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Feasibility of SODIS as a Household Water Treatment Method in Rural Tanzania

A Case Study in the Villages Bulyaheke and Mbugani

Master's thesis ACEX30-19-89 in Infrastructure and Environmental Engineering

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Master's Thesis 2019
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Cover: PET-bottles with water are placed in the sun for solar disinfection, i.e. SODIS treatment.

Typeset in LaTeX
Gothenburg, Sweden 2019

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Abstract

Having access to safe drinking water is a human right, yet unimproved water sources are every-day life for 49% of Tanzania's rural population. The aim of this study was to evaluate the feasibility of using solar water disinfection, i.e. SODIS, as a HWT method in rural Tanzania. For this purpose a case study was conducted in the villages Bulyaheke and Mbugani in the northwestern part of the country. This area have experienced cholera outbreaks during the last few years and have reported a high frequency of cases related to waterborne diseases. The microbiological drinking water quality was evaluated by determining the amount of *E. coli* bacteria in six local water collection points. A pilot study of the SODIS method in the communities were conducted, where 10 hours of solar exposure resulted in at least 92% pathogen removal efficiency compared to the raw water. Potential barriers to an implementation of the SODIS method in the communities, as well as the influencing factors for the efficiency of SODIS, i.e. solar radiation, turbidity and water containers, are also identified and discussed. In the absence of sufficient infrastructure coverage, implementing the SODIS method as a HWT method was concluded a feasible short-term solution to reach the SDG target of safe water.

Keywords: Safe drinking water, Waterborne diseases, Water disinfection, Household Water Treatment, SODIS, Solar radiation.

Acknowledgements

This case study would not have been possible without the support and assistance from several parties. We would like to express our gratitude to Engineers Without Borders Sweden, especially the project group in Gothenburg, for the initiation of the project and overall advisement along the course of the study. Special thanks are extended to the Fishers Union Organization in Tanzania, who made our stay in Bulyaheke and Mbugani possible and who supported us with all practicalities along the way. Furthermore, we are particularly grateful to the district water engineer in Buchosa for helping us get in contact with informative people and providing helpful assistance during our stay. We would also like to thank Sebastien Rauch, our supervisor at Chalmers University of Technology, for the guidance you have given us throughout the thesis.

Finally, we would like to express our sincere gratitude for the financial support provided by:

- SIDA, through a Minor Field Study scholarship
- Chalmers University of Technology, through Chalmers Mastercard Scholarship
- Torsten Janssons stipendiefond

We would not have been able to conduct this case study without any of you, so once again, thank you all.

Elin Fransson & Anna Werner, Gothenburg, June 2019

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Abbreviations

CBT	Compartment Bag Test
CI	Confidence Interval
E. coli	*Escherichia coli*
Eawag	Swiss Federal Institution of Aquatic Science and Technology
EWB	Engineers Without Borders Sweden
FUO	Fishers Union Organization
HDI	Human Development Index
HWT	Household Water Treatment
HWTS	Household Water Treatment and Safe Storage
MPN	Most Probable Number
NGO	Non-Governmental Organization
NTU	Nephelometric Turbidity Units
PET	Polyethylene terephthalate
SDGs	Sustainable Development Goals
SODIS	Solar water disinfection
TBS	Tanzania Bureau of Standards
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
UV	Ultra-Violet
WASH	Water Sanitation and Hygiene
WHO	World Health Organization

1 Introduction

It is a human right to have access to safe drinking water, consequently one of the United Nations (UN) Sustainable Development Goals (SDGs) is to ensure that the world's entire population have access to clean water [1]. Today however, almost 2 billion people in the world are in the risk of becoming sick from the use of unimproved drinking water sources or improved sources that are contaminated with faecal matter [2]. This significantly effect the health of people, which is partly shown by that nearly 1000 children die of water and sanitation-related diarrhoeal diseases each day [3]. Access to a sustainable, safe water source not only reduces the risk of diseases but it is also important for the reduction of poverty, human productivity and the country's economy [4].

Numerous studies show that simple, low-cost water treatment methods at a household level drastically can improve the microbiological quality of water, and thus reduce the risk for diseases in the population [5]. In areas that receive a high amount of solar radiation, solar disinfection of water (SODIS) is an economical and viable alternative for the treatment of water on a smaller scale [6]. Consequently, this method is often used in rural areas of developing countries that are in the proximity of the equator, like the Republic Union of Tanzania [7].

1.1 Problem statement

Even though a large number of studies have recommended SODIS as a simple, cost-efficient household water treatment (HWT) method, the worldwide usage remains relatively limited [8]. In areas with poor infrastructure and scarce access to safe drinking water, many people could benefit from practicing the method in their households. However, the success of such implementation rely on multiple factors, including local environmental conditions [9]. Theoretically, due to its geographical location, all of Tanzania should receive a sufficient amount of solar radiation intensity, hence fulfilling one of the basic requirement of SODIS [10]. Nevertheless, the solar radiation intensity is varying from place to place, making the feasibility of the method highly dependent on the location [9]. Solar water disinfection could be an alternative in many cases, yet the factors influencing its efficiency calls for a careful evaluating of the prevailing conditions. Since the main part of the previous research in SODIS is based upon testing performed in laboratories, rather than under field conditions [8], more case studies should be conducted to further determine the potential of the method.

1.2 Aim

The aim of this master thesis is to evaluate the solar water disinfection method, hereinafter SODIS method, and assess how it effects the microbiological quality of water. The objective is to do a feasibility study of introducing the drinking water purification method in the Lake Victoria region, in rural Tanzania. Another objective of this study is to identify potential barriers to the SODIS method and provide a suggestion of the next steps of the implementation process in the villages Bulyaheke and Mbugani in rural Tanzania.

1.3 Research questions

To fulfill the aim and objectives of the project the following research questions have been specified:

RQ1: How is the microbiological water quality in the area of the case study and how does it effect the communities?

RQ2: What local circumstances and technical aspects of the SODIS affects the applicability?

RQ3: How efficient is the SODIS treatment and what are the influencing factors?

1.4 Limitations

This study is limited to investigate a certain set of aspects related to the feasibility of the SODIS method and should therefore not be considered to cover all aspects associated with the concept of feasibility, e.g. the villagers attitude towards the method could not be evaluated.

The drinking water quality evaluation is limited to assess the amount of *E. coli* bacteria in the water, consequently no consideration was taken to measure e.g. viruses or protozoa in the water, or the levels of heavy metals. Besides, since the water testing took place under specific conditions at a certain time of the year, the result might be effected by climate variations. The water could only be sampled and tested during a short period, i.e. the sampling was carried out during three days and the tests were performed during two consecutive weeks. Variations in the result could thus be possible due to weather conditions and seasonal changes. Furthermore, the incubator for the tests could only handle six samples at a time, thus limiting the number of performed tests during the sampling period.

In terms of the solar radiation sufficiency for SODIS, this evaluation rely on data from satellites and was not verified by field measurements.

2
Background

The United Republic of Tanzania is a sub-Saharan country located in the eastern parts of Africa. It was formed in 1964 when the mainland region, previously called Tanganyika, and the island of Zanzibar, were united and formed a sovereign state [11]. Despite a consistent economic growth the past decade [12], Tanzania remains one of the worlds poorest countries, with the latest data from 2011 showing that 49% of its population are living in extreme poverty [13] and approximately 47% are living under the poverty line in 2017 [4]. According to the United Nations Development Programme (UNDP), Tanzania is ranked 154 out of 189 countries in the Human Development Index (HDI) [14].

The poor development rating and high poverty numbers in Tanzania have been linked to the extensive population growth [12]. Since the 1960s the Tanzanian population has increased from 10.1 to 57.3 millions in 2017, currently holding an annual growth rate of 3.1% [15]. A majority of the inhabitants are living in the regions of Dar es Salaam and Mwanza, the two fastest growing urban settlements in the country [11].

The city of Mwanza is located in the northwest region of Tanzania on the shore of Lake Victoria, the largest freshwater body in Africa. Several million people live within 80 km of the shores of the lake, making this region one of the most densely populated areas in Africa. For centuries, Lake Victoria has been a vital resource for the millions of people living along its vast coastline, but the quality of the water is decreasing due to contamination by e.g. wastewater from industries and unsustainable fishing [16]. This pollution has lead to severe consequences as studies have shown a correlation between the elevated exposure to contaminants in drinking water and critical health problems [17]. This was shown in 2016, when a study in Tanzania deemed waterborne diarrhoeal diseases to be the primary cause of death for the entire population [18].

The close relation between the health sector and issues regarding water, sanitation and hygiene (WASH) has made it an important issue for the government of Tanzania [4]. During the last few years, Tanzania has made progress in improving access to basic drinking water services to its population, i.e. from 32% in 2010 to 50% in 2015 [19]. However, the water infrastructure is highly concentrated to the urban areas, while the infrastructure in the rural parts of the country are either poor or non-existing [20]. This difference is shown in Figure 2.1 [19], where improved drinking water sources are protected from outside contamination by either the nature of the construction of through active intervention [21]. Unimproved drinking water sources are thus not protected from e.g. faecal contamination and can be in the form of e.g. dug wells, natural springs and other surface waters [22].

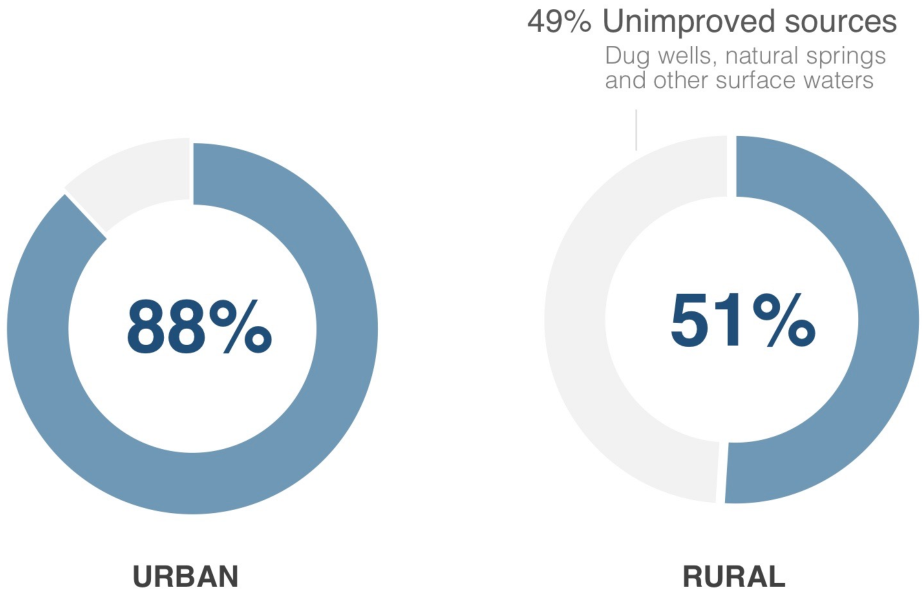

Figure 2.1: The percentage of the population in Tanzania having access to improved water sources in urban and rural areas, respectively.

2.1 Water quality and health

The growth and multiplication of microorganism do not generally occur in water, nevertheless can many pathogens survive long enough to carry infections to humans [23]. However, that microbes are present in the water does not necessarily mean that diseases are spread. To swim in contaminated water can be harmless, while eating e.g. shellfish or consuming the water might lead to sickness [24]. Thus, there are a lot of aspects to take into consideration regarding waterborne microorganisms and health issues. In the following sections the focus will be on microbiological pathogens; the effect they can have on humans, their possible sources and how they can be removed from the water at a household level.

2.1.1 Waterborne diseases

The World Health Organization (WHO) states that waterborne diseases are the cause of approximately 10% of the total burden of diseases worldwide [25]. These diseases are mostly caused by microbiological pathogens in the form of bacteria, protozoa or viruses. In developing countries the most common waterborne pathogens are diarrhoeal diseases [2], which include cholera, typhoid and dysentery [24]. According to the WHO, diarrhoeal diseases are the leading cause of mortality and morbidity for children under the age of five in the world [26].

As mentioned, diarrhoeal diseases can be caused by a number of different microorganism, where some are more aggressive in the affects on humans than others. The bacteria *Vibrio cholerae* causes an acute infection with the consequences of extreme diarrhoea and rapid depletion of body fluids and salts, which left untreated can lead to death [27]. Cholera has risen to epidemic proportions at numerous occasions in primarily sub-Saharan Africa and South Asia [28]. In 2016 there was an outbreak of cholera in the regions of Mwanza, in Tanzania, where thousands of people were affected and a few hundred people died [29].

2.1.2 Contamination sources

The greatest risk of catching microbial diseases is related to unsafe water consumption, in particular consumption of water containing traces of animal and human faeces [25]. In most cases, the faecal bacteria is spread by discharge of wastewater into freshwater and coastal seawater [30]. This is a widespread problem in developing countries, where lack of proper infrastructure result in wastewater being discharged on the ground or directly into water sources. Furthermore, studies have linked the usage of pit latrines to the presence of faecal bacteria in groundwater drinking sources [31]. The construction of the pit latrines allow microbial pathogens to leak into the soil, which spreads to the groundwater and in turn, contaminates local water recipients [32]. In addition, open defecation is still a widespread practice in many developing countries. According to the United Nations Children's Fund (UNICEF), approximately 13 % of the population in rural Tanzania was still practising open defecation in 2015 [20].

2.1.3 Water treatment methods at a household level

There are many sources for contamination of water but research have shown that HWT, and especially the extended concept household water treatment and safe storage (HWTS), drastically can improve the microbial quality of the water, as well as be highly cost-effective and rapidly be implemented to vulnerable populations [6]. According to the WHO, HWTS can furthermore play an important role, in the short and medium term, to reach the SDG target for protection and management of drinking water supplies [2]. There are many different options for HWT methods, which can broadly be grouped into five technologies [33]:

- Boiling
- Solar disinfection
- Filtration
- Chemical disinfection, e.g. chlorination
- Coagulation, flocculation and sedimentation
- Combination of methods

The most common HWT in the world is boiling, as approximately 70% of all HWT users practise the method on drinking water [34]. The boiling of water is, in itself, a straightforward process as the only requirement is to have materials for boiling. However, the efficiency of removing pathogen is related to whether the water actually boil or if it is merely heated, a human factor that is difficult to standardize [34]. Furthermore, the method is energy intensive and precautions need to be taken to avoid re-contamination during the cooling-off period and storage [33]. The following section is an in-depth description on how solar disinfection can work as a HWTS technology.

2.2 SODIS

SODIS is short for solar water disinfection and it is a HWTS method, which uses solar energy for inactivating pathogens in water [8]. This chapter aims to provide a deeper description of solar disinfection and the most important aspects of this water purification method. The sections below include an overview of the history of SODIS, the procedure and the mechanism. In addition, there is an emphasize on the theories related to the technological aspects of the removal efficiency of the method.

2.2.1 History

The principles of solar disinfection as a water purification method has been known for over 30 years [8]. The first discovery was made in 1984 by Prof. Aftim Acra at the American University in Beirut, and since then the full potential of SODIS to deactivate waterborne pathogens has been investigated rigorously [7]. In the 1990s the Swiss Federal Institution of Aquatic Science and Technology, Eawag, initiated an extensive research project on the topic. The aim of the project was to determine the potential of solar radiation to inactivate bacteria and viruses in water. As a result of the research, Eawag formulated a set of procedures for solar water disinfection usage at a household level in developing countries. Those procedures created the foundation for what today is known as the SODIS method [10].

2.2.2 Procedure for the SODIS method

The procedures in the SODIS method are designed for implementation in developing countries that are lacking access to safe drinking water [10]. By following the procedure, the method enables microbiological treatment of contaminated water on a household level. The user of the SODIS method is required to follow four steps;

1. Clean PET-bottles and remove all labels.
2. Fill the bottles with water.
3. Expose the bottles to the sun for 6 – 48 h, depending on the weather conditions.
4. Store the treated water in the bottles until consumption to avoid re-contamination.

2.2.3 Pathogen removal

Previous research show that solar disinfection has potential of removing a large number of harmful bacteria and viruses found in contaminated water. In the past 15 years, numerous studies have shown that SODIS effectively can inactivate microbial pathogens in the form of viruses, bacteria, fungi, protozoa, and helminth parasites [35]. Furthermore, a recent evaluation of HWT technologies performed by the WHO, showed that solar disinfection was consistently effective against bacteria and protozoa, and had reasonably high performance against viruses [2]. This is further acknowledged in a study by McGuigan et al., where it is indicated that viral pathogens are the most resistant to solar disinfection [8]. In Table 2.1 below, is an overview of the waterborne pathogens that has been studied and successfully inactivated through SODIS treatment. In the right column of the table are the illnesses associated with the pathogens [36, 37].

Table 2.1: Waterborne pathogens that have been determined to be inactivated by SODIS* and their impacts on humans.

Type of pathogen	**Species**	**Illness/Symptoms**
Bacteria	*Vibrio cholerae*	Cholera
	Salmonella typhi	Typhoid fever
	Shigella	Diarrhea
	Escherichia coli	Diarrhea
	Campylobacter	Diarrhea
	Yersinia enterocolitica	Diarrhea
Viruses	*Rotavirus*	Diarrhea
	Norovirus	Diarrhea
	Polio virus	Polio
Fungi	*C. albicans*	Candidiasis (fungal infection)
	Fusarium sp.	Mycotoxicosis (systemic poisoning)
Protozoa	*Giardia sp.*	Giardiasis
	C. parvum	Diarrhea
Helminth parasites	*Ascaris sp.*	Ascariasis (intestinal vorms)

**Some of the studies have been conducted under laboratory conditions, thus the inactivation has not been proven by using natural sunlight.*

2.2.4 Factors for removal efficiency

The mechanism of the SODIS method is based on a combination of effects from solar radiation, i.e. thermal heating and ultraviolet (UV) light [8]. The inactivation of the pathogens in the water is thus a result of synergistic effects. However, UV-A radiation (320 – 400 nm) is considered to be the main contributor [38, 39] as the wavelengths of UV-A causes damage to the pathogens DNA, thus deactivating the microbes [40]. A model of the SODIS mechanism and its basic principle can be seen in Figure 2.2.

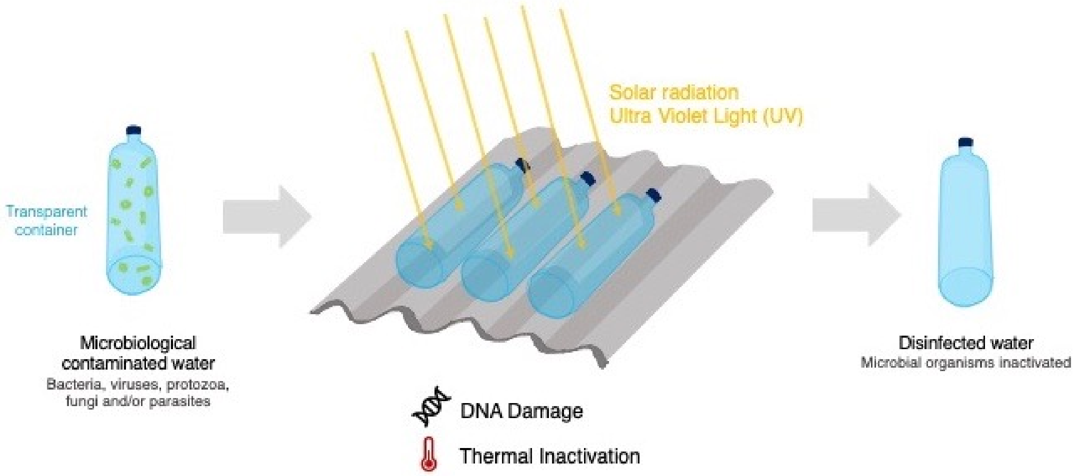

Figure 2.2: Conceptual model of the SODIS method and the involved mechanisms.

In addition, it has been shown that the properties of the containers used during the solar exposure can greatly influence the quality of the water. The following sections further describe the factors known to influence the efficiency of the SODIS method.

2.2.4.1 Solar radiation intensity

The intensity of the solar radiation is one of the factors with greatest impact on the efficiency of SODIS [41]. In this context, the term solar radiation refers to the terrestrial solar radiation, i.e. the solar radiation which passes through the atmosphere of the earth and hits its surface. The intensity of the solar radiation is the amount of solar power per unit area, often expressed in W/m^2. For ensuring that the pathogens are properly inactivated during the SODIS method, the containers need to be exposed to a sufficient amount of solar radiation intensity [42]. A large number of studies has been conducted on the topic and it has been shown that a higher amount of solar radiation intensity corresponds to shorter required exposure time for the inactivation. Yet there is currently no general model for estimating the efficiency in relation to the solar radiation intensity and other influencing factors [10]. There is, however, a threshold value based on experiments by Eawag, suggesting a minimum of 500 W/m^2 solar radiation intensity available for 3-5 hours [42]. There is also a recommended threshold value of solar radiation dose of 20.4 MJ/m^2 [10].

The main aspects affecting the solar radiation intensity is the atmospheric conditions and the geographical latitude. As a rule of thumb, areas with a latitude of $\pm$ 30°, see Figure 2.3, receive a sufficient amount of solar radiation intensity for the SODIS method [10]. It indicates the method is possible in close to the entire African continent, along with southeast Asia, northern part of South America, central America and northern Australia.

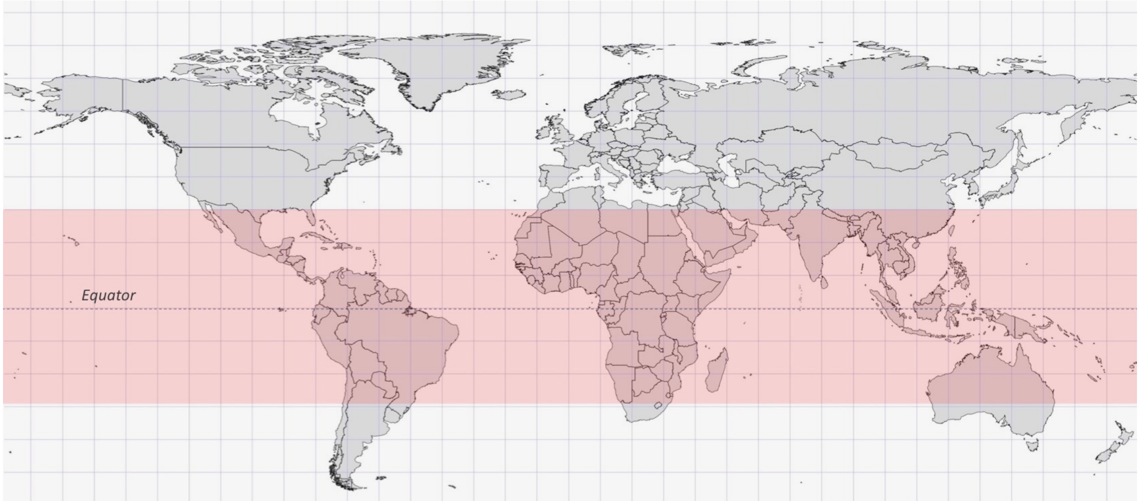

Figure 2.3: The SODIS method is applicable in the part of the world with a geographical latitude between -30° to +30°, which is shown in red.

However, since the solar radiation intensity at a certain location is dependent on more than its geographical latitude, there are additional criteria required for the SODIS method to work properly. Even within the latitude range of ± 30°, some areas does not receive the sufficient amount of solar radiation intensity. For example, in regions with frequent cloud coverage, the solar radiation intensity is reduced, thus, depending on the characteristics of the cloud coverage, the available solar radiation intensity can be substantially lower than the intensity during clear sky conditions [43]. Previous studies have also recommended not to use the SODIS method during rainy conditions, as the solar radiation would not be enough for deactivation of the pathogens [10].

2.2.4.2 Thermal inactivation and temperature

The efficiency of the solar disinfection process can be enhanced with the synergistic interaction of thermal and optical effects [5]. This means that the temperature of the water is important, as thermal inactivation of the pathogens require higher temperatures than 40°C [41]. A recent study showed that there is a risk for slowing down the disinfection process when the water temperature is close to the microbial optimum growth temperature between 35–40°C, so the synergy between irradiation and temperature is optimal above 45°C [44]. This is further acknowledged in a study made by Dejung et al., where the authors suggest a water temperature of 50°C for an increase of the inactivation process in comparison to the isolated impact of radiation or heat [45].

2.2.4.3 Containers for SODIS

There are a lot of options for choosing containers for the usage of SODIS, e.g. plastic bottles, glass bottles or special plastic bags made for SODIS [10]. However, the transparent containers are required to have high transmittance of UV-A radiation and there should be no risk of mitigating harmful compounds into the water [8]. As

PET-bottles fulfill these requirements, in addition to that they are highly available in low- and middle-income countries, they are commonly used as containers for the SODIS method [46].

Another important factor to consider is that the intensity of the solar radiation on the water samples varies with the water depth, i.e. the size and volume of the container. According to the SODIS manual by Eawag, the water depth should be less than 10 cm when using SODIS as increasing water depth reduce the UV-A radiation [10]. Studies have shown that the volume of PET-bottles can range between 0.5 L to 2.0 L without having a significant influence on the solar disinfection efficiency [5]. However, the recommendation from Eawag is to replace the PET-bottles after six months, as the ageing of PET-bottles leads to a reduction of the UV-transmittance [47]. This it further acknowledged in a few previous studies, where the risks associated with photodegradation of plastic containers after prolonged use of SODIS have been examined [7].

2.2.4.4 Position and placement of SODIS containers

The position and placement of the SODIS containers are additional factors that need to be considered, due to that the inactivation of the microbial pathogens occur in a synergism of UV-A radiation and the possibility of thermal effects. For maximal exposure to the sun the containers should be placed in a location with full sunlight throughout the day [10]. Furthermore, the containers should be placed horizontally or at a slight inclination, to minimize the water depth for the solar radiation [45]. The surface on which the containers are positioned also has an effect on the efficiency of SODIS, as the thermal deactivation can increase with a dark, absorptive surface or the optical effects can increase with the use of a reflective surface [5].

2.2.4.5 Turbidity in water samples

The level of turbidity in the water samples has been shown to have a significant effect on the inactivation process of faecal coliforms [9]. Studies have shown that water samples with high turbidity requires a considerable longer duration of solar exposure compared to samples with low turbidity [41, 44], as the suspended particles reduces the light penetration in the water [48]. However, other reports show that even though the turbidity can reduce the intensity of the irradiation, the efficiency of the solar disinfection can be slightly enhanced due to that the particles can act as photosensitizers for the thermal inactivation [5]. The authors to these studies point out though that this slight enhancement of the disinfection was only shown in moderate turbid waters, and further studies are required on samples with high turbidity.

The turbidity of water samples can be checked by placing the bottles on top of a newspaper headline. If the text is readable when looking at the neck of the bottle through the water, the sample has an approximate turbidity of 30 NTU (nephelometric turbidity units) and can be used for SODIS [49]. If the letters are not visible, a reduction of the turbidity can be done by e.g. settling and decanting, cloth filtration, sand filtration, or flocculation [10].

2.2.4.6 Storage and handling of SODIS-treated water

Research have shown that faecal contamination can occur in all stages of use, i.e. at the water source, during collection, transportation and in the homes by e.g. unclean hands [6]. Consequently, safe storage of the water during and after treatment is almost as important as the treatment itself [38]. The two significant factors that can influence the quality of the water when using the SODIS method is; regrowth of bacteria and contamination during consumption [10].

As the exposure time will vary depending on the cloud cover and the turbidity, the containers might need to be stored over night until the disinfection process can continue the next day. Studies have shown that the concentration of bacteria remains constant during this short interruption of the process [5, 50]. However, after the SODIS process is completed the literature are inconclusive whether the pathogens recovers from the solar radiation or not. Some studies recommend that the solar disinfected water should be consumed withing 24–48 hours to avoid the possibility of post-exposure re-growth of bacteria [8, 35]. Other studies claim that no bacterial regrowth will occur in the water as long as the UV-A radiation is sufficient [39, 40, 9].

Re-contamination of the water can occur in the process between treatment in the SODIS containers and the consumption of the water, through the use of e.g. unclean utensils, vessels or dirty hands [10]. However, studies have shown that containers with narrow openings and taps significantly can reduce this type of contamination [6]. Furthermore, the recommendation from Eawag is that the treated water should remain in the SODIS containers and consumed directly from there, or poured into a clean cup or glass immediately before it is drunk [49].

3

Methodology

The following chapter introduces the methodology approach of this study. First, the research design is presented, including a background and description of the case study. This is followed by collection, analysis and verification of the data, providing a description of the methods used in each procedure.

3.1 Research design

The objectives of this study was to evaluate the feasibility of the SODIS method in the rural villages of Bulyaheke and Mbugani in Tanzania. In general, feasibility studies aim to assess the practicability of a project under a certain context, hence evaluating the situation using all the relevant aspects. Prior to the conduction of this study, three focus areas with corresponding relevant aspects were defined and used as the frame for the feasibility evaluation. The focus areas are related to one research question each, as illustrated in Figure 3.1 below.

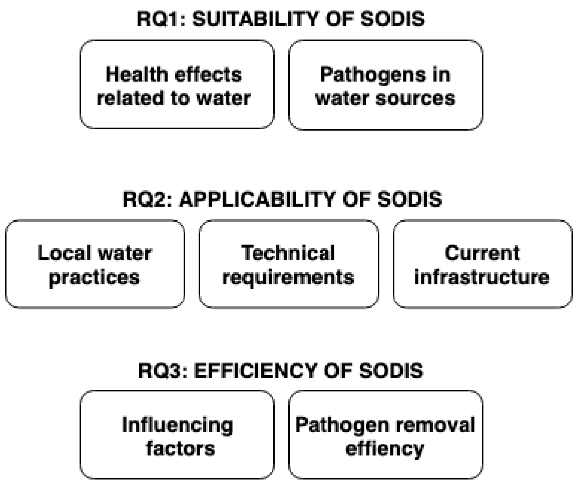

Figure 3.1: The three chosen focus areas and the aspects that are relevant for this feasibility evaluation.

Considering the complexity of the study and the high relevance of contextual conditions, a case study was deemed the most suitable method to fulfill the purpose of the study. Case studies can be constructed in numerous ways and it is one of the most frequently used methods in qualitative research [51]. When conducting a case study there are five main steps that should be included in the process, which can be seen in Figure 3.2

Figure 3.2: The five main steps involved in a case study process.

3.1.1 Background to case study

The first contact with the villages Bulyaheke and Mbugani started as a project initiated by Engineers Without Borders (EWB) Sweden in 2017. Previous EWB projects in the region had displayed a critical water situation in the fishing communities along the coast of Lake Victoria. After contact with the Non-Governmental Organization (NGO) Fishers Union Organization (FUO), the area of Bulyaheke and Mbugani was chosen as a potential location for a future project. These villages were known to have poor access to safe drinking water and in recent years cholera outbreaks had been reported in the region. EWB formed a project group with the aim of finding a way of improving the drinking water quality for the communities, hence the SODIS method was introduced as a possible solution. In the fall of 2018, the authors to this study took over the practicalities of looking into the feasibility of the SODIS method in the villages, as members of EWB.

3.1.2 Case study description

The villages of Bulyaheke and Mbugani are located in the Mwanza region at Lake Victoria in the northwestern part of Tanzania, see Figure 3.3.

Figure 3.3: Map of Tanzania with the Mwanza region highlighted in orange and a detailed map showing the location of the case study.

Bulyaheke and Mbugani are both included in the Bulyaheke Ward, which is part of Buchosa District. The center of the combined villages are positioned at the coordinates 2°18’03.4"S and 32°18’46.1"E (-2.300934, 32.312812) at an altitude of 1153 meters over sea level. The total population of Bulyaheke and Mbugani is 12000 people and the region is characterized by agriculture and fishing occupations, as can be seen in Table 3.1.

Table 3.1: Demographics of the villages Bulyaheke and Mbugani.

	Bulyaheke	**Mbugani**
Population size:	5637	6368
Number of households:	939	1061
Gender:	M:2706 F:2931	M:3311 F:3056
Main professions:	Fishing, agriculture, livestock and small scale industries	

3.2 Data collection

When conducting a case study it is recommended to use multiple methods for collecting data [51]. The methods used for collecting data in this study includes; interviews, field observations, on-site water testing and record reviewing, as can be seen in Figure 3.4.

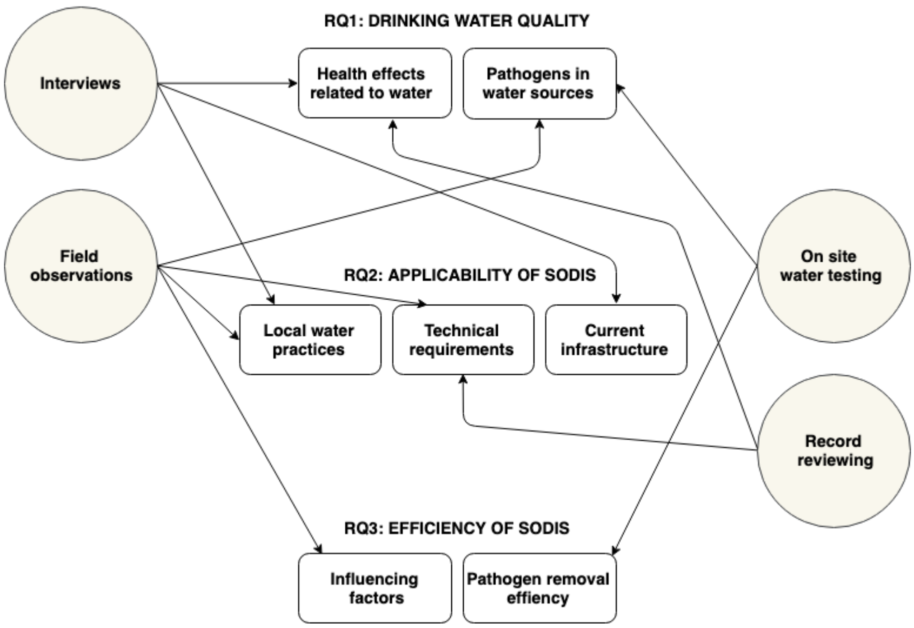

Figure 3.4: An overview of the methods used for the data collection and how they correspond to each focus area.

3.2.1 Interviews

When collecting data as part of a case study it has been argued for that unstructured, open-ended interviews is the most suitable. According to studies it is preferable if the interview is structured as a “guided conversation”, this compared to the alternative of a more formal inquiry [51]. In addition, the asked questions should preferable be formulated as "how" and not "why", as this poses a less threatening and more friendly environment for the interview object [52]. The interviews conducted for this study has, as far as possible, been conducted in accordance to the recommendations in these studies. The majority of the interviews were in the form of unstructured interviews but a few of them were formed as semi-structured. A list of the interviews conducted for this study can be found in Table 3.2 below.

Table 3.2: Interviews about water related issues were conducted with people with various occupations.

Occupation	**Interview topics**
District Water Engineer Buchosa District	- General water situation - Existing water infrastructure - Challenges and barriers
Health teacher Local Primary School	- WASH knowledge - Sanitation and health - Domestic water practises
Project Manager Local Primary School	- Projects at local school - Organization and funding
Head Teacher Local Primary School	- General information about local school - Infrastructure and facilities
Chairman Local Dispensary	- Health situation in the area - Waterborne diseases
Local women and men that were collecting water at the sampling points	- Drinking water practises

The interviewees of this study did not speak fluent English, thus, with exception to the interview with the district water engineer, all interviews were conducted using a non professional interpreter. It was the same person who translated all interviews and this person is well informed in water related issues.

3.2.2 Field observations

Collecting data through observations in the field is a useful method to gather information that might be difficult to retrieve elsewhere, e.g. observing situations that might be impolite, insensitive or unwise to talk about during interviews [53]. Thus, field observations allow researchers to get perspective of the issue from another point of view than interviews may provide. The aim of the field observations in this study was to gather information regarding the local practices of water. The observations were conducted as the samples were collected and during the walk between the sampling locations. Furthermore, observations of sanitation and water issues were made during the interviews at the local primary school. The observations were thus conducted with a purpose of providing a description of the local conditions and the knowledge of WASH in the communities. This was managed throughout the days spent in Bulyaheke and Mbugani.

3.2.3 Test of drinking water quality

The quality of drinking water can be tested in countless ways, both in laboratories and directly in the field. Recent studies have shown that there are methods that are easily used in low-resource settings, where there is no significant difference between the results from laboratory testing and these field tests [54, 55]. One of these methods is the Compartment Bag Test (CBT) that evaluates the bacterial contamination of the water through measurements of *E. coli* bacteria. This method is further recommended in the article *Evaluation of Microbial Water Quality Tests for Humanitarian Emergency and Development Settings* [56]. Furthermore, a large number of studies have addressed *E. coli* as the preferred microbial indicator organism for assessment of contaminated drinking water [7].

The CBT method is developed by Aquagenx, LLC and it is a test for detecting and measuring *E. coli* bacteria in a 100 mL water sample [57]. A chromogenic substrate is added to the sample to support the growth of *E. coli*, the sample is poured into a compartment bag and then incubated. The compartment bag is of the Whirl-Pak®type and has 5 compartments of different sizes, i.e. compartments for 56 mL, 30, mL, 10 mL, 4 mL and 1 mL. A water sample of 100 mL is thus divided in the 5 compartments and after incubation each compartment will indicate a negative (presence of *E. coli*) or positive (absence of *E. coli*) result by changing color of the sample. A yellow or brown color corresponds to a negative result, while a blue or green color corresponds to a positive result. Depending on the combination of colors in the compartments the Most Probable Number (MPN) of *E. coli* is determined and the sample can be classified according to the health risk category from WHO [22], which is shown in Table A.1 in Appendix A. The 95% confidence interval that correlates to each MPN of *E. coli* is also shown in the MPN-table made by Aquagenx, LLc. That table, along with a detailed description of the CBT method, can be found in Appendix B.

3.2.3.1 Sampling plan

Prior to performing the water tests with CBT a sampling plan was conducted, where consideration was taken to both the sampling approach and the sampling method. According to the drinking water quality guidelines from WHO the locations of the sampling points should be representative of where water is collected by the public, as well as include the conditions of the most unfavorable water source [31]. With this in mind during discussions with the local officials and the district water engineer, the locations of the sampling points were determined. The sampling plan was thus conducted based on a non-statistical sampling approach of judgmental character. A description of the six chosen sampling locations can be seen in Table 3.3.

Table 3.3: The type of collection points used for sampling locations at the villages Bulyaheke and Mbugani and their correlating sample IDs.

Sample ID	Village	Sampling location
P1	Bulyaheke	Private well
C1	Bulyaheke	Natural spring
L1	Bulyaheke	Shore of Lake Victoria
PC	Mbugani	Private well with hand-pump
SC1	Mbugani	Natural spring southeast of village
SC2	Mbugani	Natural spring northwest of village

3.2.3.2 Raw water quality

The first sampling round took place on March 26th and March 27th, 2019. The main objective during this field excursion was to test the microbiological quality of the raw water. The three sampling locations in Bulyaheke that were shown in Table 3.3, were sampled the first day and the sampling points in Mbugani the day after. The samples were collected in clean 0.5 L PET-bottles using a grab sampling method, i.e. the containers were filled by hand by either submerging the bottles in the water or pouring water from another container to the bottles. Duplicate CBTs were performed on each sample and then incubated for approximately 24 hours, with a maximal and minimal temperature according to Table C.1 in Appendix C. After the incubator time was over the compartment bags were assessed according to the MPN table from Aquagenx, LLC, which can be found in Appendix B, and the contamination and health risk category of each sample was determined.

3.2.3.3 Quality of treated water

The second sampling round took place on April 4th, 2019. During this excursion the objective was to asses the SODIS method in the local circumstances, hereinafter referred to as the SODIS Pilot study. This was done by comparison of the microbiological quality of raw water, SODIS-treated water and boiled water. Three of the six locations in Table 3.3 were used, namely P1, L1 and SC2, as shown in Table 3.4. This selection was based partly on the geographical spread of the water sources and partly on the type of source, so that these sources would still be representative of the area as well as include the most unfavorable collection point. For accordance to the recommendation of water depth for SODIS treatment in section 2.2.4.3, the 1.5 L PET-bottles were measured prior to sampling with the result of an approximate diameter of 9 cm. One 1.5 L PET-bottle was thus filled at each location for the assessment of SODIS, together with 0.5 L PET-bottles for raw water tests and boiled water tests.

Table 3.4: The water sampling locations where samples were retrieved for further testing and evaluation of the SODIS treatment.

Sample ID	Village	Sampling location
P1	Bulyaheke	Private well
L1	Bulyaheke	Shore of Lake Victoria
SC2	Mbugani	Natural spring northwest of village

When all samples were collected, the water samples in the small containers were divided so that half of the raw water was directly tested using CBT, while the rest was boiled for approximately 8 minutes and then tested with the CBT method. The time in the incubator and the minimum and maximum temperature for these tests are shown in Table C.2 in Appendix C.

The three 1.5 L PET-bottles were tested for turbidity by checking if a newspaper headline was readable through the bottle, which was described in more detail in section 2.2.4.5. Thereafter the bottles were placed horizontally on a sunlit roof together with a WADI-unit for solar disinfection. The WADI-unit is a solar powered device that measures the UV-radiation and visualizes the process of SODIS by using smiley-faces on its display. When the WADI initially is placed alongside the bottles in the sun, the display shows a sad face, and when the solar panel on the WADI has measured sufficient UV-radiation for SODIS to be complete, the display shows a happy face [58]. This measurement device has been evaluated in microbiological performance by WHO as meeting the criteria for providing targeted protection, as their assessment showed that the WADI correctly correlated solar radiation that was effective against protozoa and bacteria [2].

After four hours on the roof the WADI displayed a happy face, thus indicating the completion of the SODIS process, so approximately 1.5 dL water was withdrawn from each bottle for testing of the water quality. The bottles were then squeezed together to remove the air, and once again placed on the roof for further exposure to the sun. At dusk the bottles were put indoors for storage over night and the morning after they were again placed on the roof until the WADI-unit showed a happy face on its display. The samples were thereafter tested with the CBT method, where the time and temperature in the incubator for these samples can be seen in Table C.3 in Appendix C.

3.2.4 Record reviewing

The method of data collection through record reviewing was used in two occasions throughout this study. The first refers to RQ1 and the potential water-related health effects in the area. In this case, records from local health facilities were used for retrieving data about the occurrence of waterborne diseases in the area. The data was recorded at Lushamba Dispensary and Kakobe Health Center, both located in the Buchosa District.

The second case refers to records of climatic data, which were used to determine the available solar radiation at the location of the case study. Since the study was conducted with limited time and resources, it was not possible to collect data through own measurements. Instead, the online tool *POWER DATA ACCESS VIEWER* provided by NASA, served as the source of data. By using satellite data, this database contain records of daily total solar radiation incident from the mid 1980s until the present date.

3.3 Data analysis

The data in this study was analyzed by using thematic analysis of the conducted interviews, calculations of the CBT results for removal efficiency, and finally, a comparison of the CBT results to the drinking water guidelines from WHO and Tanzania's national guidelines. These techniques for data analysis will be further elaborated in the following sections.

3.3.1 Thematic analysis - Coding

To ensure the quality of the results, the transcripts from the unstructured interviews were analyzed by thematic analysis, also known as "Coding". The principals of coding is to identify themes or patterns in a set of qualitative data, hence simplifying the process of selecting important and interesting content in the data. Furthermore, coding provide a possibility for the researcher to analyze the relationship between frequency and the contextual conditions of a specific content [59]. Since this study include a combination of semi-structured and unstructured interviews, the coding was used to avoid presumptions and provide an extra level of validity to the results.

In the initial phase, a large number of codes were assign to the transcripts in order to describe and categorize the data. With the aim of finding reoccurring themes or patterns across the interviews, the codes from each transcript were then compared to each other.

3.3.2 Calculations

The removal efficiency of *E. coli* bacteria in the water samples using SODIS treatment was determined by the following formula:

$$\text{Removal efficiency} = \frac{M^r - M^s}{M^r} 100 \quad [\%]$$

M^r = *E. coli* bacteria in raw water sample [MPN/100mL]

M^s = *E. coli* bacteria in SODIS treated sample [MPN/100mL]

3.3.3 Comparison to guidelines

The test results from the CBT were compared to the WHO drinking water quality guidelines, which can be seen in Appendix A, and the guidelines for drinking water by Tanzania Bureau of Standards (TBS). In their *National Environmental Standards Compendium* it is, among other things, stated that drinking water in Tanzania should be free from microorganisms and safe to consume. It is specified that no organism of faecal origin should be present in drinking water, and if there are, remediation measurements should be implemented promptly [60].

3.4 Data verification

The conducted interviews were all recorded and transcribed with the consent of the interview objects. The sampling points for the CBTs were initially suggested by the officials in the villages of Bulyaheke and Mbugani. The final locations were however decided in collaboration with the district water engineer based on what locations would be most representative for the area, while also taking the most unfavorable conditions into account, in this case the water from Lake Victoria. The collection of the samples were conducted using a grab sampling method, with the use of disinfected bottles and plastic gloves. To validate the results of the CBT method all raw water samples and all SODIS-treated water samples were tested in duplicates. The area on where the testing of the samples took place was disinfected before the CBTs were initiated. Furthermore, the results of the CBTs, especially regarding the efficiency of the SODIS method, was thoroughly compared to previous studies in the research field.

4

Results

The results of this case study are presented in the following chapter. The relevance of health issues and water quality are first described, thereafter the characteristics and quality of the local water sources. Finally, the handling of water in the villages and the results regarding the SODIS method and its influencing factors are presented.

4.1 Water quality and local health effects

In the following sections the state of diseases common in the area of Bulyaheke and Mbugani are described. Furthermore, the quality of the water in the local water sources and their characteristics are also presented.

4.1.1 Presence of waterborne diseases in Buchosa district

The ten most common diseases in 2018, along with the corresponding number of cases, at two health facilities in Buchosa district, are shown in Tables 4.1 and 4.2. As can be seen in both tables, two of the most frequent recorded cases are waterborne diseases. This is further recognized in the Figure 4.1 where the distribution of cases related to waterborne diseases in the region are shown. The total number of cases are 23 617, 24 916 and 27 894 for the years 2016, 2017 and 2018, respectively. The full list of the diseases and number of cases in the region can be found in Table D.1 in Appendix D.

Table 4.1: The ten most common diseases and the total number of cases recorded in Lushamba Dispensary during 2018.

Illness	**Number of cases**
1. Urinary Tract Infections	1707
2. Malaria MRDT +ve	1008
3. Other Non-Infectious GIT Diseases	808
4. Diarrhoea With No Dehydration	473
5. Skin Infection, Non-Fungal	419
6. Other Surgical Condition	138
7. Intestinal Worms	96
8. Sexually Transmitted Infection	94
9. Skin Infection - Fungal	84
10. Acute Ear Infection	65

Table 4.2: The ten most common diseases and the total number of cases recorded at Kakobe Health Center during 2018.

Illness	Number of cases
1. Urinary Tract Infections	1001
2. Malaria MRDT +ve	796
3. Upper Respiratory Infections	686
4. Pneumonia, Non-Severe	473
5. Intestinal Worms	435
6. Diarrhoea With No Dehydration	416
7. Other Non-Infectious GIT Diseases	232
8. Mild/Moderate Anaemia	191
9. Road Traffic Accidents	149
10. STI Pelvic Inflammatory Diseases	113

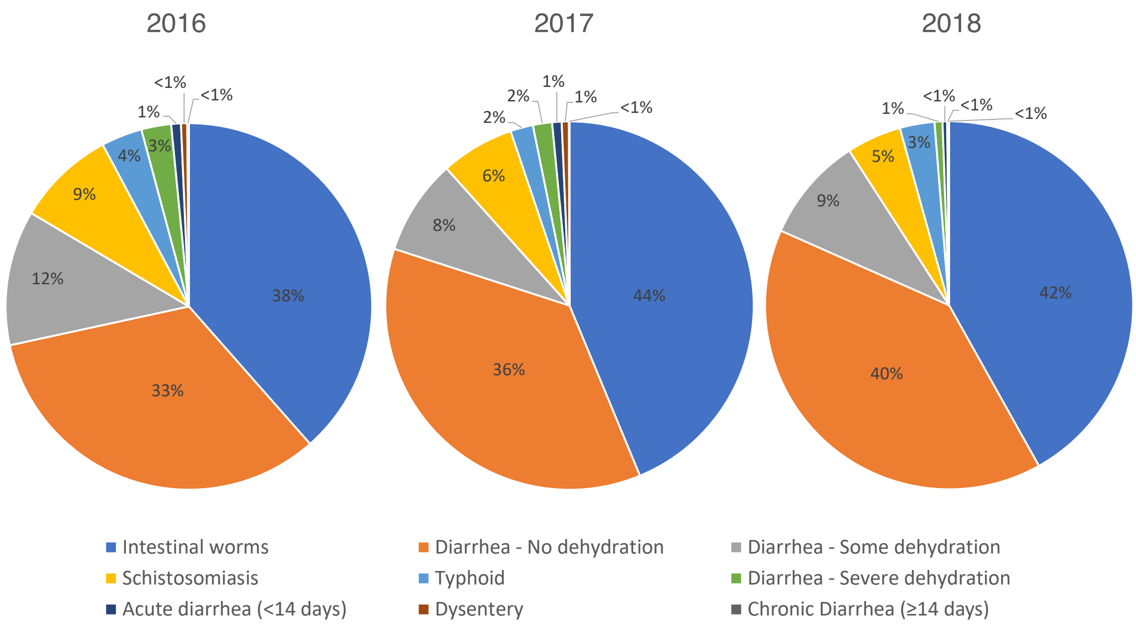

Figure 4.1: The distribution of the total yearly number of cases related to water-borne diseases recorded at health facilities in Buchosa District during three consecutive years.

In the region, the most common cases recorded during 2016-2018 were intestinal worms and diarrhoea with no dehydration. In 2018, these diseases were 41.9% and 39.8% of the total number of cases respectively. Between 2016 and 2018, diarrhoea with no dehydration increased from 33.1% to 39.8% of the total cases. Furthermore, interviews retailed that approximately 200 children per week are dismissed from school due to sickness, with the most common reason being stomach issues. The parents rarely take the children to health facilities though, as few apparently can afford the transportation costs. Interviewees mentioned that the medicine in these cases instead was provided from the local pharmacy, without prior consultation with a doctor. Other interview objects from the sampling locations furthermore acknowledged that they sometimes were sick, but they did not know if the illness originated from the water or somewhere else.

4.1.2 Characteristics and quality of local water sources

At the time of the study, the inhabitants of Bulyaheke and Mbugani did not have access to improved water. Observations and interviews showed that most of the domestic water was retrieved from surface waters, with local natural springs serving as the main source. Even if it was less common, people also collected water directly from the shore of Lake Victoria. However, in the central parts of the villages there are a few self-constructed wells providing a smaller portion of the inhabitants with water. These dug wells are shallow though and not constructed in a manner that protects the water from contamination. According to the district water engineer there are plans of extending the infrastructure to the rural parts of the Mwanza region. The plans include the construction of boreholes at governmental institutions, i.e schools and health facilities, to ensure safe water sources for the population. Presented in Table 4.3 are the test results from the water sample tests conducted on the raw water of six drinking water sources in the Bulyaheke and Mbugani area. The CBT results for the duplicate samples are shown in Table E.1 in Appendix E.

Table 4.3: CBT results for raw water from the sampling locations in Bulyaheke and Mbugani.

Sample ID	**Type of sample**	***E. coli*** **[MPN/100mL]**	**Upper 95% CI [MPN/100mL]**
P1	Raw water	> 100.00	9435.10
C1	Raw water	> 100.00	9435.10
L1	Raw water	> 100.00	9435.10
PC1	Raw water	> 100.00	9435.10
SC1	Raw water	> 100.00	9435.10
SC2	Raw water	> 100.00	9435.10

The result from the CBT show a MPN-value of >100 in all samples collected in Bulyaheke and Mbugani. According to the WHO guidelines for presence of *E. coli* in drinking water, see Table A.1 in Appendix A, a MPN of >100 corresponds to a classification of Very High Risk of contamination. Furthermore, the Tanzania national guidelines by TBS says that drinking water should not contain any faecal organisms, thus meaning that the water sources in the communities of the case study are unsafe to use for consumption.

4.2 Applicability of SODIS

In the following sections the current water situation, concerning both existing infrastructure and local practices, are presented. Furthermore are the technical aspects of the implementation of the SODIS method in the communities described.

4.2.1 Local water practices and infrastructure

As there currently is a scarcity of water infrastructure in Bulyaheke and Mbugani, there is naturally no big-scale conventional water treatment of the raw water. In contrast, the drinking water practices are highly driven by the traditional means of collecting and using domestic water. Field observations and interviews recounted for that villagers collect their domestic water in 20 L-buckets at the water collection points. The water consumption for a family varies from family to family, however the estimate of the interviewees were that each family collect around seven buckets per day. As there approximately are six persons in every household in the area, this leads to a total water consumption of about 23 L per person and day.

Interviews indicate there are no established HWT methods, thus the vast majority of the villagers do not use boiling or any other alternative method for reducing bacteria and other pathogens in the water. However, a few people mentioned that they occasionally filter the water through cloth before drinking it, where the given reason was to remove visible particles. From the interview with the district water engineer in Buchosa District, it was mentioned that the local community discard boiling the drinking water since it changes the taste of the water. Another reason that was mentioned for not boiling the water was the economical aspect of buying materials for burning.

All the same, there are some local practices aiming to prevent the water at the communal collections points from contamination. At the natural springs, water collectors are expected to remove their shoes before entering the area. The reason for this routine was explained as a way of reducing the risk of people bringing impurities into the spring. As could be seen at the sampling location CS1 in Mbugani, i.e. one of the communal, natural springs, a person was assigned the responsibility of maintaining that regulation and could issue a fine in case of violation. In addition, some of the natural springs have surrounding fences for keeping animals out.

4.2.2 Technical requirements

There are a few technical requirements for the SODIS method to work optimally. The intensity of the solar radiation, the type of containers used and placing the containers in suitable places are all important aspect, which will be further presented in the following sections.

4.2.2.1 Solar irradiation sufficiency

The distribution of the daily total radiation incident for the Bulyaheke and Mbugani area is presented in Figure 4.2 below. The data is an approximate summation of the daily radiation between the January 1984 – April 2019.

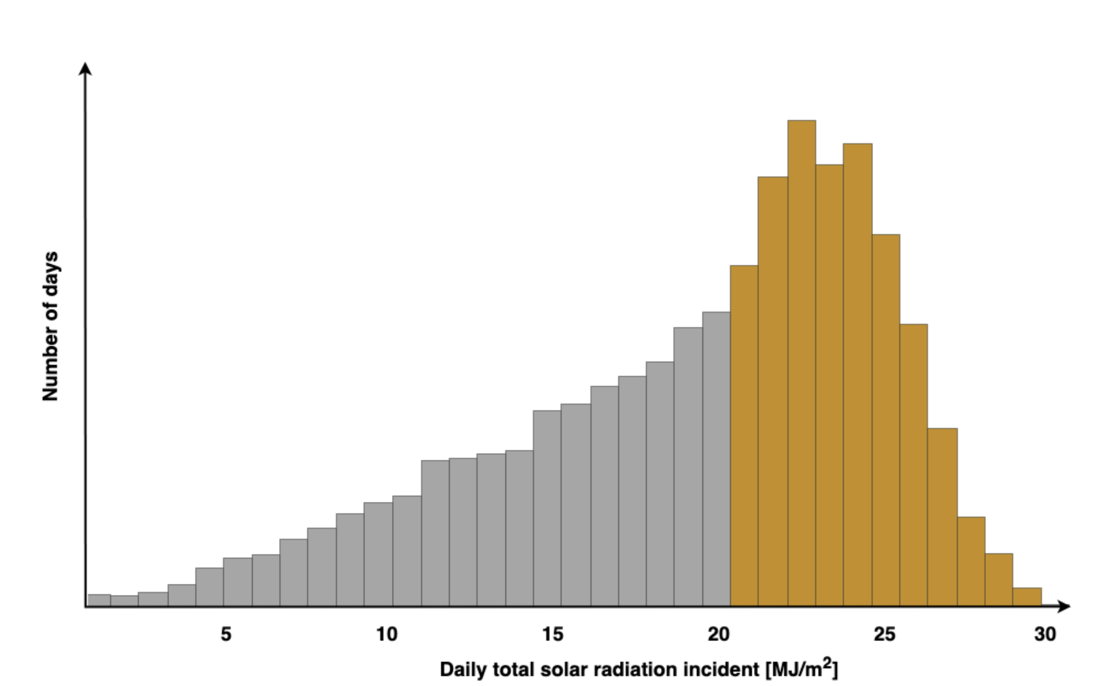

Figure 4.2: The distribution of average daily total solar radiation incident in Bulyaheke and Mbugani in the period January 1984 – April 2019, where the yellow are days above the threshold value and the grey are days below.

In 53% of the days, the dose of total solar radiation per square meter was above the SODIS threshold value of 20.4 MJ/m^2.

4.2.2.2 Practical conditions for SODIS

The observations made in the villages of Bulyaheke and Mbugani indicate they have access to suitable containers for the SODIS method. For example, 1.5 L PET-bottles were observed frequently in the households, where the price of one such bottle is equal to 0.4 USD in the local shops. Furthermore, the building structure in Bulyaheke and Mbugani, like most rural areas in Tanzania, is dominated by one-floor houses made of bricks, mud, or sometimes concrete. A majority of the houses seems to be constructed with a relatively low inclination of the roofs and smaller side houses with close to horizontal roofing occur frequently.

4.3 Efficiency of SODIS

The efficiency of the SODIS method is evaluated based on the pathogen removal efficiency. Furthermore, as several other factors for the treatment process influence the efficiency of the HWT method they are also taken into consideration.

4.3.1 Removal efficiency of pathogens

This section contains the results from the water sample tests conducted on raw water, boiled water, 4 hours and 10 hours SODIS-treated water, as can be seen in Table 4.4. The samples were retrieved from three out of the six original drinking water collections points in the Bulyaheke and Mbugani area.

Table 4.4: CBT results for raw, boiled and SODIS-treated water at three locations in Bulyaheke and Mbugani.

Sample ID	Type of sample	*E. coli* [MPN/100mL]	Upper 95% CI [MPN/100mL]
P1-2R	Raw water	> 100.00	9435.10
P1-2B	Boiled water	0.00	2.87
P1-2S4h	SODIS 4h	0.00	2.87
P1-2S10h	SODIS 10h	0.00	2.87
SC2-2R	Raw water	> 100.00	9435.10
SC2-2B	Boiled water	0.00	2.87
SC2-2S4h	SODIS 4h	> 100.00	9435.10
SC2-2S10h	SODIS 10h	0.00	2.87
L1-2R	Raw water	> 100.00	9435.10
L1-2B	Boiled water	0.00	2.87
L1-2S4h	SODIS 4h	> 100.00	9435.10
L1-2S10h	SODIS 10h	0.75*	5.34

**This is a mean value calculated from duplicates of the same sample, see Table E.2 in Appendix E for full test results.*

The health risk category from WHO, based on the amount of *E. coli* in the samples, and the removal efficiency of the bacteria in the SODIS treatment are presented in Table 4.5.

Table 4.5: Removal efficiency of the MPN of *E. coli* and the WHO guidelines categorization after 4 and 10 hours of SODIS treatment.

Sample ID	Description	Removal efficiency [%]	Category[-]
P1-2S4h	SODIS 4h	≥ 97.3	Low Risk
P1-2S10h	SODIS 10h	≥ 97.3	Low Risk
SC2-2S4h	SODIS 4h	0.0	Very High Risk
SC2-2S10h	SODIS 10h	≥ 97.3	Low Risk
L1-2S4h	SODIS 4h	0.0	Very High Risk
L1-2S10h	SODIS 10h	≥ 94.7*	Low Risk

**This removal efficiency is calculated from the mean value in Table 4.4.*

4.3.2 Influencing factors

The water of one of the natural springs in Mbugani, i.e. sampling location CS2, was observed to be murky during collection of the samples. This was deemed to be caused by turbidity in the water. Villagers collecting water from this source revealed that the turbidity in the spring varied with the season, where the water was turbid during the rainy season and otherwise the water was clear. With the use of the turbidity test describe in section 2.2.4.5, the samples were regarded to have less turbidity than 30 NTU though.

Observations from the villages indicate that the most common roof material is corrugated steel sheets, but alternative materials like thatch, wood and mud were also observed in the area. Solar irradiation on corrugated steel increase the temperature of the surface, as well as possibly enhances the optical effects of the sun rays due to reflections. Nevertheless, the variation in cloud cover and intensity of solar radiation makes it difficult to determine an exact exposure time for the SODIS method.

5
Discussion

Waterborne diseases are a widespread problem in countries all over the world. Research have shown that HWT methods drastically could increase the quality of drinking water on a household level, which in turn would lead to a decrease number of sick people. An improvement of drinking water correlates to approximately 30% reduction of diarrhoea frequency [25], which means that the use of SODIS method might be a step in the right direction to reduce the number of diarrhoeal cases in the Buchosa district.

In the following sections health issues and their connection to the quality of the drinking water in the villages Bulyaheke and Mbugani are discussed. The SODIS method, its pathogen removal efficiency and the practicality of implementing the HWT method in the communities are thereafter addressed. Finally, potential barriers for the success of introducing the SODIS treatment in the communities and the validity of the case study are discussed.

5.1 Health issues and drinking water quality

The records from the Buchosa districts health facilities show that waterborne diseases are common reasons for seeking treatment in the area. Especially people being sick with intestinal worms and diarrhoea without dehydration, consistently seems to be a very high part of the total number of cases during the last few years. Furthermore, interviews retail that approximately 200 children go home from school every week due to stomach issues and it was said that the majority of these students did not visit a health facility. Apparently this was due to that many of the parents can not afford the transportation to the health facilities in the area, and thus they buy medicines directly from the local pharmacy instead. This gives an indication that there might be a high number of unknown cases that the official records do not entail, thus bringing the actual number of people being sick to an ever higher level.

One of the reasons that waterborne diseases are spread in such a high extent is the lack of water infrastructure in the rural areas of Tanzania. As interviews retailed, the Tanzanian government plan to expand that infrastructure in the rural areas in the future, in order to comply with the SDG of safe drinking water for all. However, it is likely that this development will take several years to implement everywhere. Consequently, the local water sources that today are used are, most likely, going to be used in the near future as well.

So, it seems to be an exception rather than a rule that improved water sources, such as boreholes or water from water treatment plants, are used. Instead, water is collected for domestic use at natural springs, privately constructed wells or at other surface waters. These unimproved sources are at a constant risk to be contaminated from e.g. waste, livestock and issues regarding human sanitation. According to the interviews however, there are some precautions in place to deal with these issues. Both privately dug wells that were investigated during this study, for example, are treated mechanically approximately once a year, where sediments from the bottom of the well are removed. Furthermore, the natural springs in the area have restrictions towards people wearing shoes while collecting their water. As the health data records indicated and the CBT of the raw water quality showed though, these precautions are not enough to keep the water sources from being contaminated.

The results of the CBT together with the drinking water quality guidelines from the WHO, showed that there was a Very High Risk for contamination from the raw water at all six sampling locations. As mentioned, the six sampling locations are different types of water sources, i.e. three natural springs, one from the shore of Lake Victoria and two private wells, where one uses a hand-pump for collecting the water. The results from the CBT show that all water sources are contaminated, regardless of type. This indicates that there are multiple factors that causes the contamination. Direct contaminants from humans and animals might influence the quality of the surface waters, while, the private well that is covered and uses a hand-pump should not be particularly effected by this.

Moreover, the extensive population growth in Tanzania recently might put a strain on the quality of the ground water, as the sanitation issues with e.g. open defecation and pit latrines, are far from resolved and those contaminants can infiltrate to the ground water. Furthermore, the large amount of people inhabiting the Lake Victoria region also effects the quality of the water in other matters, as e.g. fishing activities, agriculture and industries can cause pollution of waste, heavy metals and chemicals. However, as these contaminants were not examined during this study a further analysis can not be made.

Furthermore, as previously mentioned, the raw water is considered to be unsafe to use as drinking water, according to the national drinking water guidelines in Tanzania. However, the results from the CBT only indicate that the MPN of *E. coli* is higher than 100 in these samples. This means that the actual MPN could be 100 in one sample and the maximum value of 9435 MPN/100 mL in another sample, while in the same time giving the same result. With this in mind, one can argue that the contamination of the local water sources not necessarily need to be at the same level. Although this can not be confirmed or denied in this study, there is an indication that the level of contamination varies between the water sources from the results of the SODIS treated water. The CBT on the samples from the private well showed that all bacteria were removed from the water after only 4 hours with SODIS treatment, while the other water sources required more hours in the sun for the same results.

Regardless of the level of contamination, the Very High Risk of getting contaminated through the drinking water sources is a serious problem for the communities in the case study. Interviews and observations revealed that there generally are no treatment of the drinking water in the households today, even though the health facilities recommend boiling drinking water as a precaution for diseases. Occasionally, some families filter the water through cloth to remove visible particles but they are reluctant to boil it. The reasons for this are partly habitual restrictions, and partly that boiling the water requires fuel for burning, which sometimes is to expensive for the families. Furthermore, another reason for not boiling their drinking water is that people perceive that it changes the taste of the water. These factors are difficult to discuss with the communities, since economy, traditions and preferences are different from person to person. One of the results from this study is that boiled water removes all *E. coli* bacteria from the water and thus reduces the spread of diseases. However, if people are reluctant to change their habits, do not afford to or do not comprehend the reason for boiling drinking water, it is understandable that this treatment method have been difficult to implement in the area.

This type of reasoning in the community, as well as other interviews and observations made in Bulyaheke and Mbugani, indicate that there generally is a poor knowledge regarding WASH issues. The correlation between water, sanitation and hygiene is a concept that has been rarely observed during the study. Though, there are some safety measures for preventing external contamination of the water collection points, as previously mentioned, the common way of handling and consuming water in the community should not be considered safe today.

5.2 SODIS treatment and removal efficiency

As the results of the CBT showed, the raw water at all the studied water sources are highly contaminated with faecal matter. However, the SODIS method reduced the MPN of *E. coli* considerably on three of the sampling locations in Bulyaheke and Mbugani, to a Low Risk of contamination according to the WHO. During the weather conditions of April 4^{th} – 5^{th}, 2019, when the SODIS treatment in this study occurred, the removal efficiency after 10 hours was at least 94.7% for all samples. These results can be discussion in a few different aspects. First of all, the intensity of the solar radiation is very dependent on the weather and extent of cloud cover, so if the SODIS method had been conducted on other days the efficiency of SODIS might have been different. However, the results from reviewing climatic data from NASA show that 53% of their measured days, i.e. every day from January 1984 to April 2019, the dose of solar radiation was above the threshold value for SODIS. Since the NASA measurements are based on the amount of solar radiation intensity at the surface of the earth, it takes the atmospheric conditions, i.e. level of cloud coverage, into account. The atmospheric conditions is a limiting factor of SODIS but as the analyzed data show, a majority of the days had a sufficient dose of solar radiation. However, the sufficiency of the solar radiation can not be definitely confirmed in this study and further studies on this topic should be conducted.

Secondly, the removal efficiency could also be greater than the results in this study show. The results from the CBT only indicate that the MPN of *E. coli* is higher than 100 in the tested samples. As previously mentioned, this means that the actual MPN could be 100 in one sample and the maximum value of 9435 MPN/100 mL in another sample, while in the same time giving the same result. As the CBT method used in this study have this limitation, it is consequently a possibility that the actual removal efficiency is higher. For example, if a sample contained the maximum MPN value of 9435 *E. coli* and then was reduced to 0 (with an upper 95% CI of 2.9 MPN/100 mL), the removal efficiency would instead be 99.9997%, thus very close to 100%.

Research have also shown that the turbidity of the water influence the removal efficiency of the SODIS treatment. However, even though the turbidity was higher in the natural spring in Mbugani, i.e. sampling location CS2, there were no difference in those corresponding CBT results compared to the other samples where the water source was clear. This indicates that as long as the level of turbidity is lower than 30 NTU, the factor of the turbidity might not have a major impact on the results. It is possible though that the water source might require less exposure time to reach the same level of removal efficiency when the turbidity is lower. On the other hand, some research have shown that it is also possible that higher turbidity in the water might lead to an increase of the temperature during SODIS treatment, thus increasing the thermal inactivation, and possibly also the removal efficiency. However, this was not possible to analyze further in this study so no conclusion can be drawn from this and further studies should be conducted.

With one exception, all the duplicated samples were consistent in the CBT results. However, the samples of the 10 hour SODIS treated water from Lake Victoria, i.e. L1-2S10h, were not. One of the duplicates showed that all bacteria were removed after the SODIS treatment, while the other test showed that the MPN of *E. coli* was 1.5. The result of the SODIS method shown in Table 4.4 were thus the average value of these two test. As mentioned, these duplicates were the only tested samples that gave this inconsistency, thus indicating that the sample either was externally contaminated during the performance of the CBT or that the water from Lake Victoria requires more than 10 hours of solar exposure for full SODIS treatment. Further tests from that water source would thus be beneficial for a definite conclusion on the efficiency of SODIS. However, since both CBTs resulted in a very low MPN of *E. coli*, i.e. 0.0 – 1.5, the risk of getting contaminated through consumption of SODIS treated water from Lake Victoria is probably low.

5.3 Practicality of the SODIS method

The implementation of the SODIS treatment in the villages Bulyaheke and Mbugani are basically dependent on three things; the already discussed solar radiation, the containers and their placement, and, perhaps most important of all, the opinion of the villagers. Observations retailed that there were an abundance of PET-bottles in the villages of Bulyaheke and Mbugani, so it would probably be quite easy to use such containers for SODIS treatment. On the other hand, research show that the PET-bottles need to be replaced after approximately six months as the surface of the bottles will be scratched over time, thus reducing the efficiency of the solar radiation. However, compared to buying fuel and boiling the water this study indicate that the use of PET-bottles with the SODIS method is more cost effective and would be a low-cost HWT method.

The placement of the PET-bottles is furthermore likely not an issue for using the SODIS method in the villages. The majority of the households in Bulyaheke and Mbugani have access to low-inclined corrugated steel roofs, which can be highly reflective depending on its age. As previously mentioned, reflective surfaces surrounding the bottles during solar exposure can have an enhancing effect to the inactivation process of bacteria. As a result, the sufficient duration of solar exposure for the bottles might be shorter in comparison to the duration needed for bottles placed on non reflective surfaces.

The poor knowledge about the correlation between water and health issues in the population is probably the most restraining factor for the implementation of the SODIS method. Boiling is currently not used as a HWT method in the villages, due to economical aspects as well as preferences to taste. Both of these objections probably would not be viable for the SODIS treatment however, as the SODIS method is deemed to be a low-cost HWTS and a recent study from WHO showed that the taste of the water is not effected by solar disinfection [2]. So, these two reasons the villagers have put forward would probably not be a hindrance. However, if the people are reluctant to change their habits and include boiling in their daily routines there is a risk that they would not implement the SODIS method either. In order for the SODIS treatment to get full effect and reduce the number of sick people, there needs to be a routine of constantly drinking the treated water and always have a supply of SODIS bottles on the roof for disinfection. This behavioural change will probably be difficult to accomplish and is a factor that need further investigation and taken into consideration during the development of an implementation strategy.

5.4 Barriers for implementation of SODIS

The success of introducing and implementing SODIS in Bulyaheke and Mbugani is reliant on a number of factors. This study aimed to answer to the suitability, applicability and efficiency of the method, hence, providing a foundation for evaluating the feasibility of SODIS. The consideration of positive and negative factors have been a key target throughout the evaluation and in the following section, the concrete barriers for implementing SODIS will be addressed and motivated.

The main barriers identified for a SODIS implementation are connected to the following issues;

- Variations in solar radiation
- Poor WASH knowledge
- Traditional water practices

As it has great affect on the efficiency of SODIS, the variation in solar intensity is undeniably a barrier that must be taken into consideration prior to implementing SODIS. As mentioned in Section 5.2, the sufficiency of the solar radiation could not be completely determined in this study, and is therefore pointed out as an indefinite variable. The second identified barrier for SODIS is related to the poor WASH knowledge in villages. A limited knowledge of the consequences of consuming unsafe drinking water could potentially lead to challenges for establishing the method in the communities. Finally, the traditional manner of the inhabitants in Bulyaheke and Mbugani was also identified as a potential barrier. The routines related to water was deemed to be highly affected by the traditional ways of handling domestic water. A SODIS implementation would require the people to, not only accept a new routine, but also adapt to the changes it results in.

5.5 Validity of the case study

This section aims to discuss the potential threats to validity of this study. Since the data collection included interviews as one of the main source of data, the language barrier should be acknowledge as a potential bias on the result. The majority of the interviews and observations was carried out in the local language and then continuously translated to English. However, a professional translator was not used during this study and due to the role and attitude of the person translating the interviews, it should not be excluded that it might have affected the result.

Thematic analysis was used for simplifying the process of selecting the important content in the interviews, however, there is a risk of the researchers having prejudices that might have influenced this process. For example, the codes created and used for finding correlation across the interviews might have been formed with bias.

Furthermore, it should be taken into consideration that parts of the result are highly dependent of the prevailing conditions at the time of the study. For example, the water samples used for the CBT were collected with a grab sampling approach, but since water is a varying medium, single samples can not be considered representative. Even though this study used sample duplicates for verifying the test results, repetitive sampling for a consecutive period is needed for a more comprehensive mapping of the drinking water quality.

6

Conclusion

The measurements of the microbiological quality of the drinking water showed that there are a lot of faecal contaminants present in the area of the case study today. The high concentration of *E. coli* bacteria in the raw water indicates that there is a very high risk for contamination when drinking the water. Furthermore, the records from the health facilities showed that there a lot of people who are sick every year from waterborne diseases, and the result from this study indicates that many of these cases are caused by the drinking water.

Water treatment methods at a household level are generally not used in the villages Bulyaheke and Mbugani, which might be the most restraining factor for the implementation of SODIS. On the other hand, there are basically no additional constructions or materials needed for the SODIS system to work. The majority of the houses in the area have corrugated steel roofs, which have the possibility to enhance the efficiency of the SODIS method through thermal inactivation. Furthermore, there is an abundance of PET-bottles in the communities that is suitable to use as containers for the disinfection process.

Treatment of the water by solar disinfection proved to be an efficient method to remove pathogens in the area of the case study. The pathogen removal efficiency was at least 92% for all tested water sources. This means that implementing the SODIS method in the villages Bulyaheke and Mbugani would be a efficient solution to the current problems of the contaminated water sources in the area. Furthermore, the turbidity that was observed at one of the tested water sources did not seem to influence the results of the SODIS treatment.

It is stated in the national drinking water guidelines from TBS that immediate actions are required if faecal organisms are present in drinking water. However, it will probably take years before the infrastructure is sufficiently developed in this rural part of Tanzania. Thus the SODIS method could be a feasible short-term solution to reach the SDG target of safe water, until that development has occurred. The scarcity of existing water infrastructure and rarity of established HWT methods is naturally one of the strongest arguments for a potential implementation of the SODIS method in Bulyaheke and Mbugani.

6.1 Suggestions for implementation of SODIS

As this study conclude, the SODIS method could be considered a suitable solution for improving the drinking water quality in Bulyaheke and Mbugani. For ensuring the sustainability of a potential implementation, this section will provide recommendations for what to consider when introducing the method. The three following suggestions are based on the identified barriers for SODIS.

- **Marginal in exposure time**
  The results from the SODIS pilot study indicated a relatively high removal efficiency, i.e. $\geq$ 97% after 4 hours of solar exposure for the sample from the private well, and $\geq$ 97%, $\geq$ 92% after 10 hours in the samples from the spring and lake, respectively. However, since the variations in solar radiation intensity was deemed a barrier for the feasibility of SODIS, it is suggested to include a marginal in exposure time until further testing have been performed. Initially, the recommendation is to allow the containers to be exposed to solar radiation for two full days and then, if full inactivation is continuously proven for shorter exposure time, the recommended time could be lowered to optimize the method.

- **Include program for spreading WASH knowledge**
  This study identifies the poor WASH knowledge in Bulyaheke and Mbugani as a barrier for establishing SODIS in the households. For improving the chances of the method being adapted by the communities, a potential implementation should include a program aiming to raise WASH issues and spread knowledge of the health effects related to consumption of unsafe water.

- **Start small-scale**
  To address the potential challenges of introducing new household water routines in a highly traditional community, the suggestion is to start the implementation on a small-scale level. An alternative could be to launch the SODIS method at a local school, where, after a while, teachers and pupils could be involved in spreading information about WASH issues and the instructions of the SODIS procedure to the rest of the community.

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A

Drinking Water Quality Guidelines

The guidelines from the WHO publication *Guidelines for Drinking-water Quality* regarding *E. coli* in drinking water are shown in Table A.1. The categories are related to the risk of getting sick after consumption of water from contaminated sources [22].

Table A.1: The MPN of *E. coli* per 100 ml and the corresponding health risk category from WHO.

Health Risk Category	***E. coli* MPN/100ml**
Low Risk	< 1
Intermediate Risk	$1 - 10$
High Risk	$11 - 100$
Very High Risk	> 100

B
CBT Manual

On the following pages are the manual from Aquagenx, LLC, describing every step of the way for the measurement of *E. coli* using the CBT method. The entire manual is copyright ©2013 of Aquagenx, LLC and is displayed with their consent.

Aquagenx Compartment Bag Test (CBT)

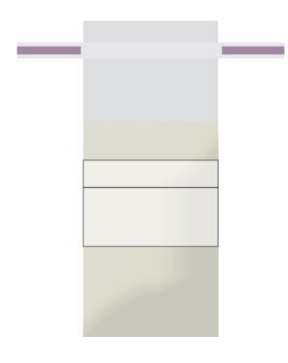
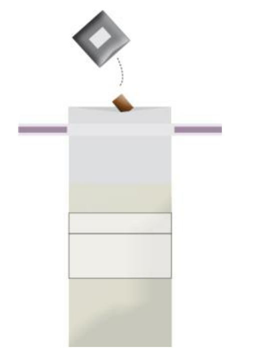
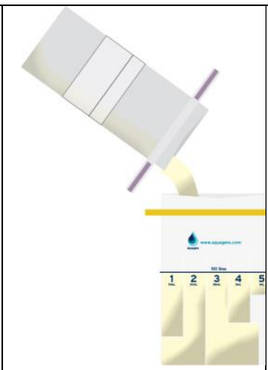
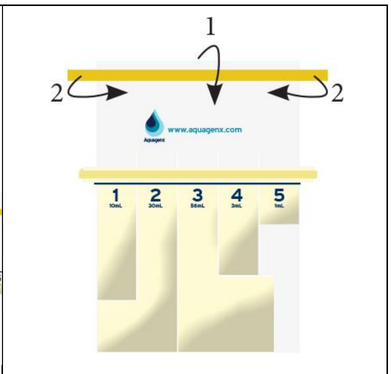
CBT *E. coli* Kit
Instructions for Use: Drinking Water

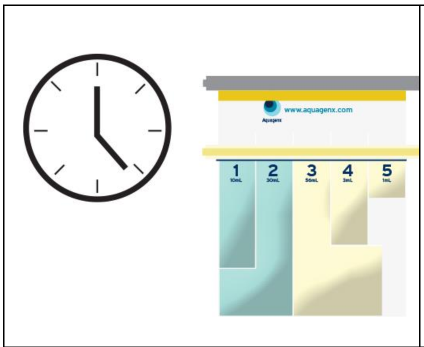
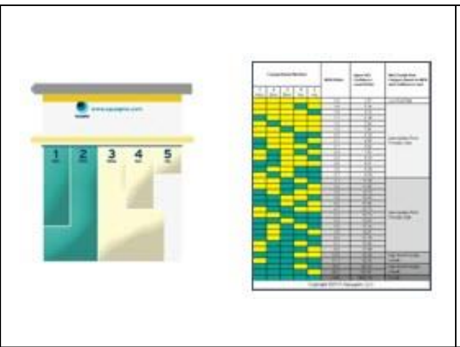
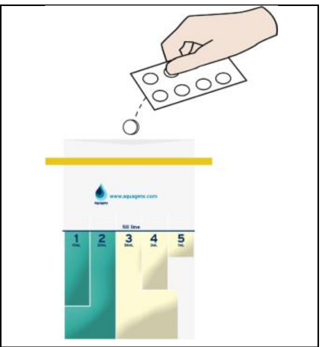
Overview
The Aquagenx CBT *E. coli* Kit detects and quantifies the Most Probable Number (MPN) of *E. coli* in a 100 mL sample. It uses a proprietary chromogenic growth medium with a glucose substrate called X-Gluc. When *E. coli* metabolize Aquagenx's growth medium, the color of the water turns blue, indicating the presence of *E. coli*. The MPN level of *E. coli* in the sample is estimated by the combination of positive and negative compartments in the Aquagenx compartment bag. Test results are obtained by easy color match using the Aquagenx color-coded MPN Table.

Shelf Life
Aquagenx *E. coli* growth medium (test bud) is stable up to 2-years after date of manufacture at 25-30° Celsius

Storage
Cold chain for *E. coli* growth medium not required. Recommended storage temperature for test bud is 15-25° Celsius. It is also safe to store test buds in a refrigerator. Protect *E. coli* growth medium from bright light.

How to Use Aquagenx CBT *E. coli* Kit

			
Collect sample	Add test bud	Pour sample into compartment bag	Attach plastic clip and roll down Whirl-Pak seal

		
Incubate 24-48 hours	Score MPN test results	Decontaminate sample

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Aquagenx Compartment Bag Test (CBT)

Aquagenx

Aquagenx CBT Most Probable Number (MPN) Table

The Aquagenx MPN Table is based on World Health Organization (WHO) “Guidelines for Drinking Water Quality,” 4th Edition. MPN of *E. coli* per 100 mL is estimated from the combination of positive and negative compartments in the bag. Yellow/yellow-brown indicates negative (absence) for *E. coli*. Blue/blue-green indicates positive (presence) for *E. coli*. Any trace of blue or blue/green in a compartment is considered positive, even just specks of blue/blue-green color or blue/blue-green sediment at bottom of a compartment.

Align your compartment bag so compartment #1 is on the left and compartment #5 is on the right. Match the color sequence of your five compartments to one of these 32 rows:

Compartment Number					MPN/100mL	Upper 95% Confidence Level/100mL	WHO Health Risk Category Based on MPN and Confidence Level
1 10mL	2 30mL	3 56mL	4 3mL	5 1mL			
Yellow	Yellow	Yellow	Yellow	Yellow	0.0	2.87	Low Risk/Safe
Yellow	Yellow	Yellow	Blue-green	Yellow	1.0	5.14	Intermediate Risk/ Probably Safe
Yellow	Yellow	Yellow	Yellow	Blue-green	1.0	4.74	
Blue-green	Yellow	Yellow	Yellow	Yellow	1.1	5.16	
Yellow	Blue-green	Yellow	Yellow	Yellow	1.2	5.64	
Yellow	Yellow	Blue-green	Yellow	Yellow	1.5	7.81	
Yellow	Yellow	Yellow	Blue-green	Blue-green	2.0	6.32	
Blue-green	Yellow	Yellow	Blue-green	Yellow	2.1	6.85	
Blue-green	Yellow	Yellow	Yellow	Blue-green	2.1	6.64	
Yellow	Blue-green	Yellow	Blue-green	Yellow	2.4	7.81	
Yellow	Blue-green	Yellow	Yellow	Blue-green	2.4	8.12	
Blue-green	Blue-green	Yellow	Yellow	Yellow	2.6	8.51	
Blue-green	Yellow	Yellow	Blue-green	Blue-green	3.2	8.38	
Yellow	Blue-green	Yellow	Blue-green	Blue-green	3.7	9.70	
Yellow	Yellow	Blue-green	Yellow	Blue-green	3.1	11.36	Intermediate Risk/ Possibly Safe
Yellow	Yellow	Blue-green	Blue-green	Yellow	3.2	11.82	
Blue-green	Yellow	Blue-green	Yellow	Yellow	3.4	12.53	
Blue-green	Blue-green	Yellow	Yellow	Blue-green	3.9	10.43	
Blue-green	Blue-green	Yellow	Blue-green	Yellow	4.0	10.94	
Yellow	Blue-green	Blue-green	Yellow	Yellow	4.7	22.75	
Yellow	Yellow	Blue-green	Blue-green	Blue-green	5.2	14.73	
Blue-green	Blue-green	Yellow	Blue-green	Blue-green	5.4	12.93	
Blue-green	Yellow	Blue-green	Yellow	Blue-green	5.6	17.14	
Blue-green	Yellow	Blue-green	Blue-green	Yellow	5.8	16.87	
Blue-green	Yellow	Blue-green	Blue-green	Blue-green	8.4	21.19	
Yellow	Blue-green	Blue-green	Yellow	Blue-green	9.1	37.04	
Yellow	Blue-green	Blue-green	Blue-green	Yellow	9.6	37.68	
Blue-green	Blue-green	Blue-green	Yellow	Yellow	13.6	83.06	High Risk/Possibly Unsafe
Yellow	Blue-green	Blue-green	Blue-green	Blue-green	17.1	56.35	
Blue-green	Blue-green	Blue-green	Yellow	Blue-green	32.6	145.55	High Risk/Probably Unsafe
Blue-green	Blue-green	Blue-green	Blue-green	Yellow	48.3	351.91	
Blue-green	Blue-green	Blue-green	Blue-green	Blue-green	>100	9435.10	Unsafe

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Aquagenx Compartment Bag Test (CBT)

WHO Guidelines for Drinking Water Quality, Table 5.4, 4th Edition, 2011

Health Risk Category	*E. coli* CFU per 100 mL
Safe	<1
Intermediate Risk/Probably Safe	1-10
High Risk/Probably Unsafe	>10-100
Very High Risk/Unsafe	>100

Procedural Notes

A short video on how to use the CBT *E. coli* Kit is on the Aquagenx website:
https://www.aquagenx.com/how-to-use-the-cbt/

1. Prepare work area

- Sanitize work area with disinfectant cleaning solution, paper towels or wipes

2. Collect 100 mL water sample with plastic bottle or Thio Bag

- White particles in sample bottle and white tablet in Thio Bag are sodium thiosulfate, which neutralizes residual chlorine in sample. Do not remove.
- Wearing disposable, thin plastic gloves is recommended. If you don’t have gloves, avoid touching inside of bottle or Thio Bag with bare hands.
- Fill sample bottle or Thio Bag to 100 mL fill mark. Record sample details.

3. Add *E. coli* growth medium to sample

- Open growth medium pouch and add test bud to sample. Leave white desiccant in foil pouch.
- Do not touch growth medium with bare fingers or hands
- Dissolve medium in sample for 10-12 minutes
- The medium dissolves from its plastic carrier. When the medium is completely dissolved, the plastic carrier turns white or nearly white.

4. Pour sample into compartment bag

- Label bag or attach barcode asset tag to compartment bag
- Tear off perforated seam at top of bag
- Rub top and sides of bag together in each compartment to open so water easily runs into compartments
- Use white tabs at top of bag to pull open
- Slowly pour sample into bag while gently tilting and squeezing bag to distribute sample amongst five compartments
- Do not pour test bud carrier into compartment bag
- Fill evenly to the top of the fill line

Aquagenx Compartment Bag Test (CBT)

5. Seal compartment bag shut

- Attach seal clip across the bag above the fill line and below the compartment top openings. Place U-shape across width of the bag above liquid level along the fill line but below compartment openings. Snap rod-shaped part of the clip from other side of bag into U-shape to lock in place.
- Close the top of the bag with the yellow Whirl-Pak seal and then roll down the bag toward the seal clip

6. Incubation Period

- During the incubation period, CBTs can develop an odor. Place CBTs in another sealed plastic bag or container during the incubation period.
- Ambient temperature incubation works at 25°- 44.5°C
- The CBT works at variable temperatures. Constant temperature control in an incubator is not required but is recommended in cooler temperatures if available.
- Below 25°C, use a portable incubator or find a warm location at or above 25°C for incubation

Incubation Period Time and Temperature Recommendations:

35-44.5°C:	Incubate 20-24 hours
31-34°C:	Incubate 24-30 hours
25-30°C:	Incubate 40-48 hours

Below 25°C: Incubate in a portable incubator 35-37°C for 24 hours, or put in or near another heat source for up to 48 hours depending on the temperature

7. Score and record test results

- Align compartments in correct sequence to Aquagenx MPN Table, hold bag up to read results
- Yellow/yellow-brown indicates negative (absence) compartment for *E. coli*
- Blue/blue-green indicates positive (presence) compartment for *E. coli*. Any trace of blue or blue/green in a compartment is considered positive, even just specks of blue/blue green color or just blue/blue green sediment at bottom of compartment
- Match color sequence of five compartments to one of 32 rows in MPN Table to obtain MPN test results
- Record test results

8. Decontaminate sample

- CBT Kit 10-Pack users add three chlorine tablets included in the kit to top of compartment bag. Seal bag with seal clip. Agitate sealed bag until chlorine dissolves.
- CBT Kit 50-Pack users source and add 1-2 mL of liquid bleach (NaOCl) or sufficient free chlorine tablets (calcium hypochlorite or sodium dichloroisocyanurate) to provide about 100 milligrams of free chlorine.
- After 45 minutes, pour contents into a sink, toilet or hole in ground and safely dispose the empty compartment bag
- Retain seal clip for reuse

C

Incubation in CBT Method

As per the description in the CBT manual by Aquagenx, LLC the incubation time and temperature are correlated for sufficient growth of *E. coli*. If the temperature in the incubator is 25 – 30 °C the recommendation from Aquagenx, LLC is to keep the samples in the incubator for 40 – 48 hours, in order for the growth medium to fully interact with the *E. coli*. Higher temperature in the incubator, on the other hand, reduces the required time. The following tables show the incubation time and temperature for all samples conducted during this thesis.

Table C.1: Incubation time and variance in temperature for collected raw water samples from all sampling locations in Bulyaheke and Mbugani.

Sample ID	Incubator Time [h]	Incubator Temp. [°C]
P1, C1, L1	24	27.8 – 44.0
PC1, SC1, SC2	25	25.8 – 44.8

Table C.2: Incubation time and variance in temperature for collected raw water samples and boiled water samples from the three sampling locations.

Sample ID	Incubator Time [h]	Incubator Temp. [°C]
P1-2R, L1-2R, SC2-2R, P1-2B, L1-2B, SC2-2B	25	27.5 – 43.3

Table C.3: Incubation time and variance in temperature for SODIS-treated water from the three sampling locations.

Sample ID	Incubator Time [h]	Incubator Temp. [°C]
P1-2S4h, L1-2S4h, SC2-2S4h, P1-2S10hA, L1-2S10hA, SC2-2S10hA	46	26.8 – 37.5
P1-2S10hB, L1-2S10hB, SC2-2S10hB	26	27.6 – 41.9

D

Diseases in Buchosa District

The number of people being sick in waterborne diseases in the Buchosa district during three consecutive years, i.e. 2016-2018, are shown in Table D.1. The percentage of these cases were shown in Figure 4.1 in Section 4.1.1.

Table D.1: Yearly number of cases related to waterborne diseases in Buchosa District.

	2016	**2017**	**2018**
Intestinal worms	9092	10902	11684
Diarrhea - No dehydration	7817	9026	11089
Diarrhea - Some dehydration	2813	2090	2576
Schistosomiasis	2056	1608	1342
Diarrhea - Severe dehydration	621	419	850
Acute diarrhea ($<$14 days)	202	207	193
Dysentery	129	157	113
Typhoid	852	495	38
Chronic diarrhea ($\geq$14 days)	34	12	9
Total	23617	24916	27894

E

All Test Results from CBT

The results from all performed CBTs during this case study are shown in this appendix. The results of the duplicate raw water samples are shown in Table E.1 and the duplicate of the SODIS treated water are shown in Table E.2.

Table E.1: All CBT results for raw water from all the Bulyaheke and Mbugani sampling locations.

Sample ID	**Type of sample**	***E. coli*** **[MPN/100mL]**	**Upper 95% CI [MPN/100mL]**
P1A	Raw water	> 100.00	9435.10
P1B	Raw water	> 100.00	9435.10
C1A	Raw water	> 100.00	9435.10
C1B	Raw water	> 100.00	9435.10
L1A	Raw water	> 100.00	9435.10
L1B	Raw water	> 100.00	9435.10
PC1A	Raw water	> 100.00	9435.10
PC1B	Raw water	> 100.00	9435.10
SC1A	Raw water	> 100.00	9435.10
SC1B	Raw water	> 100.00	9435.10
SC2A	Raw water	> 100.00	9435.10
SC2B	Raw water	> 100.00	9435.10

Table E.2: All CBT results of raw, boiled and SODIS-treated water from the three sampling locations.

Sample ID	**Type of sample**	***E. coli*** **[MPN/100mL]**	**Upper 95% CI [MPN/100mL]**
P1-2R	Raw water	> 100.00	9435.10
P1-2B	Boiled water	0.00	2.87
P1-2S4h	SODIS 4h	0.00	2.87
P1-2S10hA	SODIS 10h	0.00	2.87
P1-2S10hB	SODIS 10h	0.00	2.87
SC2-2R	Raw water	> 100.00	9435.10
SC2-2B	Boiled water	0.00	2.87
SC2-2S4h	SODIS 4h	> 100.00	9435.10
SC2-2S10hA	SODIS 10h	0.00	2.87
SC2-2S10hB	SODIS 10h	0.00	2.87
L1-2R	Raw water	> 100.00	9435.10
L1-2B	Boiled water	0.00	2.87
L1-2S4h	SODIS 4h	> 100.00	9435.10
L1-2S10hA	SODIS 10h	1.50	7.81
L1-2S10hB	SODIS 10h	0.00	2.87