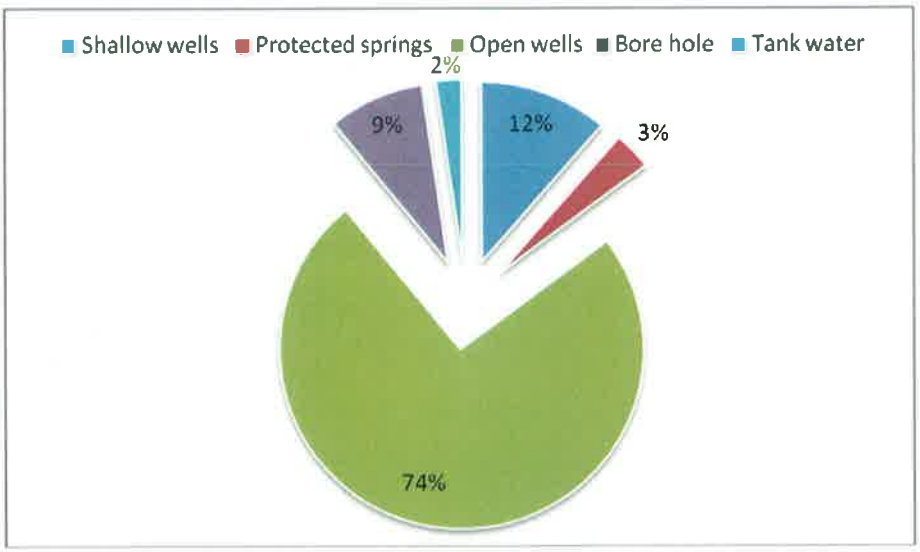


Figure 3.17: Main source of water for drinking and other domestic chores

Over 90% (160) of the respondents reported taking more than 30 minutes for a round trip to the water source and back home. Almost all the respondents (173) fetched water at least more than once a day with the majority (116) fetching water 2-3 times a day. The responsibility of fetching

water lay heavily on children with 84.6% of the respondents stating that children were responsible for water collection only 12.6% stated that mothers collected water and the men who collected water at home were only 2.9 % (Figure 3.18).

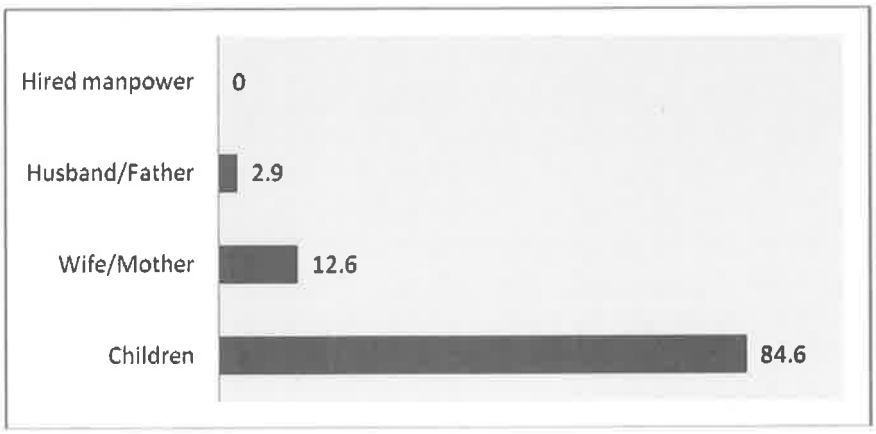


Figure 3.18: Percentage of water collection responsibility in Ndagwe Sub County

Of the 147 respondents that treated their drinking water, majority used an appropriate treatment method (Fewtrell & Colford Jr, 2004; WHO/UNICEF, 2006) with only 5 (3.4%) using cloth filtration for water treatment which is not considered an appropriate method of household water treatment

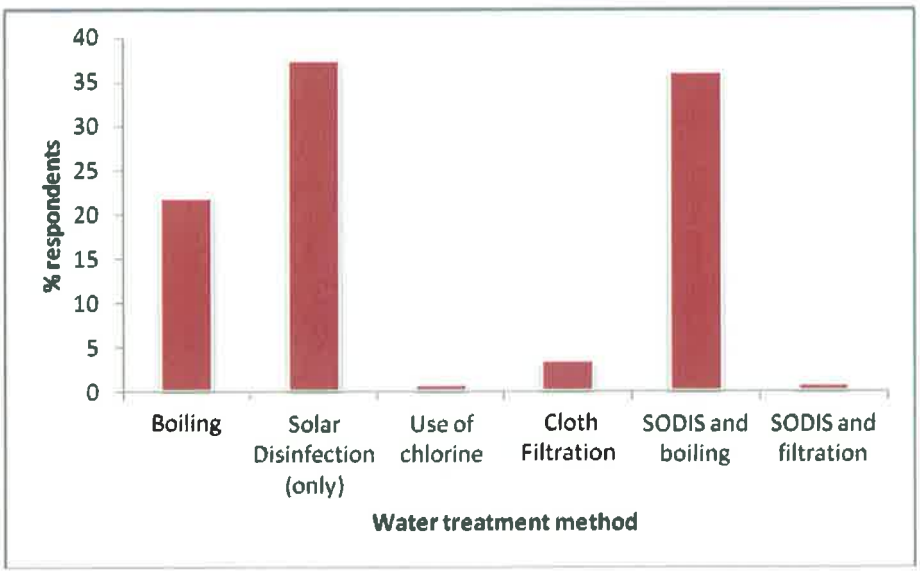


Figure 3.19: Household water treatment technologies in Ndagwe Sub County

Over 94% (165) of all the respondents (165) stated that they heard about SODIS for the first time from their school going children, 2 heard of it from a neighbour, another 1 heard about SODIS for the first time from television (media) 4 heard of it from a community health worker while 3 said they'd never heard about SODIS. When asked about their knowledge of SODIS, 54.3% (95) of the respondents were knowledgeable and could describe the SODIS process very well to the interviewer, 42.3% (74) had scanty knowledge while 5 (2.9%) could not describe the SODIS process although they had heard about it. One respondent did not answer this question. Of those who were knowledgeable, the majority were care-givers to either girl children (56.8%) or children aged 6-7 years (45.2%). Even for those caregivers who had scanty knowledge (SODIS means exposing water in plastic bottles to the sun) about SODIS, 55.4% were care-givers to females compared to 44.6% had male children. However, care givers with children aged 10 years were more likely to have scanty knowledge (37.8%) than care-givers of children of other ages.

When asked about workload of water treatment using SODIS compared to other water treatment means, 114 (65.1%) of the respondents felt that their work load had reduced; 5 (2.9%) felt that the time taken to look for bottle, cleaning them and filling them with water for SODIS treatment increased their work load while the rest (32%) said that there was no difference in workload noticed. The majority of respondents (92%) also stated that they had generally noticed reduction of illnesses episodes at home especially amongst children who were drinking SODIS treated water while 96.6% reported reduced absenteeism for their school going children. Although majority of the respondents had received a primary school level of formal education (Figure 3.20), there was no clear link between education level and SODIS use. It was however observed that the higher the level of education attained, the more inquisitive the respondent was about the efficacy of the SODIS process during the interviews.

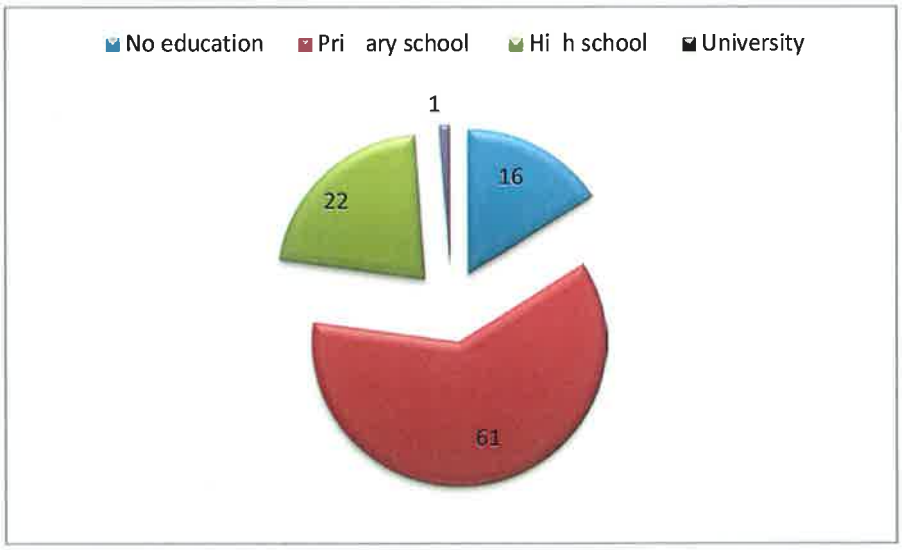


Figure 3.20: Highest level of formal education achieved by the respondents.

Table 3.40: Summary of interview based questionnaire on SODIS dissemination in Ndagwe sub-county

Question	No. of respondents	%respondents
Main Drinking water source		
Shallow wells	20	11.4
Protected springs	6	3.4
Open wells	130	74.3
Bore hole	15	8.6
Tank water	4	2.3
Water for other purposes		
Shallow wells	21	12
Protected springs	5	2.9
Open wells	130	74.3
Borehole	15	8.6
Tank water	4	2.3
Round trip to water source		
<30 minutes	15	8.6
30 Minutes	39	22.3
1 hour	67	38.3
> 1hr	54	30.9
# times water is collected/day		
Once a day	2	1.4
2-3 times	116	66.3
> 3 times	67	32.6
Water collection responsibility		
Children	148	84.6
Wife/Mother	22	12.6
Husband/Father	5	2.9
Hired manpower		
Do you treat water to drink?		
Yes	147	84
No	28	16
Water treatment methods		
Boiling	32	21.8
Solar Disinfection (only)	55	37.4
Use of chlorine	1	0.7
Filtration	5	3.4
SODIS and boiling	53	36.1
SODIS and filtration	1	0.7
No treatment, why?		
No time	5	17.2
Lack of fuel	18	62.1
Lack of treatment knowledge	1	3.4
No need (water is safe)	5	17.2
Ever heard about SODIS		
Yes		
No	172	98.3
	5	1.7
First time you heard about SODIS from:		
My child from school	165	95.9
Community health promoters	4	2.3
Friend/neighbour	2	1.2
Media (radio/television)	1	0.9
Frequency of SODIS use for water treatment		
Yes (always)	52	29.7
Sometimes	66	37.7
No never use it	57	32.6

Question	No of respondents	% respondents
No, why not?		
No time	5	8.8
Cost of bottles too high	36	63.2
Other (specify)	16 (sceptical, did not believe SODIS works)	28.1
Effect of SODIS on sickness episodes at home		
Reduced	160	92
No change noticed	11	6.3
Increased	3	1.7
Effect of SODIS on school attendance patterns		
Reduced absenteeism	168	96.6
No change noticed	4	2.3
Increased absenteeism	2	1.1
No of household members		
1-2	1	0.6
3-5	46	26.3
6-9	79	45.1
> 10	49	28
Highest Education level		
None	28	16
Primary school	107	61.1
High school	38	21.7
University	2	1.1

3.4 Glass Vs PET Field Study

The different inactivation curves of *E. coli* in water under dissimilar weather conditions are shown in Figures 3.21 and 3.22. Only data points at T_0 and T_7 for control samples are plotted since there was no significant difference in bacterial concentrations at all times. Temperature readings in both glass and PET reactors were similar under all weather conditions.

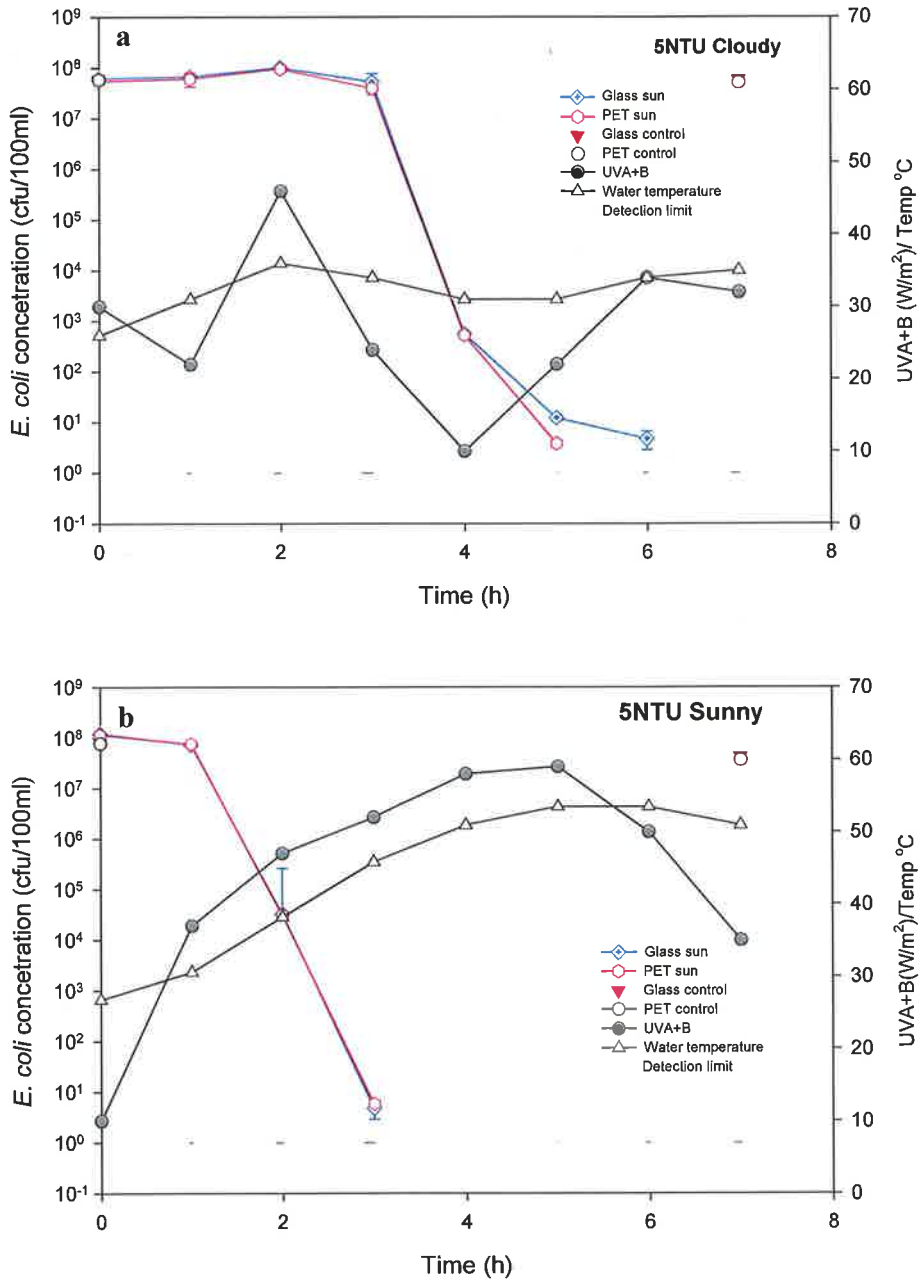


Figure 3.21: Inactivation curves of a wild strain of *E. coli* in glass and PET bottles exposed under varying conditions of turbidity and sunlight: (a) clear (5NTU) water and overcast/cloudy conditions; (b) clear (5NTU) water and natural full strong sunlight conditions.

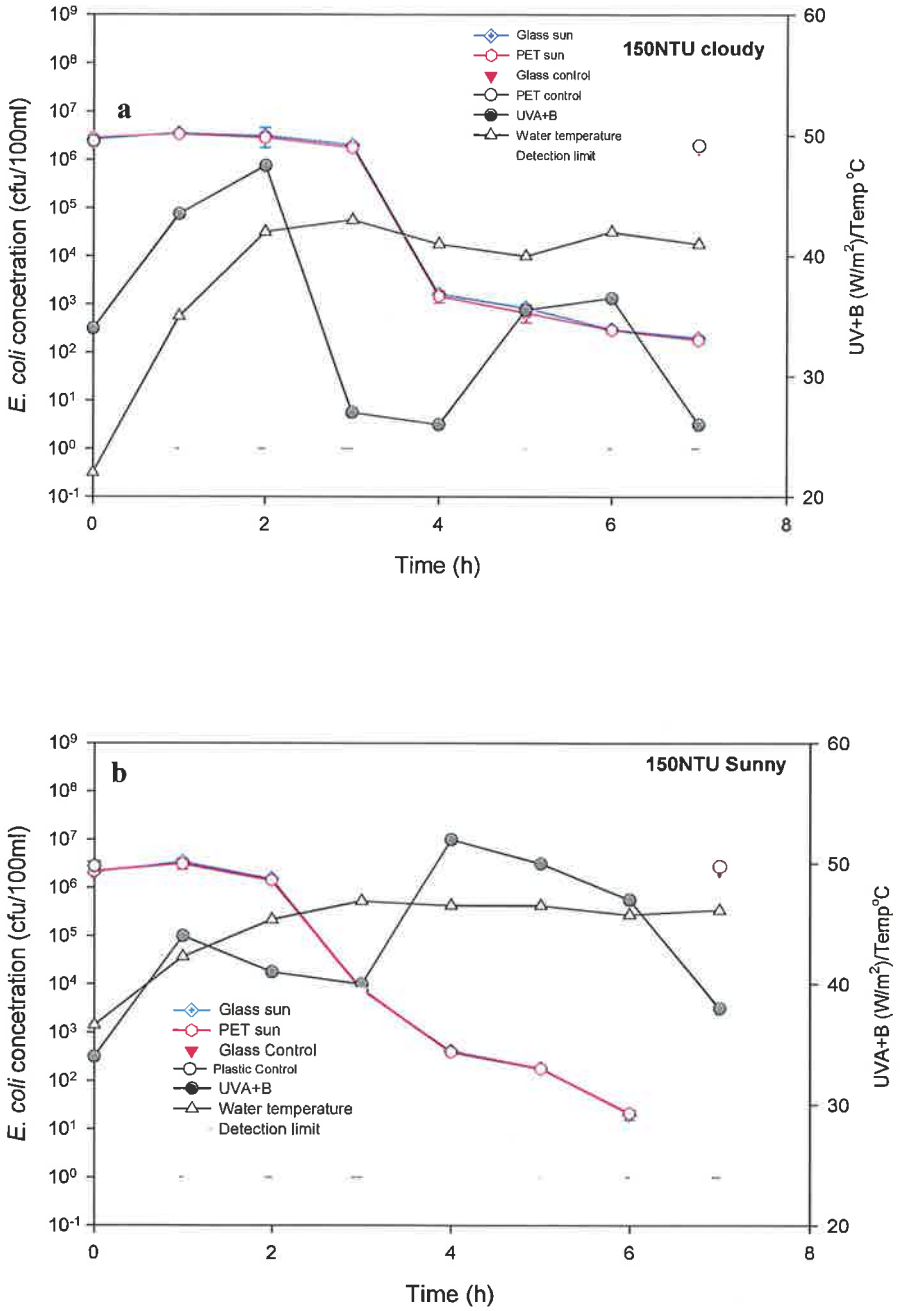


Figure 3.22: Inactivation curves of a wild strain of *E. coli* in glass and PET bottles exposed under varying conditions of turbidity and sunlight: (a) turbid (150NTU) water under natural cloudy/overcast conditions and (b) turbid (150NTU) water and full strong sunlight conditions

Generally, the lag phase of bacterial growth before start of inactivation was shorter in sunny conditions for both clear and turbid water as compared to cloudy conditions. In clear water under sunny conditions, inactivation started after the first hour while in turbid water, bacterial inactivation started after two hours. In comparison inactivation for both clear and turbid water under cloudy conditions started after the 3rd hour of exposure with a gradual rate of cell inactivation as compared to the steep drop in bacterial numbers experienced in clear water under sunny conditions.

A wide range of sunshine and cloud conditions were encountered during these experiments. Ultra-violet (UVA+B) light levels ranged from a minimum of 9W/m^2 in early morning conditions to a maximum of 60W/m^2 on completely clear sunny days. The water temperatures ranged from a low of 22°C (turbid water in cloudy weather) at the start of the experiments to a maximum of 47°C during maximum sunshine conditions for both turbid and clear water. In clear water under sunny conditions, the average irradiance and temperature recorded was 43.5W/m^2 and 39.4°C, while in turbid water under the same conditions, the same recordings were 43.3W/m^2 and 41.6°C respectively. In both cases the highest temperature recorded was 47°C. In clear water, temperature was at this peak of 47°C for two hours compared to one hour in turbid water. In comparison under cloudy conditions, the average irradiance and temperature for clear water was 27.5W/m^2 and 32.3°C while that of turbid water was 29W/m^2 and 38.3°C.

Statistical analysis showed no significant difference ($p>0.05$, 95% CI) in bacterial inactivation in all water samples between glass and PET bottles for all weather conditions with the exception of clear water under cloudy conditions. Here, there was statistical difference ($p<0.05$, 95%CI) between glass and PET reactors during the 5th and 6th hour. At these time points glass had

13±2CFU/100 mL compared to 4±0.8CFU/100 mL in PET at T_5 while at T_6 there was 5±1.4CFU/100 mL in glass compared to undetectable viable counts in PET. However, by the last hour of exposure (T_7), there were no detectable viable bacterial counts in both water samples. Table 3.42 shows the statistical analysis results of the water samples under different weather conditions.

Table 3.41: Paired sample t-test results of *E. coli* concentrations in Solar exposed water (glass and PET) under dissimilar weather conditions for both 5NTU and 150NTU water

Weather conditions	Turbidity (NTU)	*p*-value(95%CI)
Sunny	5	0.563
Sunny	150	0.381
Cloudy (overcast)	5	0.047*
Cloudy (overcast)	150	0.266

* *Significant difference*

During strong sunny conditions, complete inactivation of *E. coli* from a starting concentration of 10^8 CFU/100 mL at T_0 to below limit of detection (1CFU/100 mL) was achieved within the first three hours for clear (5NTU) water representing a reduction of at least 7-log units in bacterial concentration in both glass and PET reactors. In comparison, bacterial inactivation from 10^6 CFU/100 mL to undetectable levels in 150NTU turbid water under the same weather conditions for both reactors was achieved after a six hour exposure period representing a 5-log unit reduction value. Bacterial inactivation to below the limit of detection in clear water under overcast weather conditions (Fig 3.21a) was achieved after 6 hours of exposure. In comparison, although there was a reduction in bacterial concentration in turbid water under overcast conditions (Fig 3.22a), inactivation to below detectable limits was not achieved by the last hour

of exposure T_7. At this time point, bacterial concentration was at $2.12x10^2$ and $1.89x10^2$ CFU/100 mL in glass and PET bottles respectively.

CHAPTER FOUR: DISCUSSION AND FUTURE WORK

4.1 Water Quality

E. coli was used as a test organism because of its universal acceptance as an indicator of faecal contamination and hence quality of drinking water (WHO, 2011). The bacteria were also found to be predominant among the thermotolerant coliforms isolated from water samples in Kampala, Uganda (Howard *et al.*, 2003). However, some studies (Hazen & Toranzos, 1990) suggest that whereas *E. coli* can be used as an ideal indicator of faecal contamination in temperate waters, it might not be the appropriate indicator for tropical waters. They suggest that *E. coli* easily proliferates in tropical waters due to the high nutrient density in the water, high temperatures and solar radiation. Levels of *E. coli* might therefore be higher than the original numbers in tropical waters. In fact, McFeters (1990) in his book reports situations where high isolation of *E. coli* was encountered in absence of possible faecal contamination. Based on these observations *E. faecalis* which has been suggested as a possible alternative indicator bacterium to *E. coli* (WHO, 2011) for faecal contamination of water was also used. *E. faecalis* are abundant in human feaces, have greater persistence in contaminated water and do not multiply in polluted environments. They are also used as faecal indicators for recreational water quality (Sobsey & Brown, 2011). There is also evidence to suggest that they may have a stronger relationship to adverse health outcomes than *E. coli* (Byappanahalli, Nevers, Korajkic, Staley, & Harwood, 2012; Moe, Sobsey, Samsa, & Mesolo, 1991)

4.1.2: Physical Water Quality

Most of the samples (60.9%) were within the recommended pH range for drinking water i.e. 6.5-8.5. However, it is interesting to note that 61.5% of the samples from shallow wells fellow below pH of 6.5 and were therefore considered acidic. A study in West Africa investigating causes of

the problems of red water from hand pumps encountered by users indicated that acidic water could cause corrosion of hand pumps hence increasing the iron concentration in pumped water to almost twenty times higher than ground water (Langenegger, 1994). When insoluble iron is exposed to the atmosphere, rusting occurs leading to lowering of pH (Marianne, 2005). Causes of this acidity in shallow well water samples in our study could also have been a result of corrosiveness of the iron metal hand pump outlet through which the water is pumped.

The higher turbidity of water from open dug wells was also expected since the wells are open without any form of barrier/ protection from pollution by environmental factors (Figure 3.1). These sources also rely on surface run-off during rainstorms to recharge their water. This storm water runoff usually carries with it a barrage of debris, dust, soil particles and other contaminants which usually lead to increased turbidity of water. Often open dug wells were also used as watering holes for animals such as cattle and goats (Figure 3.2). Therefore water turbidity of these sources could also have been increased by humans and animals wading into the water in addition to animal droppings.

It was also noted that during the rainy episodes, turbidity of water from shallow wells also tended to increase. This could have been due to seepage of highly turbid storm run-off water into the shallow ground water. This phenomenon was expected since shallow wells were always located at the bottom of the valleys which eventually are the recipients of storm water run-off. In addition, the cemented rings around the shallow wells were more often than not cracked. Seepage of highly turbid storm water could easily occur through these cracks (Figure 3.4).

4.1.3 Microbial Quality

The findings on raw water quality in this study were in agreement with other studies such as that of Parker *et al.* (2010) who studied the quality of water from 346 different sources across the district of Amuria in northern Uganda. They found that water from bore-holes had the highest/best microbial quality, followed by rain harvested water, protected springs, open and covered hand dug wells. Open water sources had the worst quality in terms of thermotolerant coliforms. These findings were also in agreement with those of Opio (Opio, 2010, 2012) who carried out a study in Northern Uganda to compare water quality of open sources and boreholes. Unlike Parker and colleagues however, this study took into account shallow wells but did not include open hand dug covered wells and protected springs as these were non-existent in the study area. Ranking of water quality by source for the two indicator bacteria from the highest to lowest quality was for *E. coli*:

a) borehole,

b) rain harvested water,

c) shallow wells

d) open dug wells

For *E. faecalis* the ranking was:

a) bore-hole,

b) shallow well,

c) rain harvested water

d) open dug wells

These rankings of the different sources were not surprising. Generally as water sources are increasingly separated from the human environment, contamination pathways are reduced and hence microbial qulity of water increases/improves (Parker *et al.*, 2010). Open dug wells had the poorest quality since sources of contamination in these water sources are varied unlike the closed sources. Such sources are prone to contamination by not only human feaces, but also animal feaces and other surrouding vegetaion which can also be a source of bacterial contamination.

During the rainy seasons, open sources also become contaminated by run-off water and all the debris it carries with it. The improved sources on the other hand are closed to direct contamination by humans or animals especially the shallow wells and bore holes. Contamination in such sources may occur due to seepage of contaminants into the water source.

The markedly higher concetration of *E. faecalis* in rain harvested water compared to borehole and shallow well water could have been caused by contamination of water with bird/animal feaces. The bacteria in water can be an indicator of either human, bird or animal fecal contamination (Byappanahalli *et al.*, 2012; Feng *et al.*, 2007). It is higly unlikely that source contamination was of human origin since water was collected from the roof-tops of buildings at the schools. What is true however is that all the schools with harvested rain water and indeed all the schools had numerous trees in the compounds. These were home to different birds and other small animals such as lizards, primates etc. It is highly probabale that droppings of these birds and animals on the roofs were washed into the tanks and were not flushed out hence causing the high contamination of water with *E. feacalis.*

Only a few raw water samples from bore-holes, rain harvested water and shallow wells met the Ugandan and WHO standards of 0CFU/100ml for both the test organisms of choice (Table 3.20).

These represented 50%, 30% and 8.1% of samples from boreholes, rain water and shallow wells for *E. coli* respectively. In comparison, 60%, 13.3% and 32.4% of samples from bore holes, rain harvested water and shallow wells respectively, met the WHO/Ugandan drinking water standards for *E. faecalis*. None of the water samples from open dug wells met the standards for drinking water.

The sources from which some of the raw samples met both Ugandan and WHO standards for drinking water are classfied by the Joint Monitoring Program (WHO/UNICEF, 2012) as improved, implying that water from these sources is safe. Findings in this study however, show that such water is not necessarily safe and therefore caution should be used when estimating population access to safe water in the study area. Only samples from bore-holes had at least 50% or more of the raw samples meeting drinking water water standards while less than 33% of samples from the other improved water waters sources (rain harvested water and shallow wells) met the drinking standards for both *E. coli* and *E. feacalis*. With contamination of water not only occurring at the source but also during transportation and storage (Opio, 2012), the number of people in Ndagwe Subcounty without access to safe water may be underestimated.

It is also of concern to note that nearly half of the school/community water sources were the unimproved open dug wells whose samples did not meet drinking water standards. It is advisable for such communities to upgrade to better water quality sources. Shallow wells and deep-bore holes would be an appropriate technlogy but have a shortcoming of being expensive to construct and maintain. Masaka, the district from which the study area was created had the lowest functionality rate (66%) of improved water sources in the whole of Uganda (MWE, 2012) . Again shallow wells which were the most common improved water sources used by the schools

and community in the study area had the lowest functionality rate of 70% for all improved water sources country-wide with break down being the main cause of non-functionality. Since these are communally owned sources, repair usually takes long or may not occur forcing people to resort to other unsafe water sources which are free with no monetary costs attached to them. In light of these shortcomings, rain-harvesting would seem to be the best option to promote for the provision of safe water for the schools and community in the sub-county. Although there are no statistics on the functionality rates of rain harvesting water tanks, they may last longer than shallow wells and bore holes since they are not used by many people. Besides this, these water harvesting systems are usually indivually owned and therefore repair would be quicker in the case of break-down since the individual knows that it is his/her responsibility rather than another person's responsibility as is the case with communally owned sources. Also, the likelihood of water being contaminated during transportation and storage is reduced since harvested water is nearer to the school/home than most other gound water supplies and hence there will be no need for storage. The consumer can use just the amount needed.

4.1.4 Effect of SODIS on microbial quality

This study also adds to the evidence already shown of the effectiveness of solar disinfection as a public health measure to improve water quality and therefore population health outcomes most especially with respect to diarrheal diseases (Conroy *et al.*, 1999; Graf *et al.*, 2010; Rose *et al.*, 2006). SODIS was associated with significant (95% CI, $p<0.001$) improvement of microbial quality of water with respect to indicator organisms *E. coli and E. faecalis.* There were 2.63 and 3.47 log unit reductions for *E. coli* and *E. faecalis* respectively in treated water compared to raw water. These reduction values are higher than the ≥ 2 log reduction value (LRV) recommended

by the WHO for a house hold water treatment technology to achieve a "protective" tier status (Sobsey & Brown, 2011). However, since only one class of indicator organisms i.e. bacteria was tested and analysed, it cannot be claimed that treated water in this study achieved a protective tier status. What is true however is that there was a significant reduction in diarrheal and gastro-intestinal complaints amongst subjects during SODIS water treatment phases which could partly be attributed to improvement in the quality of drinking water. This inactivation of indicator organisms is not surprising and concurs with many other experiments that have proved SODIS to be effective in not only bacterial inactivation but also protozoan and viral inactivation (Dejung *et al.*, 2007; Joyce *et al.*, 1996; McGuigan *et al.*, 2006; Méndez-Hermida *et al.*, 2007) in both laboratory and field studies. Although Gomes *et al* (2009) in their research comparing *E. coli* and *E. faecalis* inactivation in natural waters from the Douro river in Portugal under natural sunlight report a lower inactivation rate for *E. faecalis* compared to *E. coli*, research findings in this study show a higher inactivation of *E. faecalis* than *E. coli*. These findings are in agreement with those of Dejung and colleagues (Dejung *et al.*, 2007) and Berney *et al.*, (Berney, Hammes, Bosshard, Weilenmann, & Egli, 2007) who also found *E. feacalis* inactivation to be faster than *E. coli* in their studies. The higher sensitivity of *E. faecalis* bacteria could be due to the fact that just like other gram positive bacteria they do not possess an outer membrane making it easy for the UV and UV produced oxidative species to easily permeate into the cell unlike the gram negative *E. coli* which have a membrane that has to first be destabilised before UV light can penetrate the cells (Berney *et al.*, 2007). Davies (2009) and colleagues in their study to assess solar radiation of drinking water in temperate latitudes, also show that *E. faecalis* is very sensitive to natural sunlight with complete inactivation occurring within the first three hours of exposure compared to *C. sporogenes* and somatic bacteriophage p22. This study was located in tropical conditions

where solar radiation (in the form of diffuse UV) is high even on cloudy days making it possible for microbial inactivation almost all year round. SODIS was least effective in open dug well water samples and most effective in rain harvested and borehole water. The poor efficacy of SODIS in open dug well water samples can mainly be attributed on the higher turbidity of the samples. In this study, 42 (70%) of the 60 raw water samples from open dug wells had turbidity of ≥30 NTU. The recommended turbidity threshold for effective water treatment using the SODIS method is < 30NTU (EAWAG & SANDEC, 1998; Martín-Domínguez, Alarcón-Herrera, & González-Herrera, 2005) although some studies (Joyce *et al.*, 1996) have shown SODIS to be effective even in highly turbid (200NTU) water. In highly turbid water, SODIS inactivation is not as effective especially in conditions of cloudiness. High turbidity levels can shield pathogens from disinfectants in this UV radiance, hence preventing effective disinfection. However, as much as turbidity could have had an effect on efficacy of SODIS, it is worthwhile to note that microbial load significantly reduced in these samples hence improving quality of water (Table 3.22). In addition to turbidity the rather low efficacy of SODIS in open dug water sources can be attributed to high contamination of indicator bacteria. Over 80% of the raw samples from open wells as stated in the water quality section (3.1.2.1, Table 3.20) of the results chapter fell in the high public health risk category (101-1000 CFU/100 mL) of the WHO classification for drinking water. Since a maximum value of 300CFU/100 mL was assigned for those samples which had too numerous to count bacterial growths, there was no proper way of telling exactly to what extent these water sources were faecally contaminated. Some could have been contaminated with millions of bacteria hence inactivation to below detection levels could not be achieved.

4.2 SODIS STUDY PROTOCOL

Unlike numerous SODIS intervention studies that have used the randomized controlled designs, in this study, the cluster randomized stepped wedge design was used to introduce SODIS intervention to the participating schools. The design is increasingly being used because of its obvious advantages over other cross-over designs such as the parallel and standard cross-over design. For example, in the parallel and standard cross over designs, intervention must simultaneously be applied to half of the clusters (Figure 1.12). This renders the two designs impractical especially in situations where where there are limited resources or practical/geographical constraints. Also in situations where an intervention has already been proven to have a beneficial effect, it would be unethical to withhold the intervention from subjects or to stop the intervention once it has commenced as would occur in a parallel or standard cross-over design (Hussey & Hughes, 2007; Woertman *et al.*, 2013). The stepped wedge design is useful in overcoming the above pitfalls. In addition, clusters in the stepped wedge design act as their own controls since they receive both treatment and control conditions. This not only enables estimation of treatment effect for both inter and intra-cluster comparisons but also enables the use of a smaller sample size compared to other CRTs. The design also allows for modelling of time influence on effectiveness of the intervention (Woertman *et al.*, 2013). Finally the stepped wedge design may allow for easier recruitment of subjects since they will all be assured of receiving intervention at some point in time.

SODIS having been shown to improve microbial water quality and therefore health out-comes among the consumers (Dangour *et al.*, 2013; du Preez *et al.*, 2011; Rose *et al.*, 2006), it was decided that the most ethical solution would be to use the stepped-wedge design to introduce

SODIS to different participating schools. In addition the design was also deemed to be the best option considering the rather limited finances available for this study.

4.2.1 Effect of SODIS on Pupil Attendance Patterns

Diarrhoea and GI complaints severe enough to prevent school attendance of pupils were the main outcomes used to assess impact of SODIS on the health of the subject pupils and hence their school attendance patterns. These diseases were chosen because they are commonly related to water quality (Fewtrell *et al.*, 2005; Gleick, 2002; Payment *et al.*, 1991). It was therefore hypothesised that improving microbial quality of water using SODIS treatment would have a positive effect on reduction in the prevalence of these diseases among subject pupils and therefore improvement in school attendance patterns. To avoid bias from respondents (pupils) on causes of absenteeism, other common causes of absenteeism were also recorded. These included malaria, lack of scholastic materials/fees, and work at home. Work at home and lack of scholastic materials were grouped together to form the other/miscellaneous causes during analysis. Malaria was recorded separately as it was given as one of the commonest cause of absenteeism during baseline survey and indeed from disease prevalence records obtained from the MMM clinic in Makondo (Appendix G).

The results show that general absenteeism of subject pupils from the participating schools gradually reduced from baseline through the subsequent SODIS treatment follow-ups. However, much as there was a general reduction in absenteeism due to diarrhea and GI complaints noticed from baseline to the last phase of the study, this was not significantly associated with SODIS water treatment (IRR 0.63, 95%CI, p=0.222). Neither was absenteeism due to malaria and other causes associated with SODIS treatment. Instead, absenteeism due to diarrhea and

gastrointestinal (GI) complaints was significantly associated with phase/step of SODIS treatment and type of water source. It was therefore not surprising to note that absenteeism significantly dropped during step 4 of the study (IRR 0.51, 95%CI, p=0.012). This was the last treatment phase during which all subject pupils were drinking SODIS treated water. Similarly, schools with a protected/improved water sources had significantly lower rates of absenteeism due to diarrhea and GI complaints compared to those with unprotected water sources (IRR0.51,95% CI, p=0.048). This too was not surprising because raw water from the protected sources had relatively lower levels of faecal contamination compared to that from the unprotected sources. However, it should be noted that this water from protected sources though less contaminated was still not fit for human consumption (UNBS, 2008). Also in some cases SODIS treated water was not completely disinfected and there was uncertainty as to the kind of drinking water the pupils consumed while at home. In spite of this, there was still a reduction in levels of diarrhea and GI complaints among subject pupils during all phases of SODIS treatment inclusive of pupils in clusters where intervention had not commenced. This scenario was not unique to our study. Graf *et al.* (2010) and Rose *et al.*(2006) also found that despite children in intervention SODIS groups sometimes drinking water from other unsafe sources, diarrheal episodes significantly reduced in these children when compared to controls and were not significantly different from those children who regularly drank SODIS treated water. Graf and co-workers attributed this to other hygiene and sanitation practices like washing hands and proper disposal of faeces. McGuigan and colleagues (2012) on the other hand, have postulated a possibility of immunological response resulting from a daily challenge of ingestion of partially inactivated pathogens, although this school of thought has yet to be studied and proven.

The lack of association between SODIS and absenteeism due to diarrhoea and GI complex was rather perplexing. Numerous studies have found SODIS to significantly improve microbial quality of drinking water and hence reduction in diarrheal episodes especially among children under five years of age (Conroy *et al.*, 1999; du Preez *et al.*, 2011; Du Preez *et al.*, 2010; Graf *et al.*, 2010; Rose *et al.*, 2006) and older children (Conroy *et al.*, 1996). This in turn improves general school attendance for the school-going children. Although just like the mentioned studies SODIS was able to significantly improve the microbiological quality of water in this study, the treatment was not significantly associated ($p=0.222$) with the reduced cases of pupil absenteeism due to diarrheal and gastro-intestinal complaints noticed. The same was true for the rather significant reduction in absenteeism due to malaria and other causes, especially during the last phase of treatment (February-April 2012) in comparison to the same time period a year prior. These were factors that were not expected to be influenced by water quality and therefore should have stayed relatively at the same level. Analysis of absenteeism within (intra) and between (inter) clusters was able to reveal a few insights for these scenarios as postulated below.

Cluster 1 (Table 3.37) behaved rather peculiarly with very high recorded levels of absence at the baseline (step1) which declined remarkably especially in the last phase of treatment which was carried out over the same time period but a year later. Generally, absenteeism dropped from a baseline average of 6.3 ± 3.4 days to 1.7 ± 2.2 days in step 4 of the study. There was also a significant drop in diarrhea/gastro-intestinal complaints and other causes of absenteeism, malaria inclusive. In fact, mean absenteeism recorded in cluster 1 at baseline was more than double that recorded in clusters 2 and 3 during the same time period. This was surprising considering the fact that baseline absenteeism was recorded during the same time period across all clusters and

therefore was not expected to significantly differ among all the three clusters. However, on further analysis, it was discovered that high absenteeism cases in cluster 1 were largely due to diarrhea and GI complaints mainly attributed to two schools, Kyaterekaka and Kabuyoga primary schools. Of the 544 cases of absenteeism due to D and GI complaints recorded in the cluster (Tables 3.24-3.27), 461 were attributed to the two schools while the remaining 83 cases were recorded in the remaining two schools. As already stated in the water quality chapter, none of the schools was providing treated water to pupils at baseline. In the case of Kyaterekeka primary school, the high number of GI complaints could have been caused by the water which was highly contaminated with *E. feacalis* (Table 3.25). Kabuyoga primary school on the other hand relied on water from an open dug well which was highly contaminated with both *E. coli* and *E. feacalis* (Table3.24). Both these micro-organisms can cause gastro-intestinal complications including diarrhea. These two schools were also geographically located within very close proximity to each other (Figure 2.1). It is suspected that although Kyaterekaka primary school had a rain-harvesting water tank, the pupils might actually have been using the open-dug well that was being used by Kabuyoga primary pupils for their water needs. It was not uncommon for water in the tank to be reserved for teachers while pupils resorted to other sources of water especially during the dry seasons when water was scarce.

In contrast however, Kijajasi primary school, also relied on rain harvested water which was also contaminated with *E. feacalis* and *E. coli* (Table 3.26) but did not experience as many cases of absenteeism due to diarrhea and GI complaints as compared with that recorded in the two schools mentioned above, particularly in comparison to Kyaterekaka which also had a rain harvesting water tanks system. On average the school recorded more cases of absenteeism due to

other causes compared to the other schools in this cluster. Aside from the suspicion that pupils in Kyaterekeka primary school could have at times been drinking water from open dug wells, another plausible explanation of the low number of absenteeism cases recorded due to GI and Diarrhea could have been due the fact that this is a Muslim founded school. Common Muslim hygienic practices such as ablution and washing of hands after toilet visits and before prayers could have significantly reduced the cases of diarrhea and GI. Hand washing alone has been shown to reduce diarrhea and other related among children there by improving school attendance patterns (Cairncross *et al.*, 2010; Nandrup-Bus, 2009; O'Reilly *et al.*, 2008) while religious practices can sometimes promote or prevent the transmission of disease. For example Shigellosis caused by *S. sonnei* was found to be commonly associated with Jewish communities in the Unites States (Garrett *et al.*, 2006; Gupta, Polyak, Bishop, Sobel, & Mintz, 2004)

St. Agatha Makondo primary school (the fourth school in cluster1) on the other hand had the least number of absenteeism recorded for diarrhea/gastrointestinal complaints and other cause during the same time period (Table 3.27) Although water from a shallow well used by the school was highly contaminated with *E. coli*, absenteeism rates were still low compared to the other schools in this cluster. The school was run with the help of Catholic nuns (Medical Missionaries of Mary) at the nearby health clinic. It is plausible that pupils had better knowledge about drinking untreated water and may not have been drinking the raw water but instead drank boiled water provided along with a meal by the nuns.

Also the fact that the nuns provided two meals (breakfast and lunch) for the children while at school could have been a motivating factor for the children not to miss school even if they felt unwell since they were assured of a meal at school. In addition, provision of school meals does

not only improve the nutritional status of pupils and therefore immunity to resist disease, these occasions may also be used to teach children to wash hands before and after meals, further improving disease incidence outcomes (Goyal & Drèze, 2003). In the case of St. Agatha and indeed other schools in the Sub County, this hypothesis needs to be studied. However it is common for school children in Uganda to go without a meal the whole day while at school (UBOS, 2011). Therefore the prospect of an assured meal at school would be a sufficient inducement to prevent absenteeism of pupils.

Absenteeism in cluster 2 (Figure 3.12 and Tables 3.28-3.31 and 3.37) revealed a significant drop ($p<0.05$) in absenteeism due to diarrhea and gastro intestinal complaints from baseline (1.9±1.8days) through to step 4 (0.2±0.6days) of the study. This is in spite of the fact that in step 2 SODIS had not been introduced. Total absenteeism on the other hand remained fairly constant from baseline through to step 3 but then drastically fell to average of 2.6±2.5 days from a previous average of 4.5±3.2 days in step 3 for no apparent reason. The decline in diarrhea and gastrointestinal complaints in step 2 before intervention is also not a unique case to this study. Similar studies in household water treatment trials have experienced the same phenomenon (Boisson *et al.*, 2010; Quick *et al.*, 2002). For example, Boisson and co-workers when examining the control group in their study found that diarrhea declined from baseline (12.6%) to 2-5% in a Life-straw family filter trial in the Congo. Zwane, (2011), attributes this phenomenon to frequent surveying during such studies which may act as an influence to carry out good water and sanitation practices. In addition to frequent surveying, baseline training of teachers from the schools in this study could have also caused the pupils to start SODIS treatment before intervention especially in their homes which were not being monitored. It also cannot be ruled

out that the monthly visits to schools to collect raw water samples and check on attendance record keeping during the study could also have positively influenced pupils' water and sanitation practices at both school and home.

In the third and last cluster (Figure 3.14 and Tables 3.32-3.35 and 3.37), the reduction in total absenteeism noticed was largely driven by other causes of absenteeism exclusive of diarrhea and gastrointestinal complaints. Although there was a reduction in diarrhea and gastro-intestinal complaints, these were very low compared to the same in clusters 1 and 2 for all phases of treatment. It is highly probable that that having had to wait for a long time, some schools in this cluster started implementing the intervention before they were scheduled to start hence affecting the results in this cluster. Indeed in some schools (King Godfrey primary school) small 0.5 litre bottles were found being exposed by pupils during sampling for raw water and yet the school was not scheduled to start intervention as per the study design.

The design and implementation of the study also had an effect on some of the outcomes. Initially all teachers that were to lead the different SODIS projects in their respective schools were given a training in which the purpose of the study was explained. Along with this, the teachers were also given a detailed description of the SODIS process. The teachers were very receptive of this technology since it was simple and easy to carry out and could greatly improve the health of pupils. However some of the teachers went ahead and started practicing SODIS through their own initiatives without waiting for official commencement of the treatment/intervention. This initial lack of blinding could have led to some pupils consuming treated water both at home and therefore affecting the number of absenteeism cases recorded prior to SODIS water treatment introduction. In fact in cluster 2, cases of absenteeism due to diarrhea and GI complaints (Figure

3.12) had significantly reduced in the pre-intervention phase after baseline (step 2) even before introduction of SODIS treatment.

As an incentive to encourage record keeping, teachers were given a small stipend ~ €25 at the beginning of each term. As time went on, teachers could naturally have been fatigued by the length of the study (1 year) and were not as committed to record keeping as they initially were at the beginning of the study. This is evident especially in the last phase of the study (step) where the absenteeism rates for all causes significantly reduced. Taking into account that this phase was carried out during the same time period as baseline phase but a year later (Feb –April 2011/2012), where it would have been expected that absenteeism due to other causes exclusive of diarrhea and GI complaints should have remained at relatively the same level as was recorded during baseline phase. It is possible that since teachers had already been given their incentive at the beginning of term and this being the last phase of treatment; they had no reward to look forward to. They therefore could have been less committed in their record keeping.

Under normal circumstances one would have thought that the incentive should have been given at the end of each term after records were given to the researcher. However in the Ugandan situation this would not have worked. People expect to be paid beforehand if they are to do work that they deem to be voluntary. Giving them this incentive at the beginning of the term was a sort of assurance commitment to them (teachers) that the study was not just about getting information from them and then disappearing without a trace.

It is also no secret that absenteeism amongst Ugandan teachers is rather high and morale is low due to, among other reasons, the poor pay of approximately €65/month that they receive (O'Sullivan, 2006; Yiga & Wandega, 2010) Often some of the teachers in charge of SODIS

projects in the schools were not at school whenever visits to check on progress of the study were made and yet these were nominated by the school head teachers as the their best suited for the purpose of this research. Such teachers would often be found in their shambas/gardens or engaged in other activities that could generate an extra income rather than be at school. It is therefore hard to imagine that such teachers could afford to keep proper attendance records when they too were often absent.

Previous SODIS trials have been randomized controlled trials often introduced at community level using parents or primary care givers as implementers of the technology at house-hold level (Conroy *et al.*, 1996; du Preez *et al.*, 2011; Graf *et al.*, 2010). This study was for the first time introducing SODIS to the community through the use of school children, using the randomized stepped-wedge cluster design. As previously stated, this design was chosen for ethical purposes. With each teacher being in charge of attendance monitoring of approximately 50 pupils, any slack in proper absenteeism record keeping could easily have caused an exaggerated effect on absenteeism due to the different causes.

Also, the monthly frequency of monitoring visits to the schools may not have been adequate enough keep to morale high amongst the teachers as well as attending to any inconsistences in attendance record keeping as they arose. Often the inconsistences in record keeping were noted at the end of term during data entry and would be addressed at the beginning of the following school term but the damage would have already been done. In addition to infrequent visits to the schools, there were also long periods (average of 3-6 weeks) during holidays and weekends where there was no reinforcement of SODIS treatment. Although refresher training courses at the beginning of every school term were carried out for the teachers, the extended period in which

SODIS was not being reinforced could have had an effect on the attendance monitoring of pupils.

Finally, it is also hard to rule out the possibilities of bias or stigma towards reporting of absenteeism cause by the pupils. It is especially suspected that pupils who had diarrhea may have chosen to report other causes of absenteeism such as work at home for fear of being laughed at or ridiculed by fellow pupils. Besides, diarrhea is not considered a disease by many in the study area but rather a symptom so pupils with diarrhea may not have reported being sick or may have reported other sickness even when they were suffering from diarrhea. After commencement of SODIS treatment, they may not have had diarrhea as often and attended school hence the significant decline in "other": causes of absenteeism. This however, is a plausible explanation and would require further investigations.

4.3 Follow-up SODIS Dissemination Follow-up Survey

In contrast to results of a survey carried out in Makondo parish of Ndagwe Sub-county where unimproved water sources were used by 40% of households (Macri *et al.*, 2013), results from this survey show that almost 75% of the households in Ndagwe Sub County rely on unimproved water sources for their domestic chores and drinking needs. This is more than double the Ugandan national average (33.6%) of rural households which rely on improved sources (UBOS, 2011). The fact that although the area is well served with shallow and bore-hole installations, this has not translated to increased safe water access since many of these installations have ceased functioning (Macri *et al.*, 2013). The few functioning improved sources are often far away from homesteads and often with long queues of people waiting to fetch water (Macri *et al.*, 2013). This forces the communities to resort to nearby unimproved sources which are more reliable in

terms of water supply, free of long queues and free of charge (Asaba, Fagan, Kabonesa, & Mugumya, 2013). Findings of this study also reveal that over 90% of the interviewed care-givers stated that they had a more than 30 minutes round trip to the water source and back home. Just as for water source type, the percentage of households in Ndagwe Sub-county taking more than a 30 minute round trip to the water source and back home is much higher than the rural national average of 62% (UBOS, 2011). This could be attributed to the fact that this is one of the drier and more water stressed parts of the country which experiences long dry spells (MWE, 2004). Water sources are sparsely distributed. A round trip of not more than 30 minutes to and from water source is one of the yard sticks used by the Ugandan government to measure access to water in rural areas (UBOS, 2007, 2010, 2011). This means that water access in Ndagwe sub-county is still very low when time taken to fetch water is taken into account.

Unlike studies that have placed the burden of water collection on women and girl children (Asaba *et al.*, 2013; Bennett, Dávila-Poblete, & Rico, 2005; Ghosh, 2007), our findings reveal that in Ndagwe sub-county, the burden of water collection falls disproportionately (84.6%) on children of either sex. Only 12.6% of respondents stated that women were responsible for water collection and this only happened in situations where children were either sick or were at school and so unable to fetch water. Otherwise the normal practice would be for the children to wake up early and fetch water before going to school and they would do the same in the evening after coming back from school. The possibility of going late to school for these children is of real concern due to the detrimental effect it may have on their academic performance. Of concern too is the fact that these children are not only at the risk of poor health such as fatigue, muscle aches nose bleeds and other diseases due to carrying water on their heads (Asaba *et al.*, 2013), but also

face the risk of being attacked by wild animals and humans. The children also risk death due to drowning especially at the unimproved water sources and girl children in particular also face the risk of sexual assualt on their way to and from these water sources (Asaba *et al.*, 2013; Macri *et al.*, 2013). Considering that the average household size in the sub-county is made of 6-9 people and water collection for the majority is 2-3 time a day (Table 3.40), the problem of inadequate water quantity and related health problems is real.

Surprisingly, most of the respondents (84%) interviewed stated that they treated their drinking water at household level. This percentage of households treating their drinking water is much higher than the national rural average (58.9%) reported by the 2011 Uganda Demographic Health Survey (UBOS, 2011). And unlike Asaba and co-workers, (Asaba *et al.*, 2013) who found that boiling was the preferred method of treating water at the household level in Makondo parish, our findings reveal that boiling was second to SODIS as the preferred water treatment method. This difference could have been the timing during which these interviews were conducted. Whereas interviews in this study were conducted from June to July 2012 after a year-long promotion of SODIS in schools in Ndagwe sub-county including those in Makondo parish, Asaba and colleagues conducted their survey almost a year earlier (July-November 2011) when SODIS promotion had not yet intensified. Of course courtesy bias on the part of respondents in this study cannot be ruled out since their children were participating in the school SODIS projects. It should also be noted that of the 16% that stated that they did not treat their drinking water, the majority (62.1%) cited lack of fuel as the main reason as to why they did not treat drinking water. SODIS would therefore be a timely alternative for such respondents since all that is needed is sunshine which is plentiful in the study area.

4.3.1 SODIS Dissemination by Pupils

From informal conversations with local leaders and community members during baseline and familiarisation tours of the study area, SODIS as a water treatment technology was unheard of in this area prior to the start of the project. These findings were not surprising since this technology is one of the least used HWT in Uganda , accounting for only 0.2% of all the HWT methods used in the country (UBOS, 2011). However, before our intervention, SODIS as a water treatment technology was used by 4.9% of households in Makondo parish (Macri *et al.*, 2013). Our evaluation of SODIS dissemination to the community a year later after intervention revealed that the majority (93.7%) of interviewed respondents heard about SODIS for the first time from their school-going children. The remaining respondents heard about SODIS from either a friend, media or a community health worker who was part of Water is Life programme under which this research fell. Similar to other studies, (Blanton *et al.*, 2010; Freeman *et al.*, 2012), school children in our study were effective in the transfer of SODIS knowledge back to their caregivers at home. Over 60% (105) of respondents stated that they were using SODIS for water treatment at home in addition to other water treatment methods such as boiling and filtration, and almost half (52) of these stated) that they always SODIS as a water treatment option at home. This was significant increase from the 4.9% respondents that had earlier stated using SODIS for water treatment (Macri *et al.*, 2013).

Asked about the effect of SODIS on their workload at home and general well-being of their household members, the majority of the respondents stated that SODIS reduced their workload. They stated that it was no longer necessary to look for fire wood to boil water since all that was needed for SODIS was to just leave water out in the sun as they went about their daily chores.

They also said that they noticed reduced absenteeism amongst their school going children as well as a general reduction in illness episodes amongst other household members. All these results are in agreement with many studies that have shown that improvement in water quality, sanitation and hygiene also impact on general well-being of household members and may improve attendance rates amongst school going children (M. du Preez *et al.*, 2011; Graf *et al.*, 2010; Hutton, Haller, & Bartram, 2007; Joyce *et al.*, 1996; Kasirye, 2010; O'REILLY *et al.*, 2008) and that children can be effective agents of change (Blanton *et al.*, 2010; Mwanga, Jensen, Magnussen, & Aagaard-Hansen, 2008).

Also it is important to note that female children were more likely to transfer knowledge compared to males making them very important in the dissemination of SODIS. This could be due to the fact that females are responsible for water management in the rural Ugandan homes. The girls unlike the boys are more likely to be responsible for cooking food and other household chores including the treatment and provision of drinking water in the home. They therefore were in a better position to easily transfer SODIS information to caregivers at home (usually mothers). The males on the other hand will in most cases not be involved in home chores, giving them minimal opportunity to interact with caregivers at home with regard to drinking water treatment and quality at home.

Findings in this survey concur with McGuigan and colleagues (McGuigan *et al.*, 2012) who suggest courtesy bias from respondents during interviews i.e. respondents telling the interviewer what they think the interviewer wants to hear. In this survey, there is no doubt that some of the respondents could have given us answers that they thought were being sought. However, interview sessions were usually un-announced and this gave the interviewer a chance to observe

whether water bottles were out in the sun at the various homesteads and indeed it was found that bottles were being exposed in 98(56%) of the households visited. It was also noted that the majority of respondents stated that adults in the home did not drink SODIS treated water. It was mostly children who drank the treated water. Since these interviews were conducted during the school holidays, it is most probable that the holiday-makers were responsible for the bottles found exposed in the compounds rather than the care-givers.

4.4 Glass vs. SODIS Field Study

Studies have shown that PET bottles are safe for SODIS water treatment under the normal SODIS process (Wegelin *et al.* 2001; Schmid *et al.* 2008). It is also recommended that the bottles be replaced after every 6 months to minimise the effects of bottle ageing (Ubomba-Jaswa *et al.* 2010). However, there are still concerns about the use of PET plastic bottles for SODIS water treatment. Such concerns include health risks associated with plasticisers and other carcinogenic compounds which may leach from the bottles into the water (Westerhoff *et al.* 2008). Implementation still encounters these concerns from potential users in the developing world (McGuigan *et al.* 2012). Glass, however, is not subject to photodegradation and can be used for substantially longer periods since it is more resistant to material ageing effects associated with PET plastic. Also, the UV transmittance spectrum of glass especially in the UV-A (320-400nm) range which is the most important during the SODIS process is comparable to that of PET. Glass transmittance is 89-90% compared to that of PET at 85-90% (EAWAG, 2011; McGuigan *et al.*, 1998; Shell & Adams, 2008; Eunice Ubomba-Jaswa *et al.*, 2009). This makes glass a good alternative for PET bottles in the SODIS process.

The fourth and last specific objective of this study was therefore to demonstrate that glass bottles are as effective as PET bottles in terms of microbial inactivation during the SODIS process in real field conditions. For those SODIS users still sceptical about use of PET for SODIS, or for whom PET bottles are hard to access, glass could be an alternative. The dynamics of *E. coli* disinfection observed in 1-litre glass and PET SODIS bottles using real sunlight and natural waters of different turbidity levels under dissimilar weather conditions in central Uganda were compared. *E. coli* was chosen as the test organism because of its universal acceptance as an indicator of fecal contamination of drinking water (WHO/UNICEF 2010). Also, just like other studies which have shown that *E. coli* is more resistant to the bactericidal effect of the sun compared to other bacteria such as *Campylobacter jejuni, S. epidermidis, Pseudomonas aeruginosa, Shigella flexneri. Salmonella typhimurium and Salmonella enteritidis* (Wegelin *et al.*, 1994; Kehoe *et al.*, 2004; Boyle *et al.*, 2008), the wild *E. coli* strain isolated from the water sources during the school SODIS promotion study was more resistant to SODIS relative to *E. faecalis.* Consequently, *E. coli* was deemed to be the most suitable indicator of SODIS efficacy in glass and PET bottles for this study.

Two turbidity levels of 5NTU (shallow well water) and 150NTU (Open dug well water) were used because normal turbidity of the sampled water sources varied at different times of day, with some sources having turbidity levels as high as 400 NTU especially after heavy rain or intense use (people often wade into open dug wells during the collection process). This phenomenon was mostly encountered with open dug wells during previous research on drinking water quality from the sub-county. The shallow well water was normally at 5NTU turbidity level. Studies such as those by Joyce *et al.*, (1996) and McGuigan *et al.*, (1998) have shown that SODIS bacterial

inactivation can even occur in turbid water as high as 200NTU under strong sunny conditions due to heat/ temperatures produced by the irradiance of the sun. This is in contrast to other studies which report a water turbidity of 30NTU as a threshold for SODIS efficacy (Fujioka *et al.*, 1981, Meierhofer & Landolt 2009). Joyce *et al.*, (1996) were able to show that a wild Kenyan strain of *E. coli* in turbid water (200NTU) could be inactivated to undetectable levels from a starting concentration of $20x10^5$ CFU/ mL within 7 hours after attainment of 55°C. The elevated temperatures reached during these strong sunny conditions cause bacterial inhibition through pasteurisation and inhibition of bacterial DNA repair mechanisms (McGuigan *et al.*, 2012). It should be noted however, that water turbidity was not natural and these experiments took place in controlled laboratory conditions which are not typical of field conditions. It was therefore important to also test natural water of higher turbidity under field conditions to cater for those communities that relied on water from open dug wells that were generally very turbid. A turbidity level of 150NTU was used to represent samples from such wells.

Unlike Joyce *et al.*, (1996), in this study, the highest temperature attained in turbid water under sunny conditions was 47°C and a complete bacterial inactivation was achieved after six hours. This could have been due to the lower turbidity (150NTU) which would have reduced the opacity of the water as opposed to the 200NTU turbidity level of water used by Joyce and colleagues. However, the temperatures recorded in turbid water (150NTU) under overcast conditions in this study were not high enough to bring about complete inactivation. The highest temperature experienced was 43°C and this was only for about an hour. It is for this reason that SODIS promoters recommend exposing such water for two consecutive days under extended

cloudy conditions (EAWAG, 2011). Where possible, highly turbid water can also be filtered to reduce on turbidity before SODIS treatment (Sommer *et al.*, 1997)

Bacterial inactivation rates in clear water under sunny conditions are in agreement with many other studies (Joyce *et al.*, 1996; Kehoe *et al.*, 2001; McGuigan, Joyce, Conroy, Gillespie, & Elmore-Meegan, 1998; E. Ubomba-Jaswa, Boyle, & McGuigan, 2008; Wegelin *et al.*, 1994) where synergy between temperature (≥45°C) and optical irradiance (UVA) increases bacterial inactivation. A complete inactivation of *E. coli* was reported to be normally achieved within the first three hours or less under strong sunny conditions (Boyle *et al.*, 2008). In our study, temperatures in clear water under sunny conditions were already at 45°C by the fourth hour of exposure peaking at 47°C at hours 5 and 6. Bacterial inactivation in clear water under cloudy conditions to below detection levels was achieved after 6 hours of exposure and the highest temperature attained was only 36°C, well below ≥45°C needed for thermal and optical synergistic effect hence the longer inactivation time.

Although a lot of work has been done to assess efficacy of SODIS in drinking water treatment, the material of choice has been PET rather than glass mainly because PET plastic is more easily obtained in addition to being more robust, light weight and not prone to breakages (Wegelin *et al.*, 2001). Glass though not frequently used, is inert and less prone to surface scratches (which reduce optical transmission) than PET for SODIS purposes. Results of this study show that *E. coli* inactivation in glass and PET under similar weather conditions is comparable. These results are in agreement with those of (Sommer *et al.*, 1997), who report comparable bacterial (faecal

coliforms) and viral (*V. cholerae*) inactivation between glass and PET bottles under similar laboratory and field conditions.

One of the frequently identified psychological barriers to SODIS use is that of the potential health risks associated with leaching of chemical compounds from PET bottles (McGuigan *et al.*, 2012). Montuori *et al.*, (2008) in a study to assess human exposure to phthalic acid and phthalate esters from water packed in PET and glass bottles reported that the concentrations of phthalates were nearly 20 times higher in sampled PET bottles than in glass bottles. However, the concentration of these phthalates in PET bottles did not present any risk to human health as they contributed less than 0.1% of the maximum allowable US Environmental Protection Agency (EPA) phthalate reference doses (RfDs). The RfDs estimate daily oral exposure to the human population that is likely to be without appreciable risks of deleterious effects during a lifetime. Shotyk and Krachler (2007) and Westerhoff with co-workers, (Westerhoff, Prapaipong, Shock, & Hillaireau, 2008) have also reported leaching of antimony into water packed in PET bottles. In their study of over 132 brands of bottled water from 28 countries, Shotyk & Krachler (2007) report an average antimony leaching of 19% (Candadian) and 90% European brands in water stored over 6 months at room temperature. Westerhoff and colleagues report an average of 13 days and a temperature of 85°C needed to leach 6µ/l or more of antimony, the USEPA maximum allowable level in PET bottled water. All conditions reported in these studies are not typical of the SODIS process. A recent study, (Schmid, Kohler, Meierhofer, Luzi, & Wegelin, 2008) to assess health risks associated with migration of plasticisers and chemical compounds into water exposed in PET bottles under a typical SODIS process reveals no associated human health risks. These authors further reported the maximum concentration levels of di(2-ethylhexyl)adipate

(DEHA) and di(2-ethylhexyl)phthalate (DEHP) as 0.046 µg/L and 0.71 µg/L, respectively. These values were below the WHO drinking guidelines daily consumption limits of 80 µg/L and 8 µg/L for DEHA and DEHP respectively (WHO 2011). Moreover, both DEHA and DEHP have a short term low toxicity, are not genotoxic. They have also been placed in Group 3 by the International Agency for Research on Cancer (IARC), meaning that they are not classifiable as to their carcinogenicity to humans (WHO 2011). Although all these studies show that the level of chemical compounds leaching from PET bottles into water do not pose health risks under proper SODIS conditions, misgivings still linger amongst some would be users. This mainly stems from disclaimers made by manufacturers who instruct users not to re-use plastic bottles (McGuigan *et al.*, 2012). Glass can therefore be used as alternative. However, since PET bottles are typically easier to obtain than glass, they should still be promoted for those who are not able to get glass. It is worthwhile to note that the risk of diseases contracted through consumption of microbiologically contaminated water clearly outweighs the perceived risks associated with leaching from PET into solar exposed water.

Ubomba-Jaswa and co-workers investigated the genotoxicity of solar disinfected water using bottles that were in use for 6 months under strong sunshine conditions in Southern Spain. Their recommendation that PET SODIS bottles be replaced every six months reflects the duration and limits of their study rather than any indication that genotoxic risks occur after this time. Replacing the bottle after 6 months also helps to avoid the effects of aging such as scratches which may hinder effective absorption and transmission of UV light hence affecting SODIS efficacy (Ubomba-Jaswa *et al.*, 2010). Clearly glass bottles have an advantage since they do not suffer the effects of aging and can therefore be used for longer periods. This in turn will reduce

on the cost of water treatment since there would be no need for frequent replacement of bottles unless breakage occurs.

Under strong sunny tropical conditions where high temperatures (>65°C) can easily be attained during the SODIS process, PET bottles may not be the container of choice since they are susceptible to deformation unlike glass which can withstand such temperatures. However, glass is more fragile and bulkier than plastic and may prove cumbersome to users especially in cases where batches of bottles have to be filled every day. In addition, the fact that glass can easily break and therefore cause accidents is a concern especially in situations where children are the ones responsible for SODIS. In such cases PET bottles should be encouraged since they pose a minimal risk of accidents.

Finally, glass also may be prone to theft since in most developing countries, a financial deposit is made on a glass bottle at the point of purchase (McGuigan *et al.*, 2012) such that when a client returns the bottle, this deposit is refunded. Should the bottles be exposed in areas not deemed safe they may be susceptible to theft by individuals who may want to claim this refund. In such cases, PET bottles would be more feasible since there are no financial refunds attached and bottles are normally discarded or put to other use after initial purchase.

It therefore remains the end-user's choice depending on accessibility and cost of either glass or PET bottles, concerns of health risks that may be associated with PET bottles and other factors such as container portability that will determine whether to use PET or glass bottles for SODIS water treatment.

4.4.1 Conclusions.

Drinking Water Quality

The drinking water used by school pupils and communities in Ndagwe sub-county is unfit for human consumption in its raw form as it contains high levels of faecal contamination. This is inclusive of the so-called improved water sources which should supply clean and safe.

SODIS is effective in disinfecting water to make it safe for drinking, especially water from bore-hole and rain tanks. This water has a low turbidity (<5NTU). The technology and other household water treatment technologies should therefore be promoted to improve on the quality and therefore health of the population.

Rain harvesting should be encouraged at household level. Harvested rain water is not turbid and therefore SODIS treatment would be much easier than in more turbid water from open wells and shallow wells.

SODIS and pupil Attendance patterns

The lack of significant association between SODIS and absenteeism reductions can mainly be attributed to the study implementation, which could have led to some of the above mentioned scenarios. This is especially true with regard to the noted poor record keeping on the part of the teachers who might have started with high enthusiasm at the beginning of the study but may have been fatigued as time went on and were not keeping proper records of pupil attendance patterns.

SODIS Dissemination Survey

Household water treatment technologies including SODIS not only lower health costs and increase in productivity but may also reduce school absenteeism (Hutton *et al.*, 2007) hence improvement academic performance of pupils. This is especially true for girls who more often than not must assume the responsibility of caring for ill family members (UNICEF, 2008a). Findings of this survey revealed that indeed SODIS was viewed as having a positive impact on the community in not only in terms of reduced family illness episodes and workload but also reduced pupil absenteeism from schools.

Also in comparison to boiling which was the most popular HWT in the community before this study, SODIS is not associated with cost and time used in procuring fuel for boiling water or the pollution of indoor air quality and associated respiratory infections. The technology should therefore be promoted instead of boiling.

Glass Vs PET Field comparison study

This study has shown that glass bottles are as effective as PET plastic SODIS bottles for inactivating *E. coli* in drinking water in sub-Saharan field conditions. It therefore remains the end-users choice whether to use glass of PET bottles depending on factors such as availability, affordability and portability.

4.5 Reflections/Limitations of the Study

During the course of this study, a number of limitations were encountered. Reflections on these limitations have helped to discover weaknesses in the study design used and given an opportunity to re-do the study; this is what would be done differently.

4.5.1 Water Quality Analysis

During microbial analysis of water, I obtained "too numerous to count colonies (TNTC)" from some samples especially those from open dug well sources. These were assigned a maximum value of >300CFU/100 mL. It was therefore not possible to exactly quantify the level of contamination of each sample with TNTC bacterial counts. Preparation of smaller volumes and dilutions of highly contaminated water samples would have helped eliminate this. However, this would have required a lot of media and due to financial constraints and time frame; it was not affordable to do this.

Because of climate change, rains were at times received at unexpected times and this was also true for the dry spells. The monthly sampling during the study was insufficient to give a clear picture of contamination especially with regard to seasonal variations. Weekly sampling would have helped to get a clearer picture of this relationship. In addition it would have helped to increase monitoring of pupil attendance patterns at school. However, due to distance from sampling field to the laboratory (almost 300km) it was financially and time wise not feasible to perform weekly sampling. An alternative would have been to have field test kits for quick interpretation of results and further analysis of water in the laboratory would be carried out on highly contaminated samples.

4.5.2 Attendance Monitoring Patterns

For better monitoring of pupil attendance patterns and records, at least two or more teachers from each school should be trained so that they are able to help keep each other in check for attendance record purposes and reduce on the effect of fatigue. In our study, it was only possible to train one teacher due to financial constraints. Because of this, attendance data of two schools

were transferred where the corresponding teachers were transferred to other schools was lost. These teachers went with all the records and it was not possible to trace them. If another teacher from the same school had also been trained this phenomenon would not have arisen since the remaining teacher would have kept the records.

Secondly, due to financial and personnel constraints, the researcher's visits to schools were more often than not predictable hence giving teachers ample time to organize their records and make sure that the researcher finds these ready. It would have been better to have at least two research assistants stationed in the field to perform un-announced weekly spot-checks on schools especially with regard to attendance records. It is possible that some teachers took even more than a week to monitor and keep pupil attendance records and just back dated their records at the expected scheduled visits of the researcher. This is evidenced by the fact that sometimes records were made for weekend and public holidays when pupils were not in school and therefore could not have missed school. Although such data recorded on weekends and holidays was excluded from analysis, this was a pointer that other data entered on normal school days might not have been genuine.

It would also be wise to train implementers of the SODIS project separately to avoid cross-contamination or cross-over of information from the clusters already implementing the intervention to those clusters not yet implementing it. In this study, all teachers from the selected schools were initially trained together and this could have led to some teachers implementing the technology in their schools before they were meant to start and this could have had an effect of the results got as stated above.

Finally, parents would also be more involved in the in the study from the onset. They would be tasked with reporting causes of absenteeism to data collectors to cross-check with self-reported causes by pupils. This would help us to capture data very quickly and cross-check with any anomalies in the teachers' records. Plus, it is not in doubt that parents would be more interested in the well-being of their children so would give more reliable data on their children.

4.6 Future Work

Presently, a book chapter on findings from this study is being written. This is in contribution to a book being written in collaboration with other Water is Life (WIL) researchers' on findings from each research project. This book will be used to inform and guide policy makers especially in Uganda on matters related to water safety and access in rural settings.

Plans to carry out similar study in Uganda using the same design but with the above suggestions incorporated are underway. Funding for this study is yet to be found but it is hoped that upon receipt of a grant, this project will be in collaboration with Makerere University. This will lead to the award of a master's degree program in promotion of point of use household water treatment technologies in Uganda.

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APPENDIX A: PARTICIPANT INFORMATION SHEET.

Title: A School-based Health Impact Assessment Trial of Solar Disinfection of Drinking Water in Masaka District in Uganda

Principle Investigator: Jacent Kamuntu Asiimwe.

Sponsor: Irish Aid/HEA

Description:
In this study, the above investigator will be carrying out a health impact assessment of participating pupils using attendance as a basis for monitoring health. The investigator will also conduct face to face interviews to assess the degree of SODIS dissemination into the Makondo community. Basically students and teachers will be trained in the use of SODIS and participating students will be required to drink SODIS treated water at all times during the course of this research. Their attendance will then be monitored by school teachers or nurses. Reasons for absence from school will be recorded if the participating student does not attend school on a particular day. Prior to the introduction of SODIS, the researcher will obtain non- attendance records of participating pupils from the school head teachers. The head teachers will on behalf of participating pupils and their parents sign a consent form in their presence to enable the researcher access these records, in addition one representative of the parents and one for the pupils will also sign the consent form.

The investigator will also be carrying out regular water quality laboratory tests to ascertain the quality of SODIS treated water in relation to the raw untreated water from the study area.

Risks
No study on SODIS has shown an increased contamination to water exposed to the sunlight. Rather, there have only been positive results even with minimal exposure to the sun so there will not be any increased health risk to the participants.

Some concerns have been raised about health risks associated with the deterioration of the plastic bottle material as a result of prolonged exposure to sunlight. However, no hazardous substances have been detected in bottles subjected to the standard SODIS procedure over 6 months. It is recommended that the bottles are replaced every 6 months.

Benefits:
Consistent use of SODIS for water treatment, proper water storage in addition to other use of good sanitary practices have been shown to reduce occurrence of water-related and water-borne diseases. The participants will therefore benefit through reduced disease incidents and will in turn be able to regularly attend school.

Economically, if SODIS is accepted by the community, it will help save time and money in terms of reduced disease incidents, no need to look for fuel to boil drinking water and is environmentally friendly and sustainable.

Time Commitment and Incentive.
This study will be conducted during the period of January 2011 to December 2012. The participants will be provided with and required to fill a 2 litre plastic mineral water bottle with water and expose it to the sun for a period of not less than six hours. This is the water that they will consume the following day as they expose more for the next day's consumption. The researcher estimates that this process of exposing water to the sun should take no more than ten minutes of the students' time every morning.
During school holidays, the investigator will carry out in-depth discussions and questionnaire interviews with the parents/caregivers of the participating pupils who will have already used SODIS at school to assess level of dissemination. The researcher estimates that this will not take more than twenty minutes of the care-givers' time.

As a form of incentive, the researcher will freely give additional water and sanitation health information to the participating schools and it is hoped that the general health of all pupils will improve if these practices are put in place and adhered to.

Also water quality information obtained from laboratory tests will be given to the teachers in these schools for them to be able to understand the difference in quality between treated and untreated water. It is hoped that this information will encourage the teachers to promote and continue with SODIS even after the project has wound up.

Confidentiality:
You or your child's name will not be included on any data collection instrument rather you will both be provided with a random number which cannot be traced back to you or your child after the study. Also, this informed consent will not be kept with any of the other documents completed with this project and all documents in regard to this project will be destroyed after the study.

Right to Withdraw:
You and your child's participation in this study are entirely voluntary. You may choose not to allow your child to participate without any adverse consequences to you or your child. Should you choose to allow participation of your child and later wish to withdraw from the study, you may do so at any time without incurring adverse consequences to yourself or your child.

Ethical Approval:
This study has been reviewed and approved by the Royal College of Surgeons in Ireland's Research Ethics Committee (REC). The REC has determined that this study meets the ethical obligations required by the Irish government and college policies.

If you have questions or concerns regarding this study please contact the investigator or advisors. If you have any questions, concerns, or reports regarding your rights as a research subject, please contact the REC Administrator

Investigator: *Jacent Kamuntu Asiimwe*
+256-784-092788,
jacentasiimwe@rcsi.ie

Primary Advisor: *Dr.Kevin McGuigan*
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Makerere University
+256 772577708
ckmuyanja@agric.mak.ac.ug

REC,
Research Office,
121 St Stephens Green,
RCSI,
Dublin 2

APPENDIX B: ATTENDANCE RECORD CONSENT FORM

I _____ (Full name) the headmaster of _____ (Name of School) and on behalf and in the presence of participating pupils and their parents, hereby fully and freely consent to the researcher getting non-attendance records from my school for the purpose of the study entitled: *A School-based Health Impact Assessment Trial of Solar Disinfection of drinking water in Masaka district in Uganda.*

We understand and acknowledge that the study is designed to promote scientific knowledge.
We understand that we may withdraw my consent at any stage in the study. We acknowledge the purpose of the study and any risks involved from the study procedures. The nature and purpose of such procedures has been described to us in the Information Sheet and has been explained to us by: Jacent Kamuntu Asiimwe and we have discussed these matters with her to our satisfaction

Head Teacher: _____
Date: _____

Witnessed by : _____(Parents' representative)
_____ (Pupils' representative).
Date: _____

DECLARATION BY THE INVESTIGATOR

I confirm that I have provided an Information Sheet and explained the nature and effect of the procedures of this study to the participant and that his/her consent has been given freely and voluntarily.

Signed: _____

Date: _____

Status: Principle Investigator

APPENDIX C: RCSI ETHICAL APPROVAL

Tel: +353 1 4022373 Fax: +353 1 4022449 Email: recadmin@rcsi.ie

Dr. David Smith, Acting Chair
Ms. Stephanie O'Connor, Convenor

Royal College of Surgeons in Ireland
Coláiste Ríoga na Máinleá in Éirinn

RCSI

7th October, 2010

Ms Jacent Kamuntu Asiimwe,
C/o Dr. Kevin McGuigan,
Department of Physiology,
Royal College of Surgeons in Ireland,
121 St. Stephen's Green,
Dublin 2.

Ethics Reference No:	REC601
Project Title:	Solar Disinfection of Drinking Water (SODIS)
Researchers Name:	Ms Jacent Kamuntu Asiimwe
Other Individuals Involved:	Dr Kevin G McGuigan, RCSI Dr. Brid Quilty, DCU Dr. Charles K. Muyanja, Makerere University

Dear Ms Jacent Kamuntu Asiimwe,
Thank you for your Research Ethics Committee (REC) application.

We are pleased to advise that ethical approval has been granted by the committee for this study.

This letter provides approval for data collection for the time requested in your application and for an additional 6 months. This is to allow for any unexpected delays in proceeding with data collection. Therefore this research ethics approval will expire on 31st July, 2013.

Where data collection is necessary beyond this point, approval for an extension must be sought from the Research Ethics Committee.

This ethical approval is given on the understanding that:

- All personnel listed in the approved application have read, understand and are thoroughly familiar with all aspects of the study.
- Any significant change which occurs in connection with this study and/or which may alter its ethical consideration, must be reported immediately to the REC, and an ethical amendment submitted where appropriate.

We wish you all the best with your research.

Yours sincerely,

PP Ms. Stephanie O'Connor (Convenor)
Dr David Smith (Acting Chair)

200 RCSI
1810–2010
St. Stephen's Green

APPENDIX D: UGANDA GOVERNMENT RESEARCH APPROVAL

THE REPUBLIC OF UGANDA

OFFICE OF THE PRESIDENT

PARLIAMENT BUILDING P. O. BOX 7168 KAMPALA, TELEPHONES: 2848818, 343834, 343826, 343843, 233717, 344826, 230846, FAX: 2258458/258143
Email: secretary@op.go.ug, Website: www.officeofthepresident.go.ug

ADM 154/212/01

January 4, 2011

The Resident District Commissioner
Masaka District

This is to introduce to you **Asiimwe Kamuntu Jacent** a Researcher who will be carrying out a research entitled **"WATER IS LIFE: MAZZI BULAMU Project"** for a period of **03 (three) years** in your district.

She has undergone the necessary clearance to carry out the said project.

Please render her the necessary assistance.

By copy of this letter you **Asiimwe Kamuntu Jacent** is requested to report to the Resident District Commissioner of the above district before proceeding with the Research.

Alenga Rose
FOR: SECRETARY, OFFICE OF THE PRESIDENT

Copy to: Asiimwe Kamuntu Jacent

APPENDIX E: SODIS TRAINING POSTER

SODIS IS SIMPLE

STEP 1
Wash bottles before use with brush & soap Rinse it well

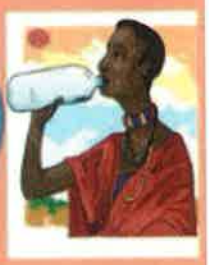
STEP 2
Fill half way with water & shake well

STEP 3
Top up the bottle

STEP 4
Cover Bottle tightly

STEP 5
Put in direct sunlight for 6 or more hours

STEP 6
Drink directly from bottle



Mukwano, have you already put your bottles into the sun today?
Mukwano, ecuppa onjjanise mukasana olwaleero?

APPENDIX F: SODIS DISSEMNINATION SURVEY QUESTIONNAIRE

Interview ad inistered questionnaire desi ned to assess the level of SODIS disse ination into the Nda we co unity throu h use of school children

Ai : To investi ate whether pupils who use SODIS treated at school are effective in the transfer of knowled e back to their ho es/co unities

Investi ator: Jacent Asii we

Purpose: Acade ic Research, Water is Life Project.

Na e of Respondent: (optional) _____

Na e of School Child Attends. _____ **A e** **Sex**

Water Source Information

1 What is the ain source of drinkin water for your household?
a) Shallow wells
b) Protected sprin s/wells
c) Open wells
d) Borehole
e) Water tank (rain harvested)
f) Tap/piped
) Other (please specify)

2 What is the ain source of water used by your household for other purposes such as cookin and hand washin etc?

a) Shallow wells
b) Protected sprin s/wells
c) Open wells
d) Borehole
e) Water tank (rain harvested)
f) Tap/piped
) Other (please specify)

How lon does it take to o there (the source), et water and co e back ho e?

a) Less than 0 inutes
b) 0 Minutes
c) 1 hour
d) More than 1 hour

b. How any ti es each day is water collected fro this source?

Once a day
2- ti es
Greater than ti es

4 Who usually oes to this source to fetch the water for your household?

a) Children

b) Wife/Mother

c) Husband/Father

d) Hired anpower

e) Other (please specify).

Water Safety and Health

5 Do you treat your water in any way to ake it safer to drink?

Yes/No

6. If yes, what usually do you do to the water to ake it safer to drink?

a) Boilin

b) Solar Disinfection

c) Use of chlorine

d) Filtration

f) Other (please specify)

If no, why don't you treat it?

a) No ti e

b) Lack of knowled e on how to treat it

c) No need (water is safe)

d) Other (please specify)

Solar water Disinfection (SODIS)

7. Have you ever heard of SODIS?

Yes/No

8 If yes to 7 above, how did you learn about this technique for the first ti e?

a) My child fro school

b) Co unity health pro oters

c) Friend/nei hbor

d) Media (radio/television)

e) Other (please specify)

9 How uch knowled e do you have about SODIS and can you ive a brief description of the technique?

a) No knowled e (have never heard of it)

b) Scanty knowled e (heard about it but not sure how to do it)

c) Very knowled eable (knows how to treat water usin SODIS)

10) Do you always use SODIS to treat your drinkin water?

Yes (always)

So eti e

Never use it

10b) If no why have you never used SODIS?

a) No ti e

b) Cost of bottles too hi h

d) Other (specify)

10c) If yes, co pared to other water treat ent ethods you have used before, have you noticed any in the a ount of work used to treat water?

No chan e notice

A ount of work has increased (explain)

A ount of work has reduced (explain)

11) Since you started drinkin SODIS treated water in your household, have you noticed any chan e in illness episodes for your school oin child?

Illness episodes have reduced (explain)

No chan e noticed

Episode have increased

11b) Have you noticed any change in your child's school attendance patterns?

Increased absence fro school

Reduced absenteeis fro school

No chan e noticed

12) Do you know that clear lass can also be used for SODIS?

Yes/No

Cost and social aspects

1) How easy is it to et plastic/ lass water bottles?

a) Very easy

b) Not easy

1 b Where/how did you et the bottles?

Fro rubbish bins

Foot paths and roadsides

Tradin centers/ arkets

Buy the fro shops

14) Are you able to buy at least two 2 litre bottles of water /year?

Yes/No

14b) what is the esti ated cost of each bottle (plastic/ lass)?

15) How any fa ily e bers are you in your household?

a) 1-2

b) -5

c) 6-9

d) > 10

16) What is the hi hest level of education you have attained?

a) None

b) Pri ary school

c) Hi h school

d) University

Thank you for your ti e

APPENDIX G: MAKONDO PARISH CHILDREN'S HEALTH DATA 2011

Date	ID	Sex	Age	Disease	Village
2011-01-03	758651	M	6	malaria	MAKONDO
2011-01-03	919159	F	7	malaria	KIYUMBAKIMU
2011-01-03	901422	F	9	malaria	KIYUMBAKIMU
2011-01-03	863358	M	10	malaria	RUYIYI PORTAZI
2011-01-07	294052	F	8	malaria	WAJJINJA
2011-01-12	297629	F	6	malaria	KANYOGOGA
2011-01-15	348597	M	8	malaria	MICUNDA
2011-01-15	135887	F	10	malaria	KIGANJO
2011-01-17	174015	F	7	Intestinal worms	WAJJINJA
2011-01-20	817898	M	9	malaria	RUYIYI PORTAZI
2011-01-21	583563	F	9	malaria	MAKONDO
2011-01-22	293172	F	10	malaria	MICUNDA
2011-01-23	580945	F	6	malaria	MICUNDA
2011-01-26	516938	M	8	malaria	MICUNDA
2011-01-26	595590	F	9	malaria	MISAANA
2011-01-27	144764	F	7	malaria	MAKONDO
2011-01-27	627515	F	10	malaria	MICUNDA
2011-02-02	598233	F	6	malaria	MICUNDA
2011-02-02	316756	F	9	malaria	KIJAJASI
2011-02-03	704760	F	7	malaria	MICUNDA
2011-02-04	225211	F	8	Intestinal worms	KIGULUKA
2011-02-04	752415	M	9	malaria	MICUNDA
2011-02-07	359693	F	6	Diarrhea - Acute	KANYOGOGA
2011-02-09	569138	F	9	malaria	MICUNDA
2011-02-10	982525	M	11	malaria	MICUNDA
2011-02-15	375628	F	8	malaria	WAJJINJA
2011-02-15	621696	M	11	malaria	MAKONDO
2011-02-17	627285	F	9	malaria	MICUNDA
2011-02-18	475590	F	10	malaria	MICUNDA
2011-02-19	411200	F	10	malaria	KIYUMBAKIMU
2011-02-22	215838	M	6	malaria	MAKONDO
2011-02-24	640689	F	9	malaria	MAKONDO
2011-02-25	362596	F	10	malaria	MICUNDA
2011-02-28	755261	M	9	Intestinal worms	MICUNDA
2011-03-01	414508	F	6	malaria	MICUNDA
2011-03-01	275026	F	7	malaria	MICUNDA
2011-03-03	269792	M	6	malaria	MAKONDO
2011-03-03	549838	F	6	malaria	MICUNDA
2011-03-04	326408	F	9	malaria	KANYOGOGA
2011-03-07	690033	M	11	malaria	MICUNDA
2011-03-08	210335	F	6	malaria	MAKONDO
2011-03-08	121208	F	10	malaria	MAKONDO

Date	ID	Sex	Age	Disease	Village
2011-03-10	561460	M	10	malaria	MICUNDA
2011-03-11	421491	F	11	malaria	MISAANA
2011-03-14	936269	F	9	malaria	KIJAJASI
2011-03-17	179468	M	6	malaria	MICUNDA
2011-03-17	559049	M	7	malaria	KIBUYE
2011-03-20	585559	F	11	malaria	KIBUYE
2011-03-23	893257	M	8	malaria	MAKONDO
2011-03-25	932649	F	6	malaria	MAKONDO
2011-03-25	688536	M	11	malaria	MAKONDO
2011-03-30	493411	F	7	malaria	MAKONDO
2011-04-04	455817	F	7	malaria	MICUNDA
2011-04-05	189256	F	6	malaria	MICUNDA
2011-04-07	704894	M	10	malaria	KIBUYE
2011-04-12	129641	F	6	malaria	MICUNDA
2011-04-19	350643	F	6	malaria	MAKONDO
2011-04-21	736928	F	6	malaria	MICUNDA
2011-04-27	884002	M	6	malaria	WAJJINJA
2011-04-27	173865	F	8	malaria	WAJJINJA
2011-04-30	181076	F	6	malaria	RUYIYI PORTAZI
2011-05-04	308323	F	6	malaria	MICUNDA
2011-05-04	262476	M	9	malaria	RUYIYI PORTAZI
2011-05-07	627515	F	10	malaria	MICUNDA
2011-05-10	881376	F	9	malaria	KIJAJASI
2011-05-11	649750	M	6	malaria	KIGULUKA
2011-05-11	310333	M	6	malaria	MAKONDO
2011-05-14	552321	F	7	malaria	MAKONDO
2011-05-14	435033	F	7	malaria	MICUNDA
2011-05-14	317917	M	7	malaria	MICUNDA
2011-05-16	657473	F	7	malaria	KIGULUKA
2011-05-16	670012	M	8	malaria	KIJAJASI
2011-05-16	317169	F	9	malaria	MICUNDA
2011-05-18	405289	M	11	malaria	KIYUMBAKIMU
2011-05-19	250202	M	11	malaria	KIGANJO
2011-05-23	383208	F	8	malaria	KIGANJO
2011-05-23	675845	F	8	malaria	MICUNDA
2011-05-24	324914	F	6	malaria	KIGULUKA
2011-05-26	240346	F	8	malaria	KIJAJASI
2011-05-26	718148	F	9	malaria	MICUNDA
2011-05-27	150477	F	6	malaria	MAKONDO
2011-05-27	565350	M	6	malaria	MAKONDO
2011-05-27	781043	F	8	malaria	KIJAJASI
2011-05-27	920922	F	10	malaria	MAKONDO
2011-05-30	142397	F	6	malaria	MICUNDA
2011-05-31	210519	M	7	malaria	KIGULUKA
2011-05-31	367905	F	10	malaria	MICUNDA

Date	ID	Sex	Age	Disease	Village
2011-06-02	984321	M	10	Intestinal worms	MAKONDO
2011-06-02	965210	F	8	malaria	KIGULUKA
2011-06-03	463375	M	11	malaria	KIJAJASI
2011-06-03	927578	M	11	malaria	MICUNDA
2011-06-05	265544	M	10	malaria	KIBUYE
2011-06-05	720393	F	11	malaria	MAKONDO
2011-06-06	194285	F	6	malaria	MAKONDO
2011-06-06	783603	F	8	malaria	MAKONDO
2011-06-06	600983	M	8	malaria	MICUNDA
2011-06-07	997323	M	6	malaria	KIYUMBAKIMU
2011-06-07	277235	F	10	malaria	MAKONDO
2011-06-08	268605	F	6	malaria	MAKONDO
2011-06-08	678021	F	6	malaria	MICUNDA
2011-06-08	645529	F	10	malaria	KIGULUKA
2011-06-08	258482	F	11	malaria	MAKONDO
2011-06-08	945983	M	11	malaria	MISAANA
2011-06-09	152770	M	7	malaria	MAKONDO
2011-06-09	732312	F	7	malaria	RUYIYI PORTAZI
2011-06-10	617383	M	8	malaria	KIYUMBAKIMU
2011-06-10	583563	F	9	malaria	MAKONDO
2011-06-10	994151	M	9	malaria	MICUNDA
2011-06-10	121208	F	10	malaria	MAKONDO
2011-06-11	756805	M	7	malaria	MICUNDA
2011-06-11	246365	F	8	malaria	KIYUMBAKIMU
2011-06-13	528334	M	7	Intestinal worms	MAKONDO
2011-06-13	688577	M	6	malaria	MAKONDO
2011-06-13	990887	F	8	malaria	MICUNDA
2011-06-13	390389	F	9	malaria	MISAANA
2011-06-13	171544	F	10	malaria	MICUNDA
2011-06-13	349237	F	11	malaria	MICUNDA
2011-06-14	500954	M	6	malaria	KIYUMBAKIMU
2011-06-14	987420	M	7	malaria	MAKONDO
2011-06-15	649750	M	6	malaria	KIGULUKA
2011-06-15	316893	M	7	malaria	KIGANJO
2011-06-15	661036	M	9	malaria	MICUNDA
2011-06-16	980250	F	6	malaria	MAKONDO
2011-06-16	439119	F	6	malaria	MICUNDA
2011-06-16	746582	F	9	malaria	KANYOGOGA
2011-06-17	482471	F	8	Intestinal worms	KAYUNGA
2011-06-17	893898	M	8	malaria	KIYUMBAKIMU
2011-06-17	910867	F	8	malaria	MISAANA
2011-06-17	597874	M	11	malaria	KIYUMBAKIMU

Date	ID	Sex	Age	Disease	Village
2011-06-18	928252	F	6	malaria	MAKONDO
2011-06-18	700518	M	8	malaria	MAKONDO
2011-06-18	461861	F	11	malaria	KANYOGOGA
2011-06-19	644882	F	7	malaria	RUYIYI PORTAZI
2011-06-19	342071	F	11	malaria	MAKONDO
2011-06-21	832085	F	10	Intestinal worms	MAKONDO
2011-06-21	366165	F	9	malaria	MICUNDA
2011-06-21	893955	M	9	malaria	MICUNDA
2011-06-21	325434	M	11	malaria	RUYIYI PORTAZI
2011-06-22	502527	F	6	malaria	MICUNDA
2011-06-22	886187	F	10	malaria	KIJAJASI
2011-06-22	400019	M	11	malaria	MICUNDA
2011-06-23	815988	F	6	malaria	KAYUNGA
2011-06-23	718744	F	7	malaria	KIYUMBAKIMU
2011-06-23	836049	M	7	malaria	MICUNDA
2011-06-23	977276	M	9	malaria	MICUNDA
2011-06-24	647861	F	7	malaria	MISAANA
2011-06-24	720852	F	11	malaria	MAKONDO
2011-06-25	680983	M	7	malaria	KANYOGOGA
2011-06-27	828435	M	11	malaria	MICUNDA
2011-06-28	694934	F	9	malaria	MAKONDO
2011-06-29	410910	F	7	Intestinal worms	RUYIYI PORTAZI
2011-06-29	807785	F	8	malaria	MICUNDA
2011-06-29	293172	F	10	malaria	MICUNDA
2011-06-29	791665	M	10	malaria	MICUNDA
2011-06-30	718614	M	11	Intestinal worms	MAKONDO
2011-06-30	404063	F	6	malaria	MICUNDA
2011-07-02	508135	M	6	malaria	KIGULUKA
2011-07-06	426252	F	6	malaria	MICUNDA
2011-07-08	374031	M	7	malaria	KIBUYE
2011-07-09	578777	M	11	malaria	MAKONDO
2011-07-11	234576	M	11	Intestinal worms	KIJAJASI
2011-07-11	339724	F	8	malaria	KIGANJO
2011-07-11	194750	F	8	malaria	MAKONDO
2011-07-12	629702	M	11	malaria	MICUNDA
2011-07-13	535957	M	6	Intestinal worms	KIGULUKA
2011-07-13	490366	F	6	malaria	KIGULUKA
2011-07-13	729228	F	11	malaria	MAKONDO
2011-07-14	839176	M	7	Intestinal worms	MICUNDA
2011-07-14	736529	F	9	malaria	MICUNDA
2011-07-15	467707	F	6	malaria	MAKONDO
2011-07-15	347529	F	11	malaria	KIGULUKA
2011-07-16	423176	F	6	malaria	MAKONDO
2011-07-18	571571	M	6	malaria	MISAANA

Date	ID	Sex	Age	Disease	Village
2011-07-18	499944	M	7	malaria	KIGANJO
2011-07-18	523164	F	9	malaria	MICUNDA
2011-07-18	808430	M	11	malaria	KIGULUKA
2011-07-19	864542	F	6	malaria	MICUNDA
2011-07-20	912267	M	11	malaria	MAKONDO
2011-07-21	858888	F	7	malaria	KIBUYE
2011-07-21	164984	F	10	malaria	MAKONDO
2011-07-21	943650	F	10	malaria	MICUNDA
2011-07-21	409017	M	11	malaria	MICUNDA
2011-07-23	909927	M	7	Diarrhea - Acute	MAKONDO
2011-07-24	226206	F	9	malaria	MICUNDA
2011-07-25	405260	F	6	malaria	MICUNDA
2011-07-25	746981	F	7	malaria	KIBUYE
2011-07-25	612094	M	8	malaria	MICUNDA
2011-07-25	586738	F	8	malaria	MISAANA
2011-07-27	352851	F	11	malaria	KIYUMBAKIMU
2011-07-27	653579	F	11	malaria	MISAANA
2011-07-28	281133	M	11	malaria	MAKONDO
2011-07-29	110105	F	6	malaria	MICUNDA
2011-08-04	322348	F	9	malaria	KIBUYE
2011-08-04	475590	F	10	malaria	MICUNDA
2011-08-05	912478	F	11	Intestinal worms	KIGULUKA
2011-08-05	173370	M	6	malaria	KANYOGOGA
2011-08-05	791280	F	10	malaria	MICUNDA
2011-08-08	990368	M	6	Intestinal worms	KIJAJASI
2011-08-08	873280	F	10	malaria	RUYIYIKATE
2011-08-12	600983	M	8	malaria	MICUNDA
2011-08-16	832557	F	7	malaria	KAYUNGA
2011-08-19	990368	M	6	malaria	KIJAJASI
2011-08-23	229947	M	9	Intestinal worms	MICUNDA
2011-08-23	459202	F	7	malaria	MICUNDA
2011-08-23	878792	F	8	malaria	MAKONDO
2011-08-29	837348	F	9	malaria	MAKONDO
2011-09-02	739933	F	6	malaria	MICUNDA
2011-09-02	498710	F	9	malaria	MICUNDA
2011-09-05	241851	F	11	Gastro-intestinal disorder (non-infective)	KIGULUKA
2011-09-07	948955	F	10	Intestinal worms	RUYIYI PORTAZI
2011-09-09	421832	F	8	malaria	KIGULUKA
2011-09-17	355427	F	6	malaria	KIYUMBAKIMU
2011-09-17	517894	F	9	malaria	RUYIYI PORTAZI
2011-09-19	299158	M	9	Intestinal worms	MICUNDA
2011-09-19	310008	F	8	malaria	MICUNDA
2011-09-19	355562	F	10	malaria	KIYUMBAKIMU

Date	ID	Sex	Age	Disease	Village
2011-09-20	444975	M	10	malaria	KIBUYE
2011-09-20	356928	F	10	malaria	MISAANA
2011-09-21	825744	F	6	malaria	MICUNDA
2011-09-27	971170	F	6	malaria	KIGANJO
2011-09-28	152770	M	8	malaria	MAKONDO
2011-10-03	550881	F	8	malaria	MAKONDO
2011-10-04	381799	F	7	malaria	MICUNDA
2011-10-06	189001	F	9	Intestinal worms	MICUNDA
2011-10-06	995959	M	10	Intestinal worms	KIGANJO
2011-10-06	117475	F	8	malaria	MICUNDA
2011-10-09	508764	F	8	malaria	KIYUMBAKIMU
2011-10-11	469893	M	9	malaria	MICUNDA
2011-10-14	609210	M	9	malaria	KIGANJO
2011-10-18	993480	F	6	malaria	MAKONDO
2011-10-27	426252	F	9	malaria	MICUNDA
2011-11-07	153505	F	7	malaria	MICUNDA
2011-11-11	984278	F	9	malaria	MICUNDA
2011-11-15	572803	M	10	malaria	KIBUYE
2011-11-17	550801	F	10	malaria	MICUNDA
2011-11-17	665748	M	11	malaria	KIJAJASI
2011-11-18	340899	M	6	malaria	MICUNDA
2011-11-18	783603	F	11	malaria	MAKONDO
2011-11-21	218966	M	8	malaria	MAKONDO
2011-11-23	990368	M	6	Intestinal worms	KIJAJASI
2011-11-23	965210	F	8	malaria	KIGULUKA
2011-11-24	240420	M	11	Diarrhea - Acute	MAKONDO
2011-11-26	361119	F	7	malaria	MICUNDA
2011-11-26	152770	M	8	malaria	MAKONDO
2011-11-28	990368	M	6	malaria	KIJAJASI
2011-11-28	921311	M	9	malaria	KIJAJASI
2011-11-28	944977	F	10	malaria	MAKONDO
2011-11-29	427296	M	8	malaria	MICUNDA
2011-11-30	249446	M	6	Intestinal worms	MISAANA
2011-11-30	353743	F	6	malaria	MAKONDO
2011-11-30	325396	F	7	malaria	KIYUMBAKIMU
2011-12-01	900232	F	10	Intestinal worms	KANYOGOGA
2011-12-01	149503	M	9	malaria	MICUNDA
2011-12-07	261609	M	8	malaria	MAKONDO
2011-12-08	762629	M	6	malaria	MAKONDO
2011-12-09	977890	M	9	malaria	MAKONDO
2011-12-09	736360	M	10	malaria	KIBUYE
2011-12-14	159668	F	6	malaria	MICUNDA
2011-12-14	261609	M	8	malaria	MAKONDO
2011-12-14	718587	F	11	malaria	RUYIYI PORTAZI
2011-12-15	142149	F	8	malaria	RUYIYI

Date	ID	Sex	Age	Disease	Village
					PORTAZI
2011-12-19	564712	M	7	malaria	MISAANA
2011-12-19	552321	F	8	malaria	MAKONDO
2011-12-19	215485	F	10	malaria	KIBUYE
2011-12-20	273397	F	6	malaria	MAKONDO
2011-12-20	583563	F	9	malaria	MAKONDO
2011-12-22	620366	F	8	malaria	KIYUMBAKIMU

APPENDIX H: MICROBIAL AND PHYSICAL WATER QUALITY DURING TRIAL PERIOD.

		Microbial load (CFU/100 L)				Physical characteristics			
School Na e	Month-Year	Total bacteria	*C. Perfringens*	*E. coli*	*E. faecalis*	PH	NTU	Te p(°C)	TDS
Kabuyo a	Apr-11	TNTC	ND	00	00	7.	100	20.5	60
Kyaterekera	Apr-11	TNTC	ND	2	149	7.2	5	21.	8
Kijjajasi	Apr-11	TNTC	ND	84	00	8	5	20.6	7
St. A atha	Apr-11	TNTC	ND	00	18	5.7	7	21.7	119
Mire be	Apr-11	TNTC	ND	00	97	6.9	0	2 .	11
Misenyi	Apr-11	TNTC	ND	18	144	6.5	5	20.	1
Nakatete	Apr-11	TNTC	ND	00	00	6.9	95	21.4	114
Arise and shine	Apr-11	TNTC	ND	00	00	6.1	100	24.5	270
Kin Godfrey	Apr-11	TNTC	ND	00	00	6.6	80	21.9	58
Bunjako	Apr-11	TNTC	ND	00	00	7.4	95	22.	180
Nda we	Apr-11	TNTC	ND	1 8	00	6.9	65	24.1	07
Ndeba Takuwa	Apr-11	TNTC	ND	4	1	6.5	5	2 .2	180
Livin Hope	Apr-11	TNTC	ND	168	178	6	5	2 .7	44
Misana	Apr-11	TNTC	ND	20	80	6.4	0	25.5	10
Kabuyo a	May-11	TNTC	ND	120	90	7.2	n/a	21.	106
Kyaterekera	May-11	TNTC	ND	6	8	8.0	n/a	21.7	19
Kijjajasi	May-11	TNTC	ND	18	8	7.9	n/a	2 .2	12
St. A atha	May-11	TNTC	ND	00	ND	6.4	n/a	22.5	1 4
Mire be	May-11	TNTC	ND	00	8	5.9	n/a	25	1 2
Misenyi	May-11	TNTC	ND	20	150	6	n/a	5	20
Nakatete	May-11	TNTC	ND	00	00	7.4	n/a	2 .7	100
Arise and Shine	May-11	TNTC	ND	124	00	6.4	n/a	24.	2
Kin	May-11	TNTC	ND	00	242	6.7	n/a	21.5	82
Bunjako	May-11	TNTC	ND	154	1 8	7.2	95	2 .	141
Nda we	May-11	TNTC	ND	00	00	6.9	68	21	40
Ndeba Takuwa	May-11	TNTC	ND	ND	ND	6.5	5	24.8	461
Livin Hope	May-11	TNTC	ND	174	68	5.	5	24.2	45
Misana	May-11	TNTC	ND	146	128	6.	25	25.9	110

ND= Not detectable, NTU =Turbidity, TDS= Total Dissolved Solids, 300 CFU/100 mL =Value assigned to plates with too numerous to count bacterial colonies, n/a= measurements not taken.

APPENDIX I: PUBLICATION ON FIELD COMPARISON OF GLASS AND PET PLASTIC SODIS BOTTLES