WATER USE PRACTICES, WATER QUALITY AND PERFORMANCE OF A CONTINUOUS SOLAR WATER DISINFECTION SYSTEM IN ISIOLO COUNTY, KENYA

Abok Elisha Onyango

B.Sc. Food Science and Technology (University of Nairobi)

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Food Science and Technology of the University of Nairobi

Department of Food Science, Nutrition and Technology

AUGUST, 2018

Declaration

This thesis is my original work and has not been presented for a degree award in any other University.

Signature…………………………………………… Date…………………………………

Abok Elisha Onyango

This thesis has been submitted with our approval as university supervisors:

Signature ……………………………………………..Date ……………………………………

Prof. Michael Wandayi Okoth

Department of Food Science, Nutrition and Technology,

University of Nairobi.

Signature……………………………………………Date……………………………………….

Dr. Catherine Nkirote Kunyanga

Department of Food Science, Nutrition and Technology,

University of Nairobi.

UNIVERSITY OF NAIROBI

Plagiarism Declaration Form for Students

Name of Student:	**Abok Elisha Onyango**
Registration Number:	**A56/76016/2014**
College:	College of Agriculture and Veterinary Sciences (CAVS)
Faculty/School/Institute:	Agriculture
Department:	Food Science Nutrition and Technology (DFSNT)
Course Name:	MSc. Food Science and Technology
Title of the work:	**WATER USE PRACTICES, WATER QUALITY AND PERFORMANCE OF A CONTINUOUS SOLAR WATER DISINFECTION SYSTEM IN ISIOLO COUNTY, KENYA**.

Declaration

1. I understand what Plagiarism is and I am aware of the University's policy in this regard

2. I declare that this **THESIS** is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work, or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

3. I have not sought or used the services of any professional agencies to produce this work

4. I have not allowed, and shall not allow anyone to copy my work with the intention of passing it off as his/her own work

5. I understand that any false claim in respect of this work shall result in disciplinary action, in accordance with University Plagiarism Policy.

Signature ____ Date: **____7th August, 2018___**

Dedication

I humbly dedicate this work to my parents Angeline and the late father Christopher to whom I am greatly indebted and by whose spirit I have lived and been strengthened to achieve through hard work.

Acknowledgement

I am greatly indebted to my supervisors, Prof. M.W. Okoth and Dr. C.N. Kunyanga, Department of Food Science Nutrition and Technology (DFSTN, UoN) , for guidance, encouragement and suggestions during the proposal development, the research and the writing that led to the successful completion of this work. Significant contribution by the late Mr. Peter Obimbo Lamuka during the initial stages of this work is greatly acknowledged.

I am grateful to the University of Nairobi and Katholischer Akademischer Ausländer-Dienst (KAAD) for the M.Sc. Food Science and Technology scholarship offer. Financial support from the Federal Ministry of Education and Research, Germany through the University of Kassel is gratefully acknowledged. I thank the management of Ewaso Nyiro North Development Authority (ENDDA) for having accepted our request to use their facilities for the field experimentations. I also thank Isiolo Water and Sewerage Company (IWASCO) for availing secondary data on water quality trends and laboratory analysis support.

My sincere gratitude goes to Mr. Bernard Muroki, Mr. Cyprian Lomatukae (ENDDA), Mr. Bernard Aliwa, Mr. Jared Omondi Jobor, Ms. Ruth Omani, Mr. George Dimbu and Mr. Abbey Khalif for technical contributions at all levels resulting into accomplishment of this work.

Finally, I thank the entire Ten Senses Africa Ltd team, family, friends and all those whose names have not been mentioned for the continuous encouragement and support towards the completion of this work.

Table of Contents

List of tables

List of Figures

List of Acronyms

SODIS	Solar water disinfection
WHO	World Health Organization
pH	Potential Hydrogen ions concentration
UV	Ultra-violet radiation
SDGs	Sustainable Development Goals
TCU	True Color Units
NTU	Nephelometric Turbidity Unit
˚C	Degrees Celsius
ROS	Reactive Oxygen Species
DNA	Deoxyribonucleic Acid
RNA	Ribonucleic Acid
H_2O_2	Hydrogen peroxide
µ	Microns
DBPs	Disinfection by-products
THMs	Trihalomethanes
Wm^{-2}	Watts per square meters
ATP	Adenosine Triphosphate
PET	Polyethylene Terephthalate
PVC	Polyvinylchloride
CPC	Compound Parabolic Collectors
Log	Logarithmic
Kgs^{-1}	Kilograms per second (Flow rate unit)
ASALs	Arid and semi-arid lands
GIT	Gastro-intestinal tract
Mm	millimeters
Km	Kilometer
P	p-value

SMEs	Small Medium Enterprises
ISO	international organization for standardization
Cfu/ml	Colony forming units per millimeter
APHA	American Public Health Association

General Abstract

Potable water scarcity is a major challenge faced by most developing nations of the world. Moreover, Arid and semi-arid lands of Kenya endure unbearable living conditions due to water pollution and limited number of water sources. Renewable energy can be tapped for use in treatment of water for use in households. The objective of this study was to determine the Water use practices, water quality and performance of a Continuous Solar Water Disinfection System in Isiolo County Kenya.

Purposive sample of 165 respondents were interviewed using a semi-structured questionnaire. In the second phase, 44 purposive water samples were collected from water sources in the study area and analysed for microbiological and physico-chemical attributes using ISO procedures. In the last phase, a continuous solar water disinfection (SODIS) system was designed using two flat plate solar collectors (each 2.34 m^2), a shell and tube heat exchanger, a solar photovoltaic pumping system and two water tanks. The system was tested under different conditions. The solar intensity and temperatures were measured using a pyranometer and digital temperature sensors respectively.

Results show that 26.5 % of the respondents use borehole water, 21.8 % use river water while 16.9 % use spring water for drinking and processing in Leparua sub-location. Urban treated water is used by 14.5 % of the respondents based in Wabera and Kulamawe location. Pans and rain water are used during rains by 3.6 % of the respondents. Boiling was the main water disinfection method used by 66.7 % of the respondents while 21.7 % used chlorination. Solar water disinfection was new to the population and used by none of the respondents. Highest mean log *Clostridium pafrigens* counts in ground and surface water were 3.16 Cfu/ml and 3.53 Cfu/ml respectively. The mean log *Staphylococcus aureus* counts were 2.87 Cfu/ml and 3.12 Cfu/ml in surface water and ground water respectively. *Escherichia coli* and total coliforms contamination was 29.88 % and

88.2 % respectively. Microbial counts in the water sources differed significantly ($p \leq 0.05$). Total coliforms had a significant negative relationship ($r = -0.76$) with residual chlorine. Highest and lowest total hardness values were 638.5 mg/l and 138.5 mg/l for borehole and tap water respectively. Calcium and magnesium ions mean values were 33.92 mg/l and 68.43 mg/l respectively. Borehole water had the lowest turbidity of 0.8 NTU. Mean value range for electrical conductivity and color were 139 µS/cm to 454 µS/cm and 13 TCU to 280 TCU respectively. Physico-chemical properties significantly differed ($p \leq 0.05$) across the water sources.

Results show a significant positive ($r = 0.87$) logarithmic change in solar radiation with time of the day. Temperature of disinfected water significantly differed with time of the day ($p \leq 0.05$). The SODIS system achieved mean log reduction for coliforms, *Escherichia coli*, *Staphylococcus aureus* and total viable counts of 3.08, 2.071, 1.368 and 3.474 respectively. Despite the difference in temperatures of the day the disinfection effect insignificantly differed ($p \leq 0.05$) for most times of the day. Flow rate was a significant exponential function of disinfection temperature ($r = 0.9738$). Isiolo County has adequate insolation and effective solar water disinfection can be enhanced extensively through optimized flow rates, disinfection temperature, holding time and solar radiation intensity.

Key words: Solar water treatment; Disinfection system; Water quality; Solar collectors; Food processing

CHAPTER ONE

General Introduction

1.0. Background of the study

Water is a non-calorific nutrient and the life wire of the body. Water occupies 70 % of the Earth crust out of which only 2 % exist as fresh water (Ferreira *et al*., 2017). However, 99 % of the fresh water sources are polluted and not accessible (Nair *et al*., 2015; Juneja and Chaudhary, 2013). Pollution of the water sources is caused low level of personal hygiene and inadequate treatment facilities for water and waste that is a consequent pollutant (Kuta *et al*., 2014). Sanitary sewers over-flows, animal droppings run-off and changes in hydrological cycle due to fluctuating climatic conditions have significantly contributed to pollution of water sources (Nair *et al.,* 2015).

Surface and ground water are the main sources drinking and food processing water for rural dwellers in developing regions (Malik *et al.*, 2010; Ahmad *et al.*, 2012; Muhammad *et al.*, 2013; Muhammad *et al.*, 2017). Water is susceptible to contamination with microorganisms, organic matter among other pollutants regardless of the source (Anyamene and Ojiagu, 2014; Gangil *et al.*, 2013; Oludairo and Aiyedun, 2015). Significantly, microbial contaminants such as coliforms, *Escherichia coli*, *Cryptosporidium parvum* and *Giardia lamblia* compromises the safety of the water (Opara and Nnodim, 2014). These pathogens cause diarrhea, giardiasis, dysentery and gastroenteritis prevalent in the developing nations (Oyedeji *et al.*, 2010; Akinde *et al.*, 2011; Aroh *et al.*, 2013; Isikwue and Chikezie, 2014; Thliza *et al.*, 2015; Oludairo and Aiyedun, 2015). High alkalinity, water hardness, electrical conductivity and pH of most of these water sources induces unpalatable taste (Anwar *et al*., 2011). Consumption of highly saline water in the long run causes high blood pressure and kidney stones (Muhammad *et al*., 2013; Muhammad *et al*., 2017). Due to pollution, point of use water treatment is required and water disinfection has been the tradition world over (Somani and Ingole, 2011).

Boiling, U-V radiation, electromagnetic radiation, use of acid, alkali, ozonation, metallic ions, hydrogen peroxide, chlorination and herbs have been used for water disinfection (Somani and Ingole, 2011). Boiling has been implicated in deforestation while most of the disinfection methods are expensive and require specialized skills for application (Gagnon *et al*., 2005). Chlorination poses unique odour and taste, and generation of certain toxic Trihalomethanes formed when chlorine solubilizes in water (Gagnon *et al*., 2005; Min Cho *et al*., 2006; Bhagwatula *et al*., 2000). Recently, solar water disinfection has emerged as an alternative water disinfection and is gradually gaining application at households (Clasen *et al*., 2007).

Batch solar water disinfection systems uses ethylene-terephthalate polymers (PET) as reactors (McGuigan et al., 2012). The PET filled reactors are exposed to sunlight for 6 hours disinfection (Dunlop *et al*., 2011; walker *et al*., 2004). Limited disinfected water volume (< 2L) and release of genotoxic acetaldehyde by PET are the major drawbacks of batch SODIS systems (McGuigan *et al*., 2012; Ubomba-Jaswa *et al*., 2009; Ubomba-Jaswa *et al*., 2010). Continuous solar water disinfection systems using solar collectors, reflectors, and a photo catalysts (TiO_2) have been used to enhance thermal inactivation(Saitoh and Ghetany, 2002; Vidal and Diaz, 2000; Dunlop *et al*., 2002). However, the enhanced continuous SODIS systems exhibited flow problems, incomplete inactivation of microorganisms, low flow rates and unknown cost of construction to establish affordability (Khaled *et al*., 2008; Gill and Price, 2010; Pansonato *et al*., 2011).

Continuous solar water disinfection systems have focused on the effect of SODIS on *Escherichia coli* and coliforms and flow rates in regions with solar radiation intensity < 700 W (Polo-López *et al*., 2011; Anthony *et al*., 2015). The effect of SODIS on pathogenic *Clostridium pafrigens*, *Staphylococcus aureus* and parasitic cysts has not been investigated. There is need to establish the effect of initial microbial load, water type, residence time, flow rate and holding time on diverse pathogenic organism and physico-chemical properties of water. The current study therefore aimed at establishing the effect of holding time, flow rates, collector arrangements systems and solar radiation intensity on river water using a continuous SODIS system in Isiolo County Kenya. Solar water disinfection can be an alternative water treatment technique for food processing and drinking water in the rural areas that have limited access to other disinfection methods.

1.1. Problem statement

Water contaminated by chemical, physical and biological contaminants poses safety risk to food products being handled. Rural set up where most of initial food processing takes place has limited access to potable water (Kuta *et al*., 2014). Poor access to clean water at household level has been linked to increases in infection and malnutrition in marginalized regions. In addition, SMEs and processing groups in these regions face many challenges in producing safe foods for consumption due to the unreliable and inadequate water sources. Physical disinfection methods such as boiling, electromagnetic irradiation, ultra-sonic and U-V radiation have found limited application due to cost and non-residual effect to guard against regrowth (Somani and Ingole, 2011). Chlorination and other chemical disinfection methods provide good germicidal treatment accrued from residual effect. However, they are relatively expensive, pose unique odour and are implicated in generation of certain potential genotoxic trihalomethanes in the disinfected water. This has necessitated alternative disinfection methods especially solar. Solar water disinfection using PET bottles as reactors though cheap, has raised concern over the release of genotoxic acetaldehyde compounds as well as the limited disinfected water volumes (McGuigan *et al*., 2012). Some of the reported continuous flow reactors have associated draw backs of incomplete inactivation of microorganisms. There exist need therefore to establish the effect of solar radiation intensity, temperature, holding time, and initial microbial load on the performance of a continuous solar disinfection flow reactor system.

1.2.Justification

Solar energy is relatively a clean and cheap energy (Chaichan and Kazem, 2016). Its use in water disinfection limits the cutting down of trees to obtain wood fuel for disinfection by boiling (Somani and Ingole, 2011). This leads to conservation of trees within the forests and consequently conservation of water catchment towers and the ecosystem at large.

Production of clean potable water provides both employment and income to various people within the economy (McGuigan *et al*., 2012), the water can be bottled and sold thereby creating employment and generating income.

Provision of clean potable water for various food handling and processing operations ensures production of safe and quality food products (Admassu *et al*., 2004) that fetch premium prices. This boosts the producers' profits, and reduce food borne illnesses and infections attributed to use of contaminated water in processing.

Improved living standards becomes a reality when members of the society have access to potable drinking water. The children who are highly susceptible to contaminated water (Cheesbrough, 2000), have reduced incidences of diarrheal diseases, child morbidity and mortality as well as increased life expectancy.

1.3.Objectives

1.3.1. Overall objective

To investigate water use and handling practices, water quality and the performance of a continuous solar water disinfection system in Isiolo County Kenya.

1.3.2 Specific objectives

1. To carry out household and community survey to determine sources, treatment techniques and utilization of water in Isiolo County in Kenya.
2. To determine the microbiological quality and contamination level of water sources in Isiolo County in Kenya.
3. To profile the physico-chemical characteristics of water sources used for drinking and processing in Isiolo County in Kenya.
4. To determine the performance of a continuous solar water disinfection system in Isiolo County, Kenya.

CHAPTER TWO

Literature Review

2.0. Historical background

Water occupies about 70 % of the earth's crust and is thus the most abundant substance in nature (Anyamene and Ojiagu, 2014; Thliza *et al.*, 2015). Safe and quality water sources is one of the basic concerns for human population (WHO, 2014). Increasing water scarcity remains a major challenge in different countries around the world (Mallick and Rojas, 2015). The severity of water scarcity in developing countries affects the drinking water supply, sanitation, food security, economy and transport (Faisal and Kabir, 2005; Paavola, 2008).

In Africa and some Asian regions, water is often carried over long distances by women and children from the sources to the households (Mallick and Rojas, 2015). About 2 % of the total water mass is fresh of which only half is available for use by the over 6 billion world's population (Manhokwe *et al.*, 2013). An estimated 768 million people remain without access to potable water (Muhammad *et al*., 2017). Moreover, 2.5 billion remain without access to improved sanitation and hygiene facilities posing high health risk and pollution of the water sources (Admassu *et al*., 2004).

In most rural areas the utilized water sources are either ground or surface water sources (Manhokwe *et al*., 2013; Kuta *et al*., 2014). The quality and safety of most of these water sources are unknown as they are influenced by seasons and location (Muhammad *et al*., 2017).

Many indices rate the human health within the tropics as poor, death among the young children are water borne related diseases (Hassan, 2009) originating from low level of personal hygiene and inadequate water treatment facilities (Kuta *et al*., 2014). The situation is quite different in developed nations with excellent water supplies and effective treatment facilities for waste

(Hassan, 2009) and consequently rare water-related diseases. Water disinfection has been adopted to meet Goal 6 of the Sustainable Development Goals (SDGs). Water supply and accessibility aims at ensuring environmental sustainability (Oludairo and Aiyedun, 2015). Water treatment methods such as use of herbs, chlorination and boiling as well as emerging technologies such as solar water disinfection are reviewed in this chapter.

2.1.Water

Water is a non-calorific, essential component of the diet that is regarded as the life wire of the body and the basis of life (Manhokwe *et al*., 2013; Oludairo and Aiyedun, 2015; Muhammad *et al*., 2017). Water constitutes an integral part of the living cell (Baloch *et al*., 2000; Garba *et al*., 2009). About 97 % water exists in oceans with higher salt concentration and thus not suitable for drinking (Manhokwe *et al*., 2013). Of the 70 % water cover, only 3 % is fresh water (Anyamene and Ojiagu, 2014; Thliza *et al.*, 2015). Glaciers and ice caps constitute 2.97 % and only 0.3 % of fresh water is available as surface and ground water for human use (Muhammad *et al*., 2013; Manhokwe *et al*., 2013). Safe drinking water is a necessity for healthy community. Fresh water supply and accessibility is limiting resource in world over. Population increase, urbanization and climate change would further worsen the world water situation in the next century (Jackson *et al.*, 2001; Essumang *et al*., 2011; Muhammad *et al*., 2013; Manhokwe *et al.*, 2013).

Water is thus a vital substance for the survival of all lives (Thliza *et al.*, 2015). It is absolutely necessary for most life driven processes (Aroh *et al.*, 2013). It is one of the indispensable resources needed for the continued existence of all living things including man given its abundance on earth (Gangil *et al.*, 2013; Onilude *et al.*, 2013). Water is one of the most important needs of all forms of life and is unavoidable in man's daily life, constituting a sizeable percentage of man's daily food intake because human bodies do not have reserve supply (Anyamene and Ojiagu, 2014). It is also an essential requirement for drinking, domestic, industrial and agricultural uses (Isikwue and Chikezie, 2014). Quality water is colorless, tasteless, odourless, as well as free from faecal contamination (Opara and Nnodim, 2014).

Water is required for maintenance of personal hygiene, food production and prevention of diseases (Thliza *et al.*, 2015). In nature water occupies about 70 % of the earth's crust (Anyamene and Ojiagu, 2014; Thliza *et al.*, 2015). Water constitute 80 % protoplasm of many living cells and aids the metabolic processes during cell growth and development as a universal solvent (Nwosu and Ogueke, 2004; Okechukwu and Chikezie, 2014). In nature water exhibits the three states of solid, liquid and gas facilitating biological activities under all environmental conditions (Thliza *et al.*, 2015).

2.2.Potable water

Potable water contains less than 1000 mg/L of dissolved solids and is safe for drinking and food processing (Muhammad *et al*., 2017). It does not contain chemical substances and microorganisms in amounts that could cause hazard to health (Oludairo and Aiyedun, 2015). It should be clear, without disagreeable taste, color or odor therefore fit for human and animal consumption. It is water that has been treated, cleaned or filtered to meet established drinking standards (Aroh *et al.*, 2013; Isikwue and Chikezie, 2014). It can be sourced from surface water such as river, streams or the ground water such as spring, well and borehole (Aroh *et al.*, 2013). Water quality is the physical, chemical, radiological and biological characteristics of water in relation to the requirements of human and animal need (Johnson *et al.*, 1997; Diersing, 2009; Danso-Boateng and Frimpong, 2013).

Agencies that regulate water quality worldwide rely on the World Health Organization (WHO) standards and guidelines for drinking water quality (WHO, 2014) so as to ensure the highest quality of potable water in order to safeguard public health (Anunobi *et al.*, 2006; Isikwue and Chikezie, 2014). Table 2.1 shows the quality characteristics of water.

It has been a challenge accessing potable water in developing countries. Most of the water sources are polluted by sanitary sewers over-flows and animal dropping surface run-offs (Maynard *et al*., 2005; Muhammad *et al*., 2013; Muhammad *et al*., 2017). At the rural set-up, the major water sources are; rivers, pipe borne sources, water boreholes, hand-dug well, dams and sometimes unprotected wells (Kuta *et al.*, 2014), a direct indicator of limited access to safe water. These water sources contain unhealthy harmful physical, chemical and biological agents. An estimated 80 % of ill health within the tropics by world health organisation (WHO, 2014) are environmental sanitation and water related (Cheesbrough, 2000; Admassu *et al*., 2004). Globally water and food borne diseases arising from water contamination have been a great concern (Olukosi *et al*., 2008).

Pollution by heavy metals from industrial wastes renders the available water sources unsafe for drinking and food processing, some of these metals raises the physical and chemical properties of the water to unacceptable levels (Juneja and Chaudhary, 2013).

Climatic changes and the trending global warming especially in the arid and semi-arid areas, increase the rate of evaporation in surface water sources and hence the concentration of dissolved solutes (Simpi *et al*., 2011; Hanasaki *et al*., 2013; Wang *et al*., 2014; Bada *et al*., 2017). Water PH, electrical conductivity, turbidity, alkalinity and water hardness among other chemical properties are greatly influenced by seasons and location (Simpi *et al*., 2011). Agricultural activities along the river banks also contributes to high water alkalinity (Pradesh *et al*., 2012). The agricultural inputs on the farms are washed off by surface run-off into the surface water sources where they accumulate (Shen and Chen, 2010). Leaching through the soil occurs as rain water percolates and infiltrates through the soil profile (Pradesh *et al*., 2012).

Rural dwellers rely on surface and ground water for drinking and food processing (Malik *et al.*, 2010; Ahmad *et al.*, 2012; Muhammad *et al.*, 2013; Muhammad *et al.*, 2017). Due to contamination, majority of the human population do not have access to potable water and are therefore exposed to water borne health risks (Muhammad *et al*., 2013). High alkalinity and pH of most of these water sources induces unpalatable taste as well as high salt intake that is implicated in high blood pressure and kidney stones (Anwar *et al*., 2011; Muhammad *et al*., 2017). However fluoride in optimal concentration in the drinking water is beneficial for strong teeth formation (Muhammad *et al*., 2013).

Table 2.1: Physico-chemical characteristics of potable water, maximum permitted level (mg/l or as stated)

Parameter	Bottled water	Un- bottled water
Colour	3.0 TCU	15.0 TCU
Temperature	Ambient	Ambient
Turbidity	5.0 NTU	5.0 NTU
pH	6.5-8.5	7.0-8.0
conductivity	1000 µS/cm	1000 µS/cm
Chloride	100 mg/L	250 mg/L
Fluoride	1.0 mg/L	1.0 mg/L
Copper	1.0 mg/L	1.0 mg/L
Iron	0.03 mg/L	0.05 mg/L
Nitrate	10 mg/L	10 mg/L
Nitrite	0.02 mg/L	0.02 mg/L
Manganese	0.05 mg/L	0.1 mg/L
Magnesium	0.20 mg/L	0.20 mg/L
Zinc	5.0 mg/L	5.0 mg/L
Total dissolved solids	500 mg/L	500 mg/L
Hardness (as $CaCO_3$)	100 mg/L	150 mg/L
Hydrogen sulphide	0.01 mg/L	0.01 mg/L
Sulphate	100 mg/L	100mg/L

TCU = true colour unit, NTU = Nephelometric turbidity unit; Source: (USESA, 2012).

2.3.Water contamination

Regardless of the sources, water is susceptible to microbial, toxic organic and inorganic contamination (Anyamene and Ojiagu, 2014; Gangil *et al.*, 2013). The presence of coliforms in potable water is used as indicator of microbial contamination (Opara and Nnodim, 2014).

Coliform bacteria are a group of enteric bacteria that include *Escherichia coli*, *Klebsiella* and *Enterobacter* species. *Coliforms* are rod shaped, gram negative organisms and ferment lactose liberating acid and gas when incubated at 37 ˚C for 48 h. *Coliform* bacteria live in the digestive tract of humans and animals and remain harmless (Opara and Nnodim 2014). Generally, *Coliforms* indicate possible contamination with pathogenic bacteria, viruses and protozoa (Anyamene and Ojiagu, 2014; Goel, 2006).

Escherichia coli is used as indicator of possible recent faecal contamination (Anyamene and Ojiagu, 2014; Onuh and Isaac, 2009; Opara and Nnodim, 2004) since it is the first bacteria present in water when contamination occurs and will be present in larger quantities than some other pathogenic microbes. Other microbial indicators of possible faecal, soil and natural water contaminations are faecal *Enterococci* especially *Enterobacter faecalis*, *Clostridium perfringens* spores, *Clostridium sporanges*, *Salmonella typhi*, *Shigella dysenteriae*, *Vibrio cholera*, *Pseudomonas aeruginosa*, *Klebsiella* spp. *Aeromonas* spp., *Mycobacterium* spp., *Alcaligens*, *Actinetobacter*, *Chromobacterium*, *Serratia spp*, *Flavobacterium spp.*, *Proteus* spp., *Bacillus subtilis*, *B. mycoides*, *Enterobacter cloaca*, *Enterobacter aeronenes*, *Nostocida fexibacter* and *Norcardia* spp. (Edema *et al.*, 2001; Tortora *et al.*, 2002; Oyedeji *et al.*, 2010; Khaniki *et al.*, 2010; Cleark, 2010; Oludairo *et al*., 2013; Onilude *et al.*, 2013; Falegan *et al.*, 2014). These could cause different disease conditions such as giardiasis, cryptosporidiosis, gastroenteritis, diarrhea, typhoid fever, cholera, bacillary dysentery, hepatitis and shigellosis (Akinde *et al.*, 2011; Thliza *et al.*, 2015; Oyedeji *et al.*, 2010; Isikwue and Chikezie, 2014; Aroh *et al.*, 2013; Hughes and Koplan, 2005). Water borne diseases are reported to account for 80 % of illnesses in developing world, killing a child every 8 seconds. This is a global public health threat (Hughes and Koplan, 2005).

Water source microbial quality is a prominent concern especially in dispensing disinfection treatment (Lee and Kim, 2002; McGuigan *et al*., 2012) since the complexity, time and cost, limit routine pathogenic organisms test. The effectiveness of water treatment methods cannot be adequately validated given the limited resources.

2.4. Socio-economic characteristics and safe drinking water

Demographic characteristics of the population influence their water handling practices as well as the source of water. Some of the demographic factors that influence water utilization and treatment techniques are discussed in this section. Isiolo County population is constituted of 52 % male and 48 % female. The majority of the ethnic groups are Somali (70 %), Garri, a sub-tribe of Somali descent (16 %) and Borana (10 %) (Lamuka *et al*., 2017). A high percentage of the population in arid and semi-arid lands (ASALs) of Kenya (66 %) have no formal education and their main occupation is livestock-keeping (70 %) (Wayua *et al*., 2012; Watete *et al*., 2016).

2.4.1. Age and size of households

Safe drinking-water for human consumption cannot be considered in isolation from other issues, of which age of the households' heads is the most important. Numerous studies have shown a strong correlation between the age of the household head and water safe use accessibility and consumption (Steg and Vlek, 2009; Arouna and Dabbert, 2010; Watete *et al*., 2013; Lamuka *et al*. 2017).

More than 35 % of population are children aged below 5 years and majority of the population are youth aged above 20 years (Muhammad *et al.*, 2017). These young people are more concerned with water safety, uses, its consumption and the spread of different types of water borne diseases (Muhammad *et al*., 2017).

Households with more residents use more water (Aitken *et al*., 1991, 1994; Gregory and Di Leo, 2003; Jeffrey and Gearey, 2006). Women and children dominate the African population, defining their role in carrying water over long distances from the sources to the households (Mallick and Rojas, 2015).

2.4.2. Level of education

Family units with advanced education levels frequently have more grounded aims to preserve water (Gilg and Barr, 2006; Lam, 2006). With enhanced level of education, goals to introduce water proficient machines are achievable (Muhammad *et al*., 2017). However, families with lower instruction participate in more water protection practices and utilize less water than advanced educated families (Gregory and Leo, 2003). The unit water consumption by the educated families are always higher. However, they are more concerned about the safe utilization of the water resources in the area.

2.4.3. Source of drinking water

Water assets and resources will be put under further weight in coming decades as population increase with growth of economy (Vorsmarty *et al*., 2000). Environmental change is probably going to additionally compound existing stressors on water supplies. Meeting this test will require sourcing selective water supplies and expanding the efficiency of existing water supplies (Postel, 2000; Alam *et al*., 2013). Four types of drinking water sources i.e. piped, protected dug well, unprotected dug well, and hand pump among other water sources are used for drinking. Different types of water sources are used for drinking purposes, irrespective of their safety on human health (Muhammad *et al*., 2017).

2.4.4. Method of household water storage

In the world, storing tap water in clean and rinsed plastic, glass, enameled metal, or fiberglass containers can extend the shelf life of water and once filled in the container, it should be tightly sealed and stored in a dark, cool location (Alam *et al*., 2013). Method of water storage at household level is divided into seven categories i.e. container with lid, container without lid, water tank on roof, drum, jericans, water cooler and pitcher (Muhammad *et al*., 2017). These containers are also used for storing the water at household level awaiting use for drinking, food processing and domestic use.

2.4.5. Interval of cleaning water storage vessels

Drinking water is drawn from fresh water sources, which represent only 3 % of the 1.4 billion cubic kilometers of water covering the earth (Manhokwe *et al*., 2013). Less than 1 % of this fresh water is safe to drink without prior treatment. Drinking water storage vessels at household level are cleaned daily, once a week/month, once a year and some households never clean the storage vessels. Majority of the population in ASALs of Kenya are illiterate and less sensitized on the importance of hygiene and sanitation (Wayua *et al*., 2012; Watete *et al*., 2016; Lamuka *et al*., 2017).

2.4.6. Method of drawing drinking water from the storage container

Many observations suggest that treating water in the home can prevent illness. In many parts of the developing world, drinking water is collected from unsafe surface sources outside the home and is then held in household storage vessels (Alam *et al.*, 2013). Drinking water may be contaminated at the source or during storage; strategies to reduce waterborne disease transmission must safeguard against both events. The methods of drawing drinking water from the storage vessels are divided into four categories: dipping a glass/jug or mug, long handle scoop, taps and others (Muhammad *et al*., 2017). In most rural set-ups, the mug used for drawing water from the vessel is the same one used for drinking, lowering the level of hygiene and increasing the health risk associated with water contamination.

2.5. Methods of water disinfection

Water disinfection methods are broadly grouped into three; physical, chemical and membrane process. Chlorination among other chemical water treatment methods are the most popular (Somani and Ingole, 2011).

2.5.1. Physical water disinfection methods

Cost and non-residual effect for safeguarding disinfected water against future contamination (Somani and Ingole, 2011) has limited the application of these methods in water disinfection. Boiling which is a common disinfection practice among others are discussed here.

2.5.1.1 Boiling

Boiling is a phase change process associated with very high heat transfer rates (Dhir and Manickam, 2012). Boiling is a complex process constituted by nucleation, bubble growth, bubble departure and dynamics and their influence on heat transfer from the heater surface (Dhir, 2006; Warier and Dhir, 2006). Bubbles slide along the heater surface after departure from their original nucleation sites propagating heat transfer (Dhir and Manickam, 2012). Studies have also shown that the sliding motion of bubbles enhances heat transfer from the heater surfaces, although the cause for this enhancement has been attributed to many sub-processes including, evaporation of thin micro-layer underneath the bubble, turbulence in the wake of the bubbles and the disruption of the thermal boundary layer due to bubble motion. Sliding bubble motion and the turbulence in the reactor causes cell disruption and induction of water disinfection (Somani and Ingole, 2011).

Disinfection by boiling is achieved when water temperature is raised to boiling point, then maintaining this temperature for about 15-20 minutes to achieve desired bacteria kill (Somani and Ingole, 2011). This method has found its application in Isiolo County for preservation of milk in the camel milk value chain (Wayua *et al*., 2012). However, the use in water treatment by households has not been established. Heating is involved and consequently fuel requirement in form of firewood, electricity and other forms must be met. The use of wood as fuel is common at household level although it has been linked to increase in deforestation as trees are cut to meet the firewood demand.

2.5.1.2 Solar radiation

Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaic, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis (Konersmann and Frank, 2011).

Solar water disinfection method has gained recognition following the realization of sunlight germicidal effect. Effectiveness and feasibility has been reported for small quantities of about 3 litres of water (Fadhil, 2003; Shibu *et al*., 2006) in solar water disinfection (SODIS). Exhaustive application in continuous solar water disinfection reactors has not been fully established, but, no taste, odour and complete germicidal destruction of target microorganisms are the reported advantages (Somani and Ingole, 2011). The full potential of solar water disinfection to inactivate a wide range of waterborne pathogens has been investigated (McGuigan *et al*., 2012)

2.5.1.3 Titanium dioxide (TiO_2) films and sunlight

(TiO_2), also called Titania. TiO_2 is a wide band semiconductor whose band-gap energy of 3.2 eV, corresponds to photons of wavelength shorter than 390 nm (UV-A) (McGuigan *et al*., 2012). TiO2 may be utilised in aqueous suspension or may be immobilized on a supporting solid substrate. Suspending the catalyst in the reactor has been reported to be more efficient due to large surface area available for the reaction. However, using micro-particles in suspension is the requirement for post-treatment retrieval or recycling of the catalyst, potentially making the treatment more complex and expensive (McGuigan *et al*., 2012). Hydroxyl radicals produced as a result of Titanium dioxide dissolution in water are the primary species responsible for microorganism inactivation. The oxidative effect of TiO_2 photo catalysis occurs by direct contact of the catalyst particle with the bacteria, and the first damage occur at the outer membrane (Sunada *et al*., 2003). Reactive oxygen species (ROS) such as Hydrogen peroxide and oxygen radical (H_2O_2, $O_2^{\bullet -}$) for induced microbial inactivation. These ROS cause fatal damage to microorganisms by disruption of the cell membrane or by attacking DNA and RNA. Other modes of TiO_2 action have been proposed including damage to the oxygen transport system within the cells or increased ion permeability in the cell membrane. The capability of TiO_2 to inactivate a wide range of pathogens has been a fruitful (McGuigan *et al*., 2012).

Titanium dioxide (TiO_2) has been used as a photo catalyst in solar water disinfection of coliform bacteria contaminated water (Silva *et al*., 2006). Titanium dioxide is added to water at a critical concentration to increase radiation absorptivity. The photo excitation of titanium dioxide particles promotes an electron from the valence band to the conduction band thus leaving an electron hole in the valence band; in this way, electron/hole pairs are generated. The photo excited electrons produces disinfection species that induces sequential germicidal effect in the water. Increased efficiency in inactivating both total and faecal coliforms and keeping the water coliform free for seven days after sun irradiation when compared with normal solar water disinfection has been reported (Somani and Ingole, 2011). This method has however found limited use due to its high cost and the need for uniform solar radiation.

2.5.1.4 U-V Radiation

Ultraviolet disinfection of water employs low-pressure mercury lamps. They generate short-wave ultraviolet in the region of 253.7 Angstroms which is lethal to micro-organisms including bacteria, protozoa, viruses, molds, yeasts, fungi, nematode eggs and algae (Brahmi and Hassen, 2011).

The mechanism of micro-organism destruction is currently believed to be due to the fact that ultraviolet causes molecular rearrangements in DNA and RNA, which in turn blocks replication (Eccleston, 1998; Brahmi and Hassen, 2011; McGuigan *et al*., 2012. The acceptance of UV disinfection at waste water plants treating in excess of one billion gallons daily is proof that UV is no longer an emerging technology, but rather an accepted technology used routinely by engineers to safeguard human health and alleviate environmental pressures.

Several investigations have reported a relationship between suspended solid concentration and fecal coliform survival in UV irradiated wastewater samples (Oparaku *et al*., 2011). There exist a synergistic use of UV with other forms of particle-penetrating irradiation in an integrated disinfection process with a greater disinfection potential. UV light disinfect aqueous solutions in different ways and disinfection might be accomplished more efficiently if the UV is carried out at low doses to inactivate the free microorganisms (Brahmi and Hassen, 2011).

U-V water treatment thus involve the application of U-V dose to kill or retard microbial cell growth and to an extent alter the cell DNA structure (Nicki *et al*., 2004). A 99.99% efficiency of disinfection is achieved with water free from suspended colloids, flowing in the form of thin sheets of about 120 mm and adequate intensity and time of exposure to U-V rays (Nicki *et al*., 2004; Somani and Ingole, 2011). This method has the advantages of short exposure period for disinfection, no taste and odour and complete destruction of microorganisms.

2.5.1.5 Electromagnetic radiation

Relies on the use of X-rays and gamma rays sourced primarily from Cobalt 60 (Co60) which exhibit high ionization power and germicidal properties that are realized at a range of 0.2µ to 0.3µ and peak at 0.26µ wavelength (Bhagwatula *et al*., 2000). Effective disinfection requires the radiation source to be close to the medium (Somani and Ingole, 2011).

2.5.2 Chemical water disinfection methods.

2.5.2.1 Hydrogen peroxide

Addition of hydrogen peroxide to turbid water, liberates nascent oxygen which induces germicidal effect. Excess hydrogen peroxide is then removed by fine filtration through a column of divided manganese dioxide and sand. The column is pre-washed with dilute $KMnO_4$ (potassium permanganate) (Somani and Ingole, 2011). Treatment of the turbid water can also be achieved at a temperature of 40 °C with addition of small quantities of hydrochloric acid acidified hydrogen peroxide, then neutralizing the excess acid (Bhagwatula *et al*., 2000). This is costly, has no residual effect and has poor germicidal properties.

2.5.2.2 Acid and Alkali

The pH dependent microbial growth is inhibited through addition of an alkali or acid that either raises or lowers the pH levels. The pH is then neutralized after the desired destruction of pathogens has been realized (Somani and Ingole, 2011). To a lay person it can be quite challenging to properly portion the acids and alkali in the disinfection procedures. There is likelihood of over portioning as well as under-portioning yielding undesirable results. Most of the acids are especially the corrosive. The mild organic acids are scarce and use in commercial water treatment is costly.

2.5.2.3 Metallic ions

Metallic ions of silver, mercury and copper exhibit germicidal effect. Introducing 0.05 - 0.1 mg/l dose of silver ions into the turbid water produces a bacterial kill in 15-18 min contact time (Min Cho *et al*., 2006). This method is costly and not suited for large scale operation.

2.5.2.4 Chlorite and chlorine dioxide

The strong disinfection and oxidising properties of chlorite ion (ClO_2^-) and chlorine dioxide (ClO_2) has found application in secondary disinfection in full-scale water distribution systems. This method is effective against cryptosporidium and five times faster in inactivating giardia than chlorine (Gagnon *et al*., 2005). Its use is however not widespread due to the high operation cost as well as odour and taste problems.

2.5.2.5 Chlorination

Chlorine is widely used for water disinfection but has one problem. In water, chlorine combines with trace amounts of naturally occurring organic matter and liberate toxic by-products on disinfection known as halogenated disinfection by-products DBPs (Clark, 1998). Toxic trihalomethanes (THMs) represent a large fraction of these halogenated DBPs, hence need for alternative disinfection methods.

2.5.3 Membrane process disinfection method

Membrane process is an emerging field in water treatment with various application in desalination, taste and colour removal as well as microbial disinfection (Fane *et al*., 2011). The involved processes are; micro and ultra- filtrations and reverse osmosis.

Technological advances and development have shown the drawback in using chlorine as disinfectant and necessity of alternative disinfectant. Currently in the developed Nations, Ozone and UV radiation are in use for water disinfection. However, in developing Nations, use of these expensive methods is limited mainly due to their costly nature (Somani and Ingole, 2011). Adequate solar insolation makes solar water disinfection more promising alternative to chlorine in water disinfection within the tropics.

2.5.4 Water treatment using traditional herbs

The major population world's population is living in rural areas, where these natural herbs are easily available (Tanushree *et al*., 2013). The effective antimicrobial activity of plants leaf extracts is due to the synergistic effect of the active components present in plant leaves. According to traditional belief Tulsi leaves (*Ocmium sanctum*) and Neem leaves (*Azadirachta indica*) have the capacity to purify water (Pavithra *et al*., 2012). Other plant species with germicidal effect are *Moringa oleifera*, *Abelmoschus esculentus (Okra)* and *Calotropis Procera* (Calotrope).

Moringa oleifera, known as Moringa, is native to north India but is now found throughout the tropics. It grows fast and reaches up to 12 m. The bark is grey and thick and looks like cork, peeling in patches. Moringa is full of nutrients and vitamins and is good food for humans and animals. Moringa helps to clean dirty water and is a useful source of medicines (Binayke and Jadhav, 2013; Tanushree *et al*., 2013).

Abelmoschus esculentus, is vegetable crop grown in the tropics (Pavithra *et al*., 2012). Okra gum is soluble in cold water. When added to turbid water, regardless of the Gum mucilage volume, the turbidity decreases as the pH increases. The reduction in turbidity is significant with higher mucilage dose (Binayke and Jadhav, 2013). The mucilage contains natural polymer molecules that aide's flocculation from a complex chemical reaction (Nacoulima *et al.*, 2000).

Calotropis procera is a tropical shrub (Binayke and Jadhav, 2013). Mostly planted as an ornamental shrub. *Calotropis procera* has been reported to contain calotropin (non-toxic proteolytic enzyme) that is traditional used in the cheese industry for milk curdling (Ogundiwin and Oke, 1983; Aworh *et al*., 1994). *Calotropis procera* has also been used for enzyme purification by precipitation (Kareem *et al*., 2002).

Water disinfection technique using herbs is virtually less costly approach render contaminated water fit for human consumption. However, this technique can be effective for the water obtained from water sources having low degree of contamination or else water can be given prior filtration with charcoal or fine sand to reduce the contamination load (Tanushree *et al*., 2013). Better germicidal effect can be realized if this technique is combined with solar water treatment (Binayke and Jadhav, 2013).

2.6 Solar energy

The sun emits about 1360 Wm^{-2} of solar radiation energy. Out of which 1120Wm^{-2} hits the earth surface (McGuigan *et al*., 2012; Chaichan and Kazem, 2016). The radiation energy induces electricity generation on photovoltaic cell and other portions induces thermic effect that raises the temperatures of the earth’s environment (Chaichan and Kazem, 2016). Absorptivity of the solar radiation on the earth surface is greatly influenced by the angle of incidents of the radiant rays (Jeng *et al*., 2009; Makrides *et al*., 2009; Chaichan and Kazem, 2016). Wavelengths of the sunrays falling on the earth surface vary depending on the prevailing weather conditions of the days as well as season (Chow, 2010; Chakraborty *et al*., 2014). These among other factors significantly affect the solar radiation intensity incident on the earth surface (Zell *et al*., 2015).

2.7. Solar energy use in water disinfection procedures

Solar energy use in house-hold water treatment has grown over the recent past (Clasen *et al*., 2007). Drinking water was placed in open trays on the sun by some Indian communities over 2000 years ago (McGuigan *et al*., 2012). Downes and Blunt (1877) rigorously determined the bactericidal effect of sunlight on water, SODIS potential to inactivate water borne pathogens was realized in 1984 when Aftim Acra and co-workers published their seminal work on disinfection of contaminated water by sunlight (Acra, 1989). Since then, investigations on solar water disinfection has been documented in various studies. Solar water disinfection is done by filling the transparent containers with contaminated water and subjected to direct exposure to radiation from the sunlight for a duration less than 6 h. After the minimum exposure, the water is potable and ready for use.

SODIS reactors are made either from glass or ethylene-terephthalate plastics. Plastic reactors are usually used for their robust advantage over glass (Dunlop *et al*., 2011; Walker *et al*., 2004). Post exposure regrowth possibilities are minimised by consuming the solar disinfected water in a period less than 24 h post exposure (McGuigan *et al*., 2012). Black painted solar water disinfection containers, placing the SODIS reactors on reflective surface and filtering the turbid water prior to filling into the reactor (Reed, 2004) are some advances made to enhance solar water disinfection efficiency.

2.8 Effect of solar radiation energy on the microbial cell structure

Thymine and cytosine base components of pyridine rings of DNA molecule of the microbial cell absorb U-V upon irradiation. The absorbed energy by the cell, facilitate formation of paired covalent linkage in the neighbouring bases of pyrimidine, consequent to dimers formation (Goodsell, 2002). Molecular DNA shape is transformed at pyrimidine dimer locus following inhibited complimentary purine-base pairing (McGuigan *et al*., 2012). The polymerase DNA copying enzyme movement is inhibited at the dimer locus, resultant effect is confusion of nucleotide to be added and deletion of two DNA bases if by chance the polymerase enzyme skip over the locus of pyrimidine dimer.

The less energetic U-V radiation near visible light excites the cell porphyrins, flavins, quinones and among other photosensitizers, forming the DNA damaging reactive oxygen species (ROS) (Reed, 2000; McGuigan *et al*., 2012), humic acid and chlorophyls on water surface, react with oxygen upon irradiation producing disinfecting effect by ROS (Schwartzenbach *et al.*, 2003; Bosshard *et al*., 2010). Cellular damage induced by exposure to irradiation from sunlight continues at darkness incubation post sunlight exposure (Bosshard e*t al.*, 2010). To achieve desired disinfection, the physiological stage and cell growth rate remains a microbiological concern parameters (Berney at al., 2006).

Escherichia coli the main disinfection studies species regular cell operations is disrupted following termination of ATP synthesis and efflux pump activity shortly on solar radiation exposure (Berney *et al*., 2006), consequently loss of glucose uptake by the cell membrane enhances the permeability of cytoplasmic membrane and ability to culture the DNA is lost.

Pathogenic water borne microorganisms especially bacteria are readily susceptible to solar water disinfection with low pace disinfection reported in faecal coliforms that occur in nature (Sinton *et al*., 2002).

2.9 Solar energy use in water treatment

Water treatment using solar energy is not a recent development and has been practiced in ancient cultures for centuries (Kean *et al*., 2014). Historical developments of solar water treatment in the recent past has been reviewed (McGuigan *et al*., 2012). It has been established that, solar water disinfection (SODIS) is one of the most practical and low-cost techniques to reduce the load of pathogenic microorganisms in water at households in low-income areas (Borde *et al*., 2016; Castro-Alferez *et al*., 2016). Some of the applications of solar in water treatment included: pasteurization, distillation and solar water disinfection.

2.9.1 Solar pasteurization

Solar pasteurization involves raising the temperature of the water by heating for a period of time sufficient to destroy pathogenic micro-organisms (Pejack, 2011). An exponential inverse relationships occurs between pasteurization temperature and time (Birzer *et al*., 2014). Pathogenic organisms such as worms and protozoa cysts are destroyed at temperatures above 55 $^{\circ}$C, whereas *Escherichia coli*, *Salmonella typhi*, *Vibrio cholera*, *Shigella spp* and Rotavirus are destroyed at temperatures above 60 $^{\circ}$C (Birzer *et al*., 2014). Therefore, pasteurization at 60 $^{\circ}$C is sufficient to effectively eliminate pathogens of concern in water.

A 4-log reduction in *Escherichia coli* was realized within 1 hour pasteurization in aluminium foil reflectors and PET plastic bottles system (Safapour and Metcalf, 1999), though this system was limited to treat less than 2 litres of water. In another solar water pasteurization system consisting of flat plate collector and an automotive thermostatic valve that released water batches upon attainment of desired temperature, 95 litres and 49 litres of water per day was obtained using the reflectors and without using the reflectors respectively (Onyango *et al*., 2009).

Konersmann and Frank (2011) used a system constituting evacuated tubes with a thermostatic valve which was used to release batches of water once the temperature was above 82 $^{\circ}$C. The system released 500 litres per day of pasteurized water (Konersmann and Frank, 2011). The cost of construction and maintenance of this system is relatively high thereby limiting the use.

2.9.2 Solar water distillation

Solar water distillation has been investigated in various research studies (Muslih *et al*., 2010; Koning and Thiesen, 2005). Solar energy from the radiation is used to evaporate the water and the distillate collected (Birzer *et al*., 2014). Solar distillation is effective on chemical, physical and microbial contaminants. However, water demineralization occurs lowering the quality (Dev and Tiwari, 2011; Birzer *et al*., 2014).

2.9.3 Solar water disinfection (SODIS)

This method has gained recognition following the realization of sunlight germicidal effect, effectiveness and feasibility on small water volumes of approximately 3 litres (Fadhil, 2003; Shibu *et al*., 2006) in solar water disinfection (SODIS). No taste, odour and complete germicidal destruction of target microorganisms are the reported advantages (Somani and Ingole, 2011). Conventionally, transparent water bottles are filled with contaminated water and placed in the sun for 6 h after which the water is presumed to be safe for use (McGuigan *et al*., 2012; Keane *et al*., 2014). Post exposure regrowth possibilities of microorganisms in water is minimized by using the batch SODIS disinfected water within 24 h after disinfection (McGuigan *et al*., 2012).

2.10 Enhancement of batch SODIS systems

Batch solar water disinfection has relied heavily on cost-effective plastic bottles as reactors inspite of the limited volume of 2 litres per batch of treated water. Glass reactors have a good solar transmittance of 90 % (Navntoft *et al*., 2008) but are more expensive than plastic reactors. Use of low-density polyethylene solar disinfection bags has been reported (Dunlop *et al*., 2011), even though release of potentially genotoxic compounds into the disinfected water from the PET bottles during long time solar water disinfection exposure has raised concern (Ubomba-Jaswa *et al*., 2009).

Painting the reactors, placing the reactors on reflective surface and filtering the turbid water prior to filling into the reactor (Kehoe *et al*., 2001; Reed, 2004; Mani *et al*., 2006) are some of the advances made to enhance solar water disinfection efficiency.

There exist a strong synergistic association between optical and thermal inactivation at temperatures greater than 45 $^{\circ}$C (McGuigan *et al*., 1998). This synergy is not achievable under normal exposure of PET bottles to the sun. To accelerate the rate of thermal inactivation of organisms, absorption of solar radiation is enhanced by use of absorptive materials and painting reactor PET bottles black (Sommer *et al*., 1997; Martin-Dominquez *et al*., 2005). The use of solar collectors and reflectors have been reported in other studies. (Kehoe *et al*., 2001; Saitoh and Ghetany, 2002; Wegelin *et al*., 2001).

Illumination of batch PET reactors only on one side facing the sun necessitated the use of reflector mirrors to concentrate solar radiation in the reactor bottle (McGuigan *et al*., 2012). Aluminium foil attached to a SODIS reactor produced a double increase in water disinfection rate (Kehoe *et al*., 2001). Walker *et al*. (2004), also reported a reflective food grade solar disinfection pouch to enhance the physiological effect of the solar radiation on microorganism on irradiation.

2.11 Continuous solar water disinfection systems

With the limited volume of disinfected water obtained using batch SODIS systems, attempts have been made to improve on disinfected water volume by enhanced thermal inactivation using flat plate flow reactors and incorporation of titanium dioxide as aphotocatalyst (Dunlop *et al*., 2002; Sichel *et al*., 2009). A PVC circuit, covered with acrylic layer and a catalyst incorporated in the system produced a 4 log coliforms reduction as well as an increase in disinfected water output (Caslake *et al*., 2004). Continuous SODIS system despite being advanced than batch systems, they also have associated limitations (Ubomba-Jaswa *et al*., 2009).

Solar photo-reactors fitted with compound parabolic collectors (CPCs) and recirculation systems at two flow rates of 0.033 kgs^{-1} and 0.167 kgs^{-1} were used to study the effect of the total volume of treated water and the flow rate on inactivation. Irrespective of the exposure time, flow rate and bacteria inactivation are inversely associated (Ubomba-Jaswa *et al*., 2009). Bacteria need maximum exposure to solar radiation than being subjected to sub-lethal U-V doses repeatedly for long durations without achieving complete germicidal action (McGuigan *et al.*, 2012; Ubomba-Jaswa *et al*., 2009). Bacteria inactivation depended on U-V dose other than irradiance (Ubomba-Jaswa *et al*., 2009). With continuous flow systems, the lethal dose was also delivered to the bacteria but in an intermittent manner, resulting in approximately a 2 log Coliform forming units per milliliter concentration of residual viable bacteria remaining after the 5 hour duration of disinfection.

A single pass continuous flow reactor with a flow rate of 0.167 kgs^{-1} using a CPC reflector of 1.0 concentration factor assembled in eight panels completely inactivated 100 Cfu/ml of coliforms after a 20 minutes single pass residence time (Gill and price, 2010). Similarly, a 2 log reduction in *Escherichia coli* in a 50 liters continuous pilot scale flow reactor on grey water was reported (Pansonato *et al*., 2011). A 1.89 concentration factor CPC reflector in a continuous single pass flow reactor, achieved a reduction in residence time required for disinfection and a higher volume of disinfected water (Polo-lopez *et al*., 2011).

Waste heat during cooking has been used to disinfect water at the rural areas (Islam and Johnston, 2006). The treated water is continually collected, though, this system is limited on large scale water disinfection operation. A parabolic trough concentrating solar collector with a passive flow temperature regulation in a continuous flow water disinfection systems has been reported (Duff and Hodgson, 2005; El-Ghetany and Dayem 2010).

Anthony *et al*. (2015) developed a continuous-flow, gravity-fed system with flat reflectors that used simple solar oven to heat incoming water to pasteurisation (70 $^{\circ}$C) in seven minutes. The waste heat from the system is recaptured for preheating water to be treated. The solar ovens are in design of closed boxes with clear face to trap heat for incident radiation from the sun.

Anthony *et al*. (2015) prototype consisted of solar collector box made from plywood, window-insulating plastic, 33.3 m of PEX tubing, a metal absorber plate, reflective Mylar, hinges and screws. A simple shell-tube heat exchanger was built from 1.2 cm OD copper pipe mounted inside a 2.54 cm OD PVC pipe (shell). The 1 m by 1.3 m solar collector had three reflectors to maximize irradiative sunlight into the box. Water flows through 33.3 m of PEX tubing mounted on a 1 m by 1.3 m steel plate and is sealed with a solar window (clear plastic sheet) to prevent heat loss. The metal absorber plate below the array of tubing increases heat transfer to the water flow (Cramer *et al*., 2013). The heat exchanger, which uses the hot water exiting the solar collector to preheat the water that is about to enter the solar collector, is mounted on the side of the box. Outer connective tubing that carries hot water is insulated in order to prevent unnecessary heat loss.

The optimal flow rate for reaching pasteurisation temperatures of the system was about 0.0025 kgs^{-1}. The solar thermal pasteurisation design worked at 700 Wm^{-2} and disinfection was achieved at high throughputs (Anthony *et al*., 2015).

An isolated tank of 500 liters connected by 1.25 cm PVC tubing to a smaller 125 liters formed part of a continuous solar disinfection reactor designed by Khaled *et al*. (2008) and the water level was controlled by a float valve and submersible pump that also served water into the PET reactors.

The reactor was held by a metal frame similar to that of flat solar water heaters. The frame was tilted by 45 $^{\circ}$ for maximum radiation interception and then connected to 125 liters disinfected water storage tank. The pump was controlled by a light activated switching unit that utilized a photovoltaic cell to switch the pump on when light is available dictated by the output voltage of the photovoltaic cell (two hours after sunrise) and off when light is not available (one hour before sunset). Later Khaled and co-authors installed a flat solar water heater and a heat exchanger for water circulation in the PET reactor and regulated the temperature of out coming water from the reactor respectively. The solar water heater depended on convective circulation established from solar heating to move the water from one tank to the other (Khaled *et al*., 2008). The heat exchanger during the operation of the system was to aid in increasing the temperature of the water going into the solar disinfection reactor in order to decrease the time needed to raise the temperature of the water. The system was also equipped with a thermal one-way valve to regulate the flow of water between the solar heater and the reactor. The one-way valve opens when the temperature of the water reaches the desired temperature and thus starts the whole process of disinfection (in the morning) and closes when the temperature of the water decreases below the limit (close to sunset). The design faced flow problems especially at elevated temperatures mainly in the form of reduction in flow rates and sometimes back flow problems. Thus, the exposure times needed to achieve the required water disinfection had to be changed slightly by decreasing the flow rate of water through the reactor (Khaled *et al*., 2008). This adjustment of flow rate provided additional exposure time. Further modifications of the design are necessary to cab the flow problems. Based on the bacterial species examined, water turbidity is a major factor influencing water disinfection by natural UV radiation and that on increased exposure time or filtration methods are needed to reach maximum bacterial inactivation Khaled *et al*.(2008).

El-Ghetany and Dayem.(2010) designed a continuous flow solar water disinfection system that consisted of a 200 liters contaminated water tank, clean water tank, shell and tube heat regenerator, flat-plate solar collector, control unit fitted with measuring instruments and a frame. A 4 m head pressure was used to pass water through the collector from the contaminated water tank. Significant amount of water disinfected was obtained at different set temperatures. A flat plate collector of 160 cm by 11 cm by 0.05 cm thickness was fabricated from eleven steel fins aligned with nine copper tubes of 7 mm diameter (El-Ghetany and Dayem, 2007; El-Ghetany and Dayem, 2010). The collector had an area of 2.34 m^2 oriented at angle of 30 ˚. The system realized approximated 400 liters output of hot disinfected water at 60 ˚C set temperature. Volume of hot water produced increased to maximum at noon followed by a gradual decrease during disinfection hours after noon, this was attributed to solar variation trends (El-Ghetany and Dayem, 2007).

Thermo siphon solar water heating system with a single flat plate solar collector produced 3.6 liters per hour of hot water at 80 ˚C per square meter of the flat plate reactor for each kWh of incident solar energy (Bansal *et al*., 1988). Similarly 2.85 liters per hour of hot water at 70 ˚C per square meter of flat reactor for every kWh incident radiation was reported by El-Ghetany and El-Seesy. (2005).

2.12 Influence of turbid water condition on solar disinfection

Solar water disinfection kinetics is greatly influenced by presences of organic matter as well as inorganic matter in the contaminated water preceding disinfection procedures (Sichel *et al*., 2007). Under real disinfection, river and sewage water gives a good prediction of germicidal effect (McGuigan *et al*., 2012). Water exhibiting osmotic pressure arising from the presence of inorganic ions limit solar water disinfection, radicals of hydrogen peroxide and hydroxyl propagates the U-V induced bactericidal effect (Hoerter *et al*., 2005), hydrogen carbonate anions interact with the free radicals producing carbonate radical ($CO_3^{\circ -}$) whose reactivity interaction with organic molecules is low on comparison to oxygen radical (O°) (Canonica *et al*., 2005), side absorption of solar radiation by the hydrogen carbonate anion limit the amount of radiation incident on the microbial cells in water.

2.13 Solar Collectors

Solar collectors and thermal energy storage components are the two basics subsystems in solar thermal applications. Good optical performance is a key characteristic of solar collectors (Zalba *et al*., 2003), while thermal storage density, excellent heat transfer rate and durability are key to the thermal storage sub-systems (Zalba *et al*., 2003; Sharma *et al*., 2009). A discussion on thermal analysis and practical application of various solar collectors especially on solar disinfection is necessary (Kalogirou, 2004).

Solar collectors are usually classified into non-concentrating collectors and concentrating collectors (Tian and Zhao, 2013).

2.13.1 Flat-plate collectors

Flat-plate solar collectors are often permanently fixed in position, and therefore need an appropriate orientation. A typical flat-plate solar collector usually consists of glazing covers, absorber plates, insulation layers, recuperating tubes (filled with heat transfer fluids) and other auxiliaries (Tian and Zhao, 2013). Low-iron caste glass has better glazing properties attributed to its relatively high transmittance for solar radiation of approximately 0.85–0.87 and an essentially zero transmittance for the long-wave thermal radiation (Khoukhi and Maruyama, 2005). Adding a Teflon film as second glazing increased overall performance by 5.6 % at 50 $^{\circ}$C (Hellstrom *et al*., 2003). The absorber plate is usually coated with blackened surface in order to absorb as much heat as possible (Tripanagnostopolous *et al*., 2000; Wazwaz *et al*., 2002), however, various colour coatings have also been proposed in the literatures. In addition, to further improve the thermal performance of a collector, heat loss from the absorber also needs to be reduced. The heat absorbed by the absorber plate needs to be transferred to working fluids rapidly to prevent system overheating (Slaman and Griessen, 2009).

Excellent heat transfer performance is necessary in solar receivers. Kumar and Reddy (2009) investigated heat transfer enhancement of solar receivers with porous insertions and found that significant heat transfer improvement (64.3 %) was obtained. Lambert *et al*. (2006) found that oscillating flow can significantly improve heat transfer by increasing thermal diffusivities of the working fluids in solar collectors. Ho *et al*. (2005) employed a double-pass structure for solar receiver and achieved a better heat transfer rate.

2.13.2 Hybrid PVT Collectors

Hybrid photovoltaic/thermal (PVT) collectors simultaneously convert solar energy into electricity and heat (Aste *et al*., 2008). A typical PVT collector consists of a PV module with peak efficiencies in the range of 5 –20 % and an absorber plate (acting as a heat removal device) attached on the back of the PV module (Tian and Zhao, 2013). The heat removal plate cools the PV module down to a suitable temperature for better electrical performance, and at the same time, it collects the waste heat, to be re-utilised for domestic hot water production and adsorption cooling systems low temperature applications (Wang and zhai, 2012).The use of low concentration non-imaging optics with PVT has also received some attention (Brogen *et al*., 2000; Brogen, 2001). All the results indicated that hybrid PVT systems can achieve increased energy conversion efficiency with potential cost benefits (Hung *et al*., 2001) With detailed theoretical models for PVT collectors being developed, the complicated balance between thermal outputs and electrical outputs has been investigated (Zondag *et al*., 2002).

2.13.3 Enhanced hybrid PVT collectors – Bifacial PVT

Hybrid PVT Collectors can be classified into those that use water as the heat removal medium, and those that use air. Water is a desirable working fluid in hybrid PVT collectors, because of its high heat capacity and excellent optical properties (Tian and Zhao, 2013). A 4 cm-thick water layer reduced the optical reflection and the thermal drift in a water-submerged solar panel system, with a 15% increase in photovoltaic efficiency (Tina *et al*., 2012). Water absorbs the sunlight mainly in the infrared region, transparent nature of water allows for absorption of long-wavelength and short-wavelength irradiation to produce heat and electricity respectively (Tian and Zhao, 2013). Bifacial Photovoltaic module covered by water to absorb long wavelength radiation to produce heat and transmit short wavelength for electricity production, recorded approximately 40 % more electric energy production than a conventional PVT system (Robles *et al*., 2007), with no noticeable increase in the system cost.

However, they established that the system efficiency in a bifacial PVT module can be further improved if the waste heat can be recovered to produce domestic hot water. The double-flow passage not only removes excess heat more efficiently, but also saves the pump in the system which gives an even higher electricity output (Tian and Zhao, 2013).

2.13.4 Heliostat field collectors

Concentrating collectors have much higher concentration ratio than non-concentrating collectors, with a higher thermodynamic efficiency (Tian and Zhao, 2013). The Heliostat Field Collector, consists of a number of flat mirrors called heliostats. With changing sun position during the day, the collector's mirrors need to be appropriately oriented to focus incident radiation to a central tower. The orientation of every individual heliostat is controlled by an automatic control system powered by altazimuth tracking technology. In addition, to place these heliostats with a higher overall optical efficiency, an optimised field layout design is needed. Wei *et al*. (2010) proposed a technique to design the optimised field layout. An optimised field layout of heliostats can efficiently reflect solar light to the central tower, where a steam generator is located to absorb thermal energy and heat up water into the high-temperature and high-pressure steam (to drive turbine generators). The heat transfer fluid inside the steam generator can either be water/steam, liquid sodium, or molten salts (usually sodium nitrates or potassium nitrates), while the thermal storage media can be high temperature synthetic oil mixed with crushed rock, molten nitrate salt, or liquid sodium (Medrano *et al*., 2010; Gil *et al*., 2010).

Central tower solar collectors can be classified into external type and cavity-type, depending on which kind of central receiver is used. It is located at the top of the central tower; it comprises 24 panels (receiver diameter: 7 m), six of which are for preheating water and eighteen for producing steam. External receivers typically have a height to diameter ratio of 1:1 to 2:1. In order to reduce heat loss, the area of the receiver is usually designed to be as minimum as possible. However, the lower limit of the receiver area is determined by the maximum operating temperature of the heat exchange tubes and the heat removal capability of the heat transfer fluid, to protect heat transfer fluid from being overheated. The lower limit of the receiver area can be reduced by either using the tubes of higher temperature tolerance, or using the heat transfer fluid of higher heat removal capability. Heat transfer fluid includes water or steam, synthetic oils, liquid sodium and molten salts, among which molten salts and liquid sodium have much higher heat removal capability than steam and synthetic oils (Battleson, 1981). The flux from the heliostat field is reflected through an aperture (about one third to one half of the internal absorbing surface area (Battleson, 1981) onto the absorbing surfaces which form the walls of the cavity. The aperture size is minimised to reduce convection and radiation losses without blocking out too much of the solar flux arriving at the receiver. The primary limitation on receiver design is the heat flux that can be absorbed through the receiver surface and transferred into the heat transfer fluid, without overheating the receiver walls and the heat transfer fluid within them.

2.13.5 Parabolic dish collectors

Parabolic dish collectors use an array of parabolic dish shaped mirrors to focus solar energy onto a receiver located at the common focal point of the dish mirrors. Heat transfer fluid contained in the receiver is then heated up to desirable working temperatures and pressures in order to generate electricity in a small engine attached to the receiver (Tavakolpour *et al*., 2008). Engines currently under consideration include Stirling and Brayton engines (Zhang *et al*., 2007). Parabolic dish-engine systems have the advantage of high optical efficiency, low start-up losses and good modularity.

2.13.6 Parabolic trough collectors

Parabolic trough collectors can concentrate sunlight with a concentration rate of around 40, depending on the trough size (Tian and Zhao, 2013). The focal line temperature can be as high as 35 °C to 40 °C. The key component of such collectors is a set of parabolic mirrors, each of which has the capability to reflect the sunlight that is parallel to its symmetrical axis to its common focal line. At the focal line, a black metal receiver (covered by a glass tube to reduce heat loss) is placed to absorb collected heat. An experimental study by Bakos (2006) to investigate the effect of the axis tracking of parabolic trough on the sunlight collected, indicated that the measured collected solar energy on the tracking surface was significantly larger (up to 46.46 %) compared with the fixed surface. In addition, Kacira *et al*. (2004) found that the optimum tilt angle varied from 13 ° in summer to 61 ° in winter.

Parabolic trough collectors have advantages of being scalable, in that their trough mirror elements can be installed along the common focal line, they only need two dimensional tracking as opposed to dish-engine collectors that need three-dimensional tracking and can achieve higher tracking accuracy than dish-engine collectors.

CHAPTER THREE

Sources, Treatment Techniques and Utilization of Water in Isiolo County in Kenya

Abstract

Water is an integral component in agricultural activities, food processing industry. It is significant among the pastoral communities of Kenya for watering livestock. Frequent droughts experienced in Arid and semi-arid lands (ASAL) has limited pastoralists' access to diverse and unpredictable water sources and quality. The purpose of this study was to establish water sources, treatment techniques and usage using a cross sectional study in which 165 respondents were interviewed using a semi-structured questionnaire. Results show that 26.5 % of the respondents use borehole water, 21.8 % use river water while 16.9 % use spring water for drinking and processing in Leparua sub-location. Urban treated water is used by 14.5 % of the respondents based in Wabera and Kulamawe location. Pans and rain water are used during rains by 3.6 % of the respondents.

Boiling was the main water disinfection method used by 66.7 % of the respondents and 21.7 % used chlorination. Solar water disinfection was new to the population and used by none of the respondents.

The quality and safety of ground water sources used in Isiolo County is unknown. The County government need to develop an education system to promote adult education and as well institute technical training centers. This will provide the residents with basic technical skills to facilitate the effective adoption of water treatment techniques. Regular analysis of water sources to be carried out by the public health department to regularly advice on the state of the water quality and if any the mitigations to adopt to address the deviation of quality changes to unsafe extremes

Key words: Water Quality, Water Sources, Disinfection, Processing, Households, Water Usage.

3.0 Introduction

Water is a non-calorific nutrient and the life wire of the body (Thliza *et al*., 2015: Adegoke *et al*., 2012). Water integrates a large component of the cellular structure as well as being essential in the diet (Garba *et al*., 2009). Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all (Oludairo and Aiyedun, 2015). Water is used by individuals for drinking, cooking and other food processing operations, cleaning and sanitation and agricultural operations including watering of animals which is significant among the pastoral communities in Kenya(Anyamene and Ojiagu, 2014, Isikwue and Chikezie, 2014; Muhammad *et al*., 2017). The most common sources of water are surface water (rivers, pans, springs, lakes) and ground water (boreholes, shallow wells, and open wells) (Aroh *et al.*, 2013; Hamidu *et al*., 2017; Jura and Kuntala, 2017). Rain water is used to supplement domestic and agricultural water. Rural set–up water sources are; connection pipes 6.5 %, boreholes 58.5 %, hand-dug wells 1.5 %, and unprotected wells 20 % (Kuta *et al*., 2014). It has been reported that 13.5 % of the rural population source their waters from rivers, springs and pans, with an insignificant proportion of the residents using the limited seasonal rain water (Kuta *et al*., 2014; Muhammad *et al*., 2017). Insignificant proportion of the rural population use season dependent rain water, thus limited access to potable water (Oyelude and Ahenkorah, 2011; Akinde *et al.*, 2011; Adebayo *et al.*, 2012; Kuta *et al*., 2014).

Shortage and pollution of the readily accessible water sources is evident in many regions of the developing nations (Wright *et al*., 2012; Gangil *et al*., 2013; Oludairo and Aiyedun, 2015). This is largely attributed to low level of personal hygiene and inadequate treatment facilities for water and waste that are consequent pollutants (Oyelude and Ahenkorah, 2011; Akinde *et al.*, 2011; Adebayo *et al.*, 2012; Kuta *et al*., 2014). Pollution contaminants result from events such as over-flows from sanitary sewers and run-off of animal dropping into the water sources especially the rivers and dams (Maynard *et al*., 2005). In the rural areas where agriculture is the major economic activity, heavy settlement along the river bank is evident with few observable personal hygiene facilities such as toilets (Thliza *et al*., 2015). Due to the inadequacy of these facilities, the residents resort to other alternatives such as the small bushes and thickets along the river (Balogun *et al.*, 2014). During heavy rains the human wastes in the bushes are carried by surface run-off into the river, pans and other surface water sources (Bada *et al*., 2017). Gastro intestinal tract (GIT) infections have been reported to result from exposure to the contaminated water through ingestion, engagement in recreational activities and irrigation (Umoh *et al*., 2006).The World Health Organization (WHO) estimates that up to 80 % of ill health in developing countries are water and sanitation related (WHO, 2014; Ahiablame *et al*., 2012). High incidence of childhood diarrhea, helminthiasis, trachoma and the overall high mortality rates are associated with poor environmental sanitation (Olukosi *et al*., 2008; Thliza *et al*., 2015; Maduka *et al.*, 2014). Major cases of these illnesses are reported in rural areas of developing nations with limited supply of potable water (Caslake *et al*., 2004; Omalu *et al*., 2010; Oyelude and Ahenkorah, 2011; Akinde *et al.*, 2011; Adebayo *et al.*, 2012; Muhammad *et al*., 2017; Lamuka *et al*., 2017).

The presence of faecal coliforms in water indicates contamination and renders the water unsafe for food processing and direct human consumption (Garba *et al*., 2009). Faecal coliforms and *Escherichia coli* have been the main indicator organisms for assessment of deterioration in microbiological water quality (Ahmed *et al*., 2005; Opara and Nnodim, 2014; Oludairo and Aiyedun, 2015).

As a mitigation to water pollution, water treatment has been a trend of the modern world (Zhang *et al*., 2014). Traditionally, herbs have been used by rural communities to treat their drinking water and milk preservation (Wayua *et al*., 2012). Boiling, chlorination and UV treatment are among the recent disinfection techniques (Somani and Ingole, 2011).

Water sources and disinfection methods vary with environmental, climatic conditions and extent of pollution per location. The effectiveness of traditional water treatment techniques such as use of herbs are unknown. However, the chlorination and other modern water disinfection techniques relies heavily on the technical know-how of the end users. Low literacy level among the rural population in Isiolo County is attributed to the prevalence of food and water borne illness (Lamuka *et al*., 2017). Ground water sources contain high concentrations of dissolved salts that are implicated in high blood pressure and kidney stones (Abok *et al*., 2018). There is thus need to establish the water sources, the treatment techniques and handling practices in Isiolo County as a yardstick to invent an appropriate disinfection technology.

3.1 Materials and methods

3.1.1 Study site

The study was conducted in Isiolo County, Kenya. Isiolo is located 285 kilometers north of Nairobi, covering an area of 25, 336.1 square kilometers. Isiolo County is located within: 00°21′N 37°35′E / 0.350°N 37.583°E / 0.350; 37.583. Isiolo County consists of two sub-counties; Isiolo North and Isiolo South. Administratively, Isiolo County consists of six divisions namely Central, Garbatulla, Sericho, Merti, Oldonyiro and Kinna with a total of 22 locations and 44 sub-locations (Figure 3.1). The county has an estimated population of 143,211 people as per the 2009 census. Isiolo is classified as Arid and Semi-Arid Land (ASAL) (Lamuka *et al*., 2017). The County is predominantly flat with low lying plains that rise gradually from an altitude of 200 m above sea level at Lorian Swamp in the north to about 300 m above sea level at Merti Plateau. The arid and semi-arid nature of the area has resulted into three climatic zones that experience different weather patterns. The zones are: Arid zones, where rainfall is between 300 and 350 mm covering Central and Garbatulla divisions. The semi-arid zones with rainfall between 250 and 650 mm per annum covers the Oldonyiro and Kinna divisions. The very arid zone, where rainfall is between 150 and 250 mm per annum covers Merti and Sericho divisions. The annual temperatures range from a minimum of 12 ˚C to a maximum of 28 ˚C.

Owing to the arid and semi-arid climatic conditions and the social-cultural context of the county, the main economic activities are limited to pastoralism, subsistence agriculture, small-scale trade, and harvesting of gum Arabica (Wayua *et al*., 2012; Watete *et al*., 2016; Lamuka *et al*., 2017).

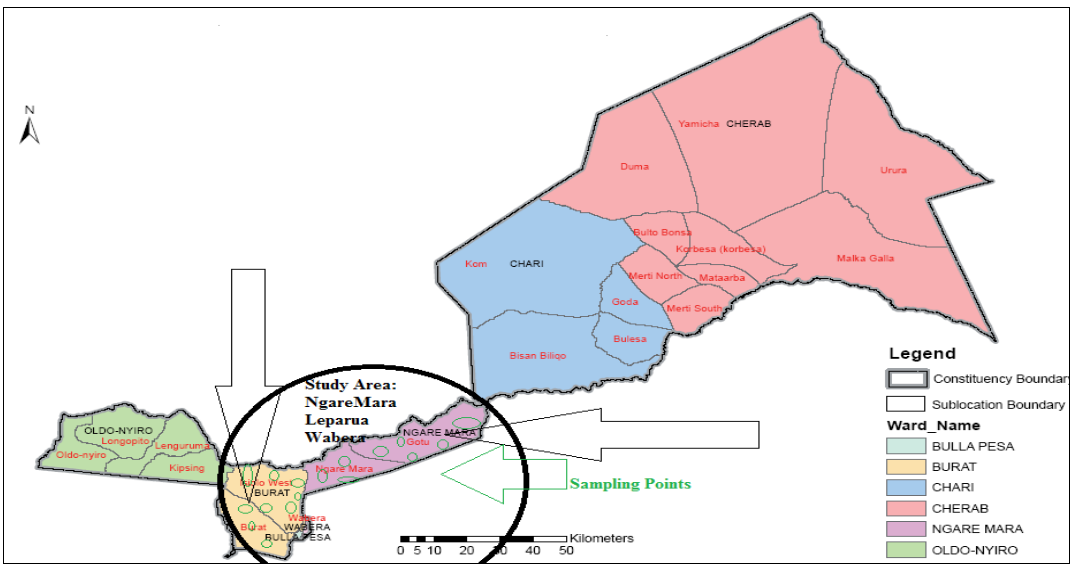

Figure 3.1: Map showing the administrative units of Isiolo County.

3.1.2 Study design

The study was a cross-sectional survey using pre-tested semi-structured questionnaires. Both qualitative and quantitative data collection methods were used to determine the household water sources and treatment methods. Isiolo central was purposively selected for this study based on its urban nature with diverse water sources as well as its accessibility as compared to Merti, Garbatulla, Kinna, Sericho and Oldonyiro divisions.

3.1.3 Sample size

Isiolo County has a dispersed population and majority are pastoralists thus making it hard to reach out a large number of respondents. As at the time of study, all the head households both male and female were exhaustively interviewed using the questionnaires. This translated to a total of f 165 respondents distributed across the four locations of Ngare Mara, Burat, Wabera and Kulamawe was used for the study.

3.1.4 Data analysis

Quantitative data were represented in Tables. Both descriptive and inferential statistical tests including correlation at 5 % and 1 % levels of significance for the variables were carried out using statistical analysis system (SAS) version 9.1.3. Frequencies and percentages were calculated for each variable.

3.2 Results and Discussion

3.2.1 Results

3.2.1.1 Socio-demographic characteristics of the respondents

The socio-demographic characteristics of the respondents are presented in Table 3.1. Based on gender distribution of the respondents, 65.5 % were females while 34.5 % were males. Out of the 165 respondents, 73.3 % were below the youthful age of 40 years with only few aged people above 60 years. On the basis of the level of literacy: primary school drop-outs were 15.2 %, those who have completed primary 10.9 %, secondary drop-out 6.1 %, completed secondary14.5 %, tertiary level colleges 2.4 %, university graduates 9.7 % and informal education 29.1%. The levels of literacy among the respondents was low. However, adult education is being used as a tool to mitigate illiteracy. It was found that 29.1 % of the respondents were undertaking adult education. Human transport is the major means for drawing water from the sources to the households. The youthful members of the society who are energetic enough to cope with the situation hence their larger numbers among the households population of greater than 73.3 %. Isiolo central is multi religious attributed to its cosmopolitan nature with the majority (66.1 %) being Christians. They are followed by Muslims and traditionalists at 23.6 % and 10.3 % respectively. 23.6 % Muslims and 10.3 % traditionalists. Religion depended on the location of the respondents. Majority of the Christians resided in Ngare Mara and Burat locations. Notably, the Muslim respondents were majorly drawn from Wabera and Kulamawe Locations.

Table 3.1 : Socio-demographic characteristics of the respondents

Gender	**No. of respondents**	**Percentage of respondents (%)**
Male	57	34.5
Female	108	65.5
Total	**165**	**100**
Level of Education	**No. of respondents**	**Percentage of respondents (%)**
In primary	6	3.6
Primary drop-out	25	15.2
Completed primary	26	15.7
In secondary	10	6.1
Secondary drop out	6	3.6
Completed secondary	24	14.5
Tertiary level college	4	2.4
University	16	9.7
Informal education	48	29.1
Total	**165**	**100**
Age	**No. of respondents**	**Percentage of respondents (%)**
<20 years	14	8.5
21 – 40 years	107	64.8
41- 60 years	38	23.1
> 60 years	6	3.6
Total	**165**	**100**

n =165; Values are number of respondents

A weak significant positive relationship (r = 0.22) existed between age and level of education of the respondents. Most of the young respondents were either continuing with their education in primary, secondary or tertiary level colleges. Adult education was given the highest hedonic value of 9. The observed positive correlation therefore indicate that adult education was mainly embraced by older people aged above 40 years who constitute the 29.1 % of the respondents in adult education. Age, gender and location were insignificantly ($p \leq 0.05$) associated.

3.2.1.2 Water sources for domestic use and processing

The major water sources for domestic use and processing in Isiolo County are presented in Table 3.2.

Borehole water was the most used water source used by 26.7 % of the respondents. Pan water and rain water were the least used water sources owing to their seasonality that depends entirely on rains, only 3.6 % of the respondents use pan and rain water for domestic purposes. The main water sources varied from one location to another. Ngare Mara had no access to springs and urban treated water. The dominant water sources in Ngare Mara were boreholes, closed and open shallow wells. Water sources in Buretti location are mainly the leparua spring and Ngare Ndare River. However, a single borehole was located at Ngare Ndare station. Tap water supply was only limited to 14.5 % of the respondents residing in urban center areas of Wabera and Kulamawe locations. In some cases, especially the rural areas, the water used for food processing differed from the water used for drinking. For Isiolo County, the same water source is used for all the household activities depending on availability. Majority of the respondents did not have access to improved and safe water sources (Table 3.2). The quality of surface and ground water used by the respondents was unknown.

Table 3.2: Water sources for domestic use and processing in Isiolo County

Source of water	No. of Respondents	Percentage of respondents using the water source (%)
River	36	21.8
Spring	28	17.0
Borehole	44	26.7
Tap	24	14.5
Closed shallow wells	17	10.3
Open shallow wells	10	6.1
Pans and Rain	6	3.6
Total	**165**	**100**

n = 165;

3.2.1.3. Distance and the means of transport from the water sources to the households

The distance from the water sources and mode of transportation are presented in Table 3.3. Human transport is being used by 71.5 % of the respondents. To a smaller extent, the introduction of motor bikes has gained some little application in accessing the water sources and is being used by 1.2 % of the respondents (Table 3.3). Despite the diversity in the water sources most of the respondents sourced their water within an average distance of 1 km as indicated by 59.1 % of the respondents. Some of the respondents had to move quite a long distance in search of water. The respondents who source water over a distance of greater than 5 Km were 17.9 %.

Table 3.3: Distance from water sources to households and means of transport used by respondents to fetch water.

Distance from water source to household	Percentage of respondents (%)	Means of transport used	Percentage of respondents (%)
<1 Km	59.1	Hand cart	20
1 - 2 Km	13	Animal (donkey)	7.3
2 - 5 Km	10	Human	71.5
>5 Km	17.9	Motorbikes & Trucks	1.2
Total	100	Total	100

n = 165;

3.2.1.4. Water treatment techniques

A larger proportion of the respondents do not treat their water for domestic and processing. Only 37.9 % of the respondents indicated that they treat their water for food processing the other 62.9 % consume their water as it is fetched with no technique to enhance its safety. Thus exposure to higher risks of water borne infections.

Various water treatment have been used in the traditional society to the current modernized generations. Out of 37.9 % of the respondents that treat their water before use in food processing and other domestic activities, 66.7 % of them boil their water, 21.7 % use water guard tablets. In special cases, 8.3 % of them employ a combination of boiling and chlorination alternately and 3.3 % of the population use herbs for disinfecting the water as shown in Figure 3.2. Solar as a method of water disinfection had no application at all except that solar energy was applied in pumping water from the boreholes.

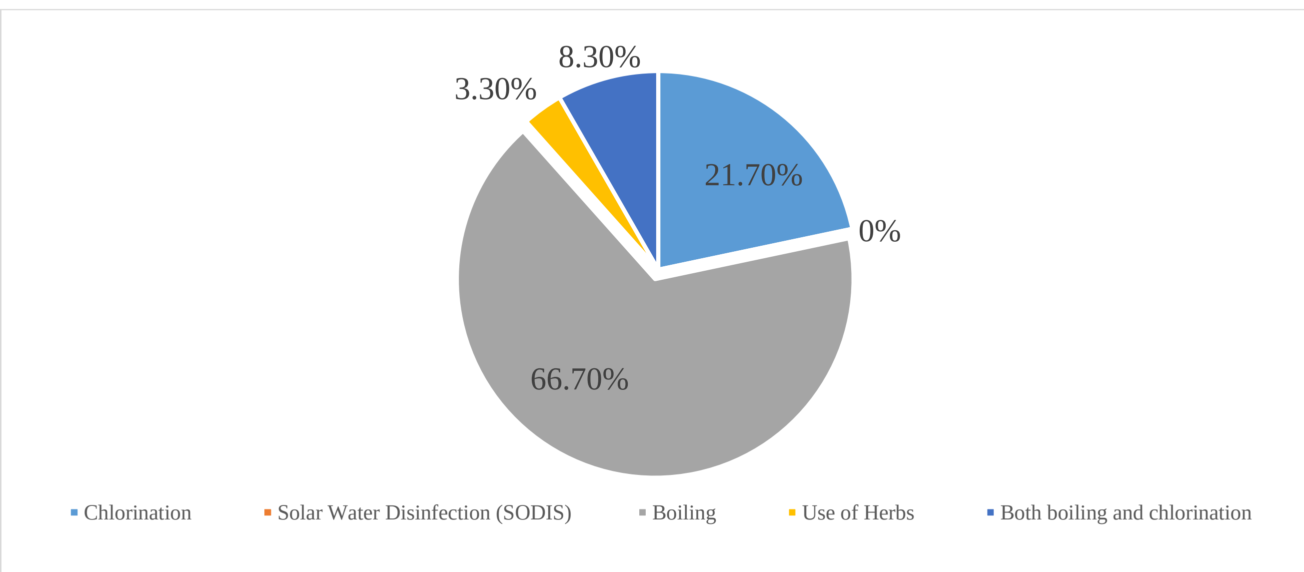

Figure 3.2: Methods of water Treatment

Piped water from the county council is assumed to be treated and safe for use. However, 38.8 % out 14.5 % of the respondents that use tap water retreat their water before use. The remaining 61.2

% of treated urban water supply users accepted that the water was safe and there was no need for further treatment in their opinions. Retreating was perceived as unnecessary added cost.

3.2.1.5. Types of vessels for fetching and storing water

Water sources are accessed using specialized vessels whose application vary from household to household and from location to location. Jericans with lids are used by 62.5 % of the respondents to fetch water and only 3.7 % of the respondents still use pots to fetch water. Use of jericans with lids is an indication of the valuable steps taken by households to ensure water safety all the way from the source to the houses. For water storage, 74.5 % of the respondents store their water in jericans, 17% store water in pots and only 8.5 % of the respondents had access to water storage tanks. Table 3.4 shows the vessels used for fetching and storing drinking and process water.

Table 3.4: Storage vessels of water for food processing

Vessel for fetching water	Percentage of Respondents (%)	Water storage vessels	Percentage of Respondents (%)
Pots	3.7	Pots	17
Jericans without lids	30.2	Jericans	74.5
Jericans with lids	62.5	Water tanks	8.5
Pipe	3.6	**Total**	**100**
Total	**100**		

n = 165;

3.2.1.6 Hygiene in drinking water handling

On hygienic water safety handling practices, Figure 3.4 shows that 70.9 % of the respondents use different containers for drawing drinking water from the vessels and another for drinking. Only 25.5 % uses the same container for drawing and drinking the water. Noticeable proportion of 3.6 % of the population from time to time interchanges their mode of drawing water and end up using both listed methods.

3.2.1.7. Water borne illnesses

The type of water sources used and the household water handling practices can be hazardous and eventually associated health risk to varied age groups within the population who use them.

The diverse water sources in Isiolo County exposes the population to diverse water induced health conditions which varied from one location to another based on handling practices and sources. Water borne illness cases were reported by 52.7 % of the respondents. The most adversely affected age group by water borne illnesses were children aged below 10 years as shown in Table 3.8.

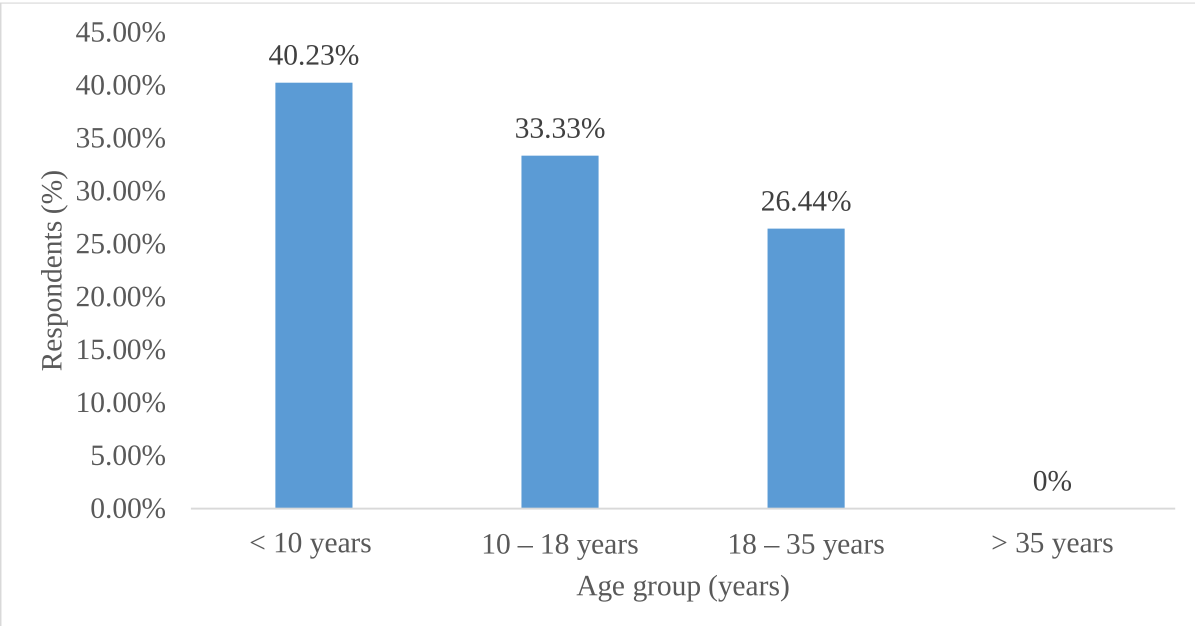

Figure 3.3: Age group of the population affected by water borne illness

Out of the 52.7 % of the water related illness reported by respondents, the major symptoms were diarrhea 39.8 % and abdominal pains 40.9 %. These two symptoms are mainly associated with food and water borne illness.

3.2.2. Discussion

3.2.2.1. Socio-demographic characteristics of the respondents

Isiolo County is an ASAL area. Pastoralism is the predominant economic activity, and the male gender are the ones involved in looking after the herds (Wayua *et al*., 2012; Watete *et al*., 2016; Lamuka *et al*., 2017). Consequently, it is hard to get the male gender for interviews as most of them move early in the morning in search for pasture and watering points for the herds. Isiolo County generally has higher number of females than male as reported by Wayua *et al*. (2012).

Majority of the respondents (64.8 %) were youthful, aged less than 40 years, with ability to incorporate new technologies and inventions in water treatment as well as conservative management of water and water sources in order to have access to safe water (Muhammad *et al*., 2017). The approximate age of most heads of households in the ASALs is 40 years (Wayua *et al*., 2012; Watete *et al*., 2016). Literacy level in the arid and semi-arid areas in Kenya is low (Wayua *et al*., 2012; Watete *et al*., 2016; Lamuka *et al*., 2017). Among the respondents in this study, only 12.1 % of them had tertiary level training. Majority had informal education (Lamuka *et al*., 2017). Educated population tends to access more improved and safe water sources (Muhammad *et al*., 2017). Given the acceptance of informal education among the respondents, trainings on water safety and community hygiene through effective water disinfection to eventually lower the number of water borne illness cases among the population is achievable.

Religion of the respondents depends on their location. Most respondents in Burat and Ngare Mara are Christians while those in Wabera and Kulamawe are Muslims (Wayua *et al*., 2012). Socio-cultural activities are influenced by religion. Religious practices significantly differ across the religions. Some religious beliefs and activities are hindrance to water disinfection. The use of chlorine compound for water disinfection is prohibited by some interdenominational Christian churches that claim the chemical nature of chlorine is toxic and against their beliefs (McGuigan *et al*., 2012). But the observed practices of water use and disinfection in Isiolo depended less on the religious beliefs and mainly depended on the available water source.

3.2.2.2. Uses of water in Isiolo County

In the small medium enterprises, water is mainly used for mixing food components, cleaning food processing equipment's, washing hands before and after operations and for waste disposal. Similar water uses were observable at the household level (Ahiablame *et al*., 2012). A lot of water is used at household level for drinking food processing, cleaning and watering animals (Ahiablame *et al*., 2012; Muhammad *et al*., 2017). The scarcity of water supply limits the use of the water sources for agricultural irrigation activities (Zhang *et al*., 2014). Irrigation was only practiced by a few farmers around Leparua spring. The perception of household uses was that, water for other domestic uses such as cleaning of food process equipment needed not to be treated as supported by 28.7 % of the population respondents (Muhammad *et al*., 2017). In most cases pan water was used for watering animals. Pans which were closer to human settlements in Isiolo County doubled as source of water for domestic use.

3.2.2.3 Water sources utilized by residents in Isiolo County

Water sources varied from one region to another and with the diverse climatic zones in Isiolo, a wide range of water sources exist. The water sources are categorized based on whether they are surface water sources or ground sources (Kuta *et al*., 2014; Hamidu *et al*., 2017). Isiolo County have the following water sources: 21.8 % river, 16.9 % spring, 26.5 % borehole, 14.5 % tap, 10.6 % protected shallow wells, and 9.3 % open shallow wells and 0.5 % pans and other water sources which are similar to findings by Kuta *et al*. (2014). Most of the respondents depend on ground water sources for drinking and domestic use which are perceived to be safe (Muhammad *et al*., 2017). The water sources depended on seasons and location. Pans are in use during rainy seasons or just after heavy rains when water collects in the pans. River and spring water were limited to locations near the rivers and spring. Leparua sub-location had only access to Leparua spring water and river Ngare Ndare. Therefore, their only water sources for domestic use, food processing and drinking were river and spring. In Ngare Mara location, access to spring, river and urban treated water supply was limited. The available river water source was the seasonal Ngare Mara River. Consequently the dominance of shallow wells and boreholes were the main observable water sources in the region. For areas closer to the town such as Wabera location, the Urban treated water was in supply but only 10.6 % of the entire population had access to safe treated water. It's therefore evident that a larger proportion of the population had limited access to potable water (Ahiablame *et al*., 2012; Kuta *et al*., 2014). Any available water source is being used regardless of the water safety (Muhammad *et al*., 2017). This exposes the population to risk of water borne and food borne illnesses (Hassan, 2009; Ahiablame *et al*., 2017; Lamuka *et al*., 2017).

The surface water sources were open and exposed to higher risks of contaminations. During dry seasons, the river banks provide excellent grazing zones for animals. River Ngare Ndare in Leparua named after its use to mean "goat's water" served as grazing ground for goats. The goats were observed grazing along and a cross the river banks, urinating and dropping their wastes in the river water. The animal wastes contribute to the heavy load of contamination of the water sources (Maynard *et al*., 2005; Muhammad *et al*., 2017). Since the pollutants are of gastrointestinal tract origin, coliforms and *Escherichia coli* among other faecal micro-organisms find their routes into the water (Yang *et al*., 2004).

Ground water sources are important resources in meeting the daily needs (Bada *et al*., 2017; Hamidu *et al*., 2017). On the contrary, complaints were raised on the hardness of borehole and shallow wells water due to their association with bedrocks of the Earth crust. As water infiltrates and percolates into the earth crust, it dissolves the rocks minerals that remains dissolved in the water drawn (Bada *et al*., 2017; Hamidu *et al*., 2017). These minerals give the water distinctive characteristic hardness, alkalinity, color and taste which can either be desirable or undesirable.

In seasons of heavy rains, rain water is harvested. Turbidity rises as the rain water collects dust within the atmosphere among other pollutants, making the water unsafe for consumption before any pre-treatment (Namu *et al*., 2017). Similarly, the pans and rivers water gets more turbid during rainy seasons rendering them unsuitable for direct consumption (Namu *et al*., 2017).

The residents are thus supplied with clay sieves for water filtration and that 37.6% of the respondents used clay sieve to filter the water and reduce microbial load (Muhammad *et al*., 2017). Some used traditional herbs for purifying the water as well as induce germicidal effect brought about by the organic acids in the herbs when they dissolve in water (Somani and Ingole, 2011).

3.2.2.4. Distance and means of transport of water between the sources and the household

Most of the respondents get their water from within their locality at a distance of less than one kilometer. Respondent's usage of water was regardless of the source whether surface or ground water (Hamidu *et al*., 2017). Distance and water source are not significantly correlated ($r = 0.029$). Some water sources are located more than 5 km away from the respondent's households. Educated members of the society are more enlightened on water safety and always desire to have access to safe water thus seek it regardless of the distance to the source. Some residents of Ngare Mara and Leparua areas located more than 5 km away from the town center where there is treated urban water supply were observed to fetch their water from the town centre. This practice was in disregard of the available water sources in their locality which they perceive to be unsafe (Muhammad *et al*., 2017). This is explained by the significant positive relationship between education and water sources (r = 0.165). Majority of the respondents sought their water from within a distance of 1 km and human transport remained effective and affordable among the respondents. Hand carts, animals and the motorbikes have been used by the respondents for water sources that are located more than 1 km away from their households. Means of accessing the water sources are not modernized owing to the low level of literacy among the population (Wayua *et al*., 2012; Watete *et al*., 2016; Lamuka *et al*., 2017).

3.2.2.5 Water treatment techniques

Processes and techniques for decontaminating water to improve quality and safety are diverse and depend on the characteristic of the water (Muhammad *et al*., 2017). The techniques are either physical or chemical (Somani and Ingole, 2011). Boiling was the most common water disinfection method used by 66.7 % of the population, chlorine 21.7 % of population, 3.3 % used herbs, and 8.3 % used both chlorine and boiling method and similarly reported by Muhammad *et al*. (2017). Solar water disinfection had no popularity among the population since it is a new technology in its invention stages (McGuigan *et al*., 2012; Somani and Ingole, 2011). Cultural practices and perceptions of chemical treatment have limited the use of chlorine and its compounds. In water, chlorine combines with trace amounts of naturally occurring organic matter and liberates disinfection by-products (DBPs) such as halogenated DBPs. The toxic trihalomethanes (THMs) represent a large fraction of these halogenated DBPs. People associate these DBPs with infections and cancer (McGuigan *et al*., 2012). Therefore, there is need for alternative disinfection methods. Traditionally, bitter herbs have been used and are still in use among rural population as a method of water treatment as well as preservation of milk (Wayua *et al*., 2012). The herbs release phenolic compounds into the water thereby altering the pH and consequently the micro-environment of the water (Somani and Ingole, 2011). Some of the phenolic compounds are acidic and are active germicidal compounds. The pH dependent microbial growth is inhibited through addition of alkaline or acidic herbs that either raise or lower the pH (Somani and Ingole, 2011). Though herbs are active in inducing germicidal effect (Somani and Ingole, 2011), the extent of bacterial kill in the target water is hard to determine and requires specialized skills and technical know-how which might be lacking among the population given the low literacy levels (Oyedeji *et al*., 2010; Wayua *et al*., 2012; Watete *et al*., 2016; Lamuka *et al*., 2017). There is over-reliance on indigenous knowledge on the safety of water treated using herbs among the population.

The small thickets within the pastoral areas browsed on by Camels (Lamuka *et al*., 2017) provide the needed wood biofuel for water boiling at almost zero cost since the trees are readily available thereby making boiling a popular method of water treatment among the rural population of Isiolo County (Wayua *et al*., 2012). Raising the temperature of the water to its boiling point by heating using wood biofuel, then maintaining it at that boiling point temperature for about 15-20 mins achieves desired bacteria kill (Somani and Ingole, 2011).

Though solar water disinfection is gaining popularity among various rural populations as a clean and cheap alternative (Fadhil, 2003; Shibu *et al*., 2006), its adoption and use for water treatment in Isiolo was noticeably limited. Solar energy was only used in powering borehole water pumps for easy distribution of the water to a wide coverage area within the borehole locality. Another renewable energy source that is in use is wind, in wind mill powered boreholes.

3.2.2.6 Types of containers for fetching and storing water

Containers with lids especially the twenty litres jericans are the popular containers for storage and transportation of water in Isiolo County (Wayua *et al*., 2012). Safe water storage is necessary especially for water that has been treated in order to avoid cross contamination (Muhammad *et al*., 2017). The environment is polluted and can lead to water contamination (Gangil *et al*., 2013).

Therefore, protected jericans are necessary to limit water contamination during transportation and storage at the household. Majority of the respondents are currently using jericans with lids that are improved versions from the conventional usage of open pots and jericans and minimize risk of water contamination (Oludairo and Aiyedun, 2015).

3.2.2.7 Method of drawing drinking water from the storage container

Water is the basis of life and its safety and wholesomeness all the way from the source, storage and use is significant (Thliza *et al*., 2015; Aroh *et al*., 2013; Oludairo and Aiyedun, 2015). At household level, the users have a responsibility to ensure water safety through their handling activities (Muhammad *et al*., 2017). To a smaller extent, notable proportion of the respondent population had adopted a cleaning system for their water storage containers. This is a safety trend worldwide (Muhammad *et al*., 2017). In some households, the same container was being used for drawing water from its source and for drinking water from the storage container (Muhammad *et al*., 2017). This kind of system serves as an avenue for easy spread of some communicable diseases. But this was under transition as a few households were in the process of adopting a system where the cup used from drawing water from the storage containers is different from the one used for drinking. Access to improved water sources significantly induced improved water storage methods (r = 0.206). Similarly, level of education significantly influences the kind of methods used for storing drinking and food process water (r = 0.159).

3.2.2.8 Waterborne illness

Prevalence of illnesses whether food borne or water borne is high among the population in the arid and semi-arid areas (Lamuka *et al*., 2017). Worldwide over 1.1 billion people are at risk of water induced infections (Ahiablame *et al*., 2012). In developing nations most of the deaths are reported in children aged below 10 years (Ahiablame *et al*., 2012). Isiolo County is not an exception as 38.9

% of the 52.7 % reported water borne illness were for children aged below 10 years. The major symptoms were diarrhea (39.8 %) and abdominal pains (40.9 %) which are mainly associated with foodborne and water borne illnesses and remain of concern globally (Caslake *et al*., 2004; Olukosi *et al*., 2008).

3.3. Conclusion and Recommendations

The quality and safety of ground water sources used in Isiolo County is unknown. The low level of literacy level cannot effectively facilitate the use of chlorination, traditional herbs and other water treatment techniques that require specialized technical Know-how. Prevalence of water borne illness in Isiolo County is high due to limited access to potable water. To achieve sustainability development goal 6. The County government need to develop an education system to promote adult education and as well institute technical training centers. This will provide the residents with basic technical skills to facilitate the effective adoption of water treatment techniques. Regular analysis of water sources to be carried out by the public health department to regularly advice on the state of the water quality and if any the mitigations to adopt to address the deviation of quality changes to unsafe extremes.

The County Government should invest in putting up water treatment plants in each of the administrative units in Isiolo County to facilitate supply of improved piped water sources to the residents. This would reduce the long distance travels in search for water and risk of cross contamination.

Solar water disinfection to be adopted as one of the water treatment techniques given the adequate solar insolation of greater than 800 Wm^{-2} and the adoption of solar energy for powering boreholes by some community members in Isiolo County.

CHAPTER FOUR

Microbiological Contamination of Water Sources in Isiolo County in Kenya

Abstract

Water security and safety is a vital component of arid and semi-arid regions of Kenya. Potable water accessibility and supply is limited due to fluctuating climatic conditions and environmental pollutions that claims the wholesomeness of most water sources. The aim of this study was to establish suitability of these water sources for drinking and use in industrial food processing by the small and medium enterprises (SME's). A total of 60 water's surface and ground water sources samples were purposively collected aseptically from the four administrative units (Ngare Mara, LMD, Leparua and Wabera) of Isiolo County. ISO 16649-3, 688-2, 7937, 9308-1 and 18744 were used for enumeration of *E.coli*, *Staphylococcus aure*us, *Clostridium pafrigens*, *Coliforms* and cysts.

Highest mean log *Clostridium pafrigens* counts in ground and surface water were 3.16 Cfu/ml and 3.53 Cfu/ml respectively. Similarly the mean log *Staphylococcus aureus* counts were 2.87 Cfu/ml and 3.12 Cfu/ml in surface water and ground water respectively. *Escherichia coli* and total coliforms contamination was 29.88 % and 88.2 % respectively. Microbial counts in the water sources differed significantly ($p \leq 0.05$). The mean log differences were compared at 1 and 5 % levels of significance. Ground and surface water sources were highly contaminated with microorganism to levels regarded as unsafe by the Kenyan and WHO standards for potable water. Point of use water disinfection is thus necessary.

Key words: Water quality, water sources, potable water, processing, microbial contamination

4.0 Introduction

Water is an important component of every life (Mberekpe and Eze, 2014; Thliza *et al*., 2015; Oludairo and Aiyedun, 2015; Edbert *et al*., 2017). Water supply and accessibility is Goal 6 of the sustainability development goals (SDGs), and aims at ensuring environmental sustainability (Oludairo and Aiyedun, 2015). Historically, efforts to ensure access to safe drinking and food processing water have been focused on the community based water sources (Muhammad *et al*., 2017). Most regions of the developing nations are experiencing shortage of potable water as improved water sources are only limited to urban centers (Omalu *et al*., 2015). Isiolo County has limited water sources that include both surface and ground water sources (Aroh *et al.*, 2013; Hamidu *et al*., 2017). In a bid to promote healthy living among inhabitants of the County, a reliable potable water is essential for sustainable development, health, food production and poverty alleviation (Balogun *et al*., 2015). Water shortage and pollution of the readily accessible water sources is evident in many regions of the developing nations (Oludairo and Aiyedun, 2015; Gangil *et al*., 2013; Muhammad *et al*., 2017). This is largely attributed to low level of personal hygiene and inadequate treatment facilities for water and wastes that are consequent pollutants (Kuta *et al*., 2014).

Increase in population has induced more pressure on the available water sources, consequently more than 1.2 billion people worldwide do not have access to safe water (Boubetra *et al*., 2011; Adegoke *et al*., 2012; Maduka *et al*., 2014). Millions of people die yearly from diarrheal disease and a larger proportion are children aged below 5 years (Muhammad *et al*., 2013). Besides causing death, water-related diseases also prevent people from working and leaving active lives (Memon *et al*., 2011).

Water is susceptible to contamination with microorganisms and organic matter among other pollutants regardless of the source (Anyamene and Ojiagu, 2014; Gangil *et al.*, 2013; Oludairo and Aiyedun, 2015). Significantly, microbial contaminants such as coliforms, *Escherichia coli*, *Cryptosporidium parvum* and *Giardia lamblia* compromises the safety of the water (Opara and Nnodim, 2014). Presence of *Escherichia coli*, *Klebsiella* and *Enterobacter* species in water is a likely indicator of the presence of pathogenic organisms such as *Clostridium pafrigens*, *Salmonella, and* Protozoa (Anyamene and Ojiagu, 2014). These pathogens cause diarrhea, giardiasis, dysentery and gastroenteritis common among the rural dwellers of developing nations (Oyedeji *et al.*, 2010; Akinde *et al.*, 2011; Aroh *et al.*, 2013; Isikwue and Chikezie, 2014; Thliza *et al.*, 2015; Oludairo and Aiyedun, 2015).

In Isiolo county ground water is dominant over surface water and is less susceptible to bacterial pollution. The soil and rocks through which groundwater flows screen out most of the bacteria (Momba *et al.,* 2012). But freedom from bacterial pollution alone does not mean that the water is suitable for use in food processing and drinking. Many unseen dissolved mineral and organic constituents are present in ground water in various concentrations. Most are harmless or even beneficial; though occurring infrequently, others are harmful, and a few may be highly toxic (Momba *et al*., 2012). The extent to which the ground and surface water used for drinking and food processing in Isiolo County are contaminated with microorganism is yet to be determined. This shall then serves as a yardstick to adopt an effective water disinfection technology to supply potable for the residents and mitigate the current prevalence water borne illness.

4.1 Materials and Methods

4.1.1 Study setting

The study was conducted in Isiolo County, Kenya. Isiolo is classified as Arid and Semi-Arid Land (ASAL) (Lamuka *et al*., 2017). Isiolo County is located within: 00°21′N 37°35′E / 0.350°N 37.583°E / 0.350; 37.583. The main water sources include, Isiolo River, Ngare Ndare River, Leparua spring, boreholes, shallow wells, pans and dry river beds. The quality of water from these sources depends on seasons and location.

4.1.2 Data collection

Isiolo central was purposively selected for this study owing to its urban nature with diverse water sources as well as its accessibility compared to the other divisions. Purposive sampling was employed based on the available water sources in Isiolo central. The samples were first coded based on the type of water source as BH, SW, SPR, R, PAN, and TROUGH representing Borehole, shallow well, spring, rain, pan, and Trough water respectively. The second part of coding of 1, 2, 3 and 4 represented the administrative sampling locations of Leparua, Ngare Mara, LMD and Wabera respectively. The last part of the sample code consisted of alphabetical letters to represent the different sample sites of the same water source from the same administrative sampling location. As such BH2F is a code for borehole water (BH), sampled from Ngare Mara (2) and the sixth sample unit (site) of borehole water type from Ngare Mara (F). For chlorinated urban water, TAP followed by numerical number was used for identification to represent the number of units since they are only available in one administrative sampling area of water and thus no need to differentiate the administrative sampling location.

Water sampling was done as per APHA method (2012). The samples were transported to the laboratory for analysis within 48 hrs post-sampling owing to the long distance between sampling points and analysis station.

4.1.3 Sample size

Sixty water samples were purposively sampled aseptically for analysis from Isiolo central. The samples consisted of 35 and 20 ground and surface water sources samples respectively while 5 chlorinated urban water were collected at five different consumer tap points. Secondary data on total coliforms, Escherichia coli and residual chlorine for treated Isiolo river water and raw water for over a period of 6 years (2011-2016) were collected from Isiolo Water and Sewerage Company (IWASCO). The secondary data was analyzed to establish the water quality trends prior to the study.

4.1.4 Analytical methods

4.1.4.1 Enumeration of *Escherichia coli*

Enumeration of *Escherichia coli* was done as described in ISO 16649-3: 2015. About 28.1 g of *Brilliance Escherichia coli*/coliform selective media was suspended in 1 litre of distilled water. The media was gently boiled to completely dissolve, then cooled to 45 ˚C, the molten media was then transferred to sterile plates. One milliliter of each serial dilution of 10^{-1} to 10^{-3} was transferred to spread plates aseptically in duplicates and the plates incubated at 37 ˚C for 24 hrs. Purple colonies on the selective media typical of *Escherichia coli* were enumerated.

4.1.4.2 Enumeration of Coagulase positive *Staphylococcus aureus*

Colony counts of *Staphylococcus aureus* in water were enumerated as described by ISO 6888-2 (2010). About 28 g of Baired parker selective media was suspended in 1 litre of distilled water, the mixture was then autoclaved at 121 ˚C for 15 minutes, allowed to cool to 45 ˚C and 50 ml of egg yolk tellurite emulsion was added. One milliliter of each serial dilution of 10^{-1} to 10^{-3} was transferred to spread plates aseptically in duplicates and the plates incubated at 37 ˚C for 24 hrs. Coagulase positive black colonies on the selective media typical of *Staphylococcus aureus* were enumerated.

4.1.4.3 Enumeration of *Clostridium pafrigens*

Colony counts of *Clostridium pafrigens* was done as per ISO 7937: 2016. About 38 g of Differential reinforced clostridia media was suspended in 1l of distilled water, boiled to dissolve, autoclaved at 121 ˚C for 15 minutes. Cooled to 45 ˚C. Fifty milliliters of egg yolk emulsion was added. From each of the serial dilution of 10^{-1} to 10^{-3},1ml was transferred to spread plates aseptically in duplicates and the plates incubated anaerobically at 44 ˚C for 48 hrs. At this temperature other Clostridia species are inhibited, and with egg yolk to induce lecithinace activity typical of *Clostridium pafrigens* gave motile rod shaped black colonies on the selective media which were then enumerated.

4.1.4.4 Determination of total coliforms

Enumeration of total coliforms was done as described by ISO 9308-1.2014. About 28.1 g of *Brilliance* E. coli/coliform Selective media was suspended in 1 litre of distilled water. The media was gently boiled to completely dissolve, then cooled to 45 ˚C, the molten media was then transferred to sterile plates. From each of the serial dilution of 10^{-1} to 10^{-3}, 1ml was transferred to spread plates aseptically in duplicates and the plates incubated at 37 ˚C for 24 hrs. All typical pink colonies on the selective media were enumerated.

4.1.4.5 Enumeration of Cysts

Enumeration of cysts was done using microscopy techniques described by ISO 18743: 2015, ISO 18744.2016 for *Hook worm*, *Cryptosporidium* and *Giardia lamblia* respectively. Microscopic morphological characteristics were used for the enumeration of *Amoeba cyst*.

4.1.4.6 Data Analysis

Analysis of variance (ANOVA) at 5 % level of significance to compare means of the microbial water quality among all the sampled surface, ground and treated urban water sources, using statistical analysis software (SAS) version 9.0. Least significant difference (Lsd) was used to separate the means. Pearson correlation was used to establish the relationship among the microbiological quality aspects of the sampled water.

4.2 Results

4.2.1 Microbial counts in the water sources

The mean microbial counts in various water sources utilized by residents of Isiolo County is shown in Table 4.1.*Escherichia coli* was absent in Trough water. River water had the highest mean log *Escherichia coli* count of 1.63 Cfu/ml. *Escherichia coli* Contamination levels insignificantly ($p \leq 0.05$) differed across the water sources. Pan water had the least mean log coliforms count of 3.21 Cfu/ml while shallow well had the highest mean log coliform counts of 3.71 Cfu/ml. Mean log total coliforms counts across all the water sources significantly differed ($p \leq 0.05$).

Pan water had the least mean log *Staphylococcus aureus* count of 0.9 Cfu/ml while shallow well water had the highest mean log *Staphylococcus aureus* count of 3.34 Cfu/ml. the mean log Staphylococcus aureus counts in the water sources insignificantly ($p \leq 0.05$) differed among the water sources

Spring water had the highest mean log *Clostridium pafrigens* count of 3.91 Cfu/ml whereas Tap water had the lowest mean log *Clostridium pafrigens* count of 2.11 Cfu/ml. Notable significant ($p \leq 0.05$) differences among the water sources occurred.

Table 4.1: Microbial counts (log Cfu) in various water sources in Isiolo

Water source	***E.coli* (Cfu/ml)**	***Total coliforms* (Cfu/ml)**	***Staphylococcus aureus* (Cfu/ml)**	***Clostridium pafrigens* (Cfu/ml)**
Borehole	1.14±0.61 a	3.34±0.51ab	2.82±0.25a	3.14±0.22a
Spring	1.56±0.21a	3.69±0.71abc	2.95±0.35a	3.91±0.29b
Tap	0.78±0.11 a	3.43±0.10abc	2.49±0.37a	2.12±0.19a
Shallow well	1.18±0.12a	3.71±0.59abc	3.34±0.47a	3.01±0.36a
River	1.63±0.15a	3.32±0.61ab	2.65±0.36a	2.94±0.38a
Trough	0.0±0.0 a	3.46±0.35ac	3.08±0.15a	3.55±0.34ab
Pan	0.79±0.06 a	3.21±0.29a	0.91±0.06a	3.24±0.47ab

1. Values are means of 10 determinations ± standard deviations.

2. Values with the same letters on the same column are not significantly different at 5 % level of significance.

4.2.2.1. *Coliform*, *Staphylococcus aureus* and *Clostridium pafrigens* in Ground water sources

The mean log *Clostridium pafrigens*, *Staphylococcus aureus* and *Coliforms* counts in ground water sources are shown in Table 4.2. BH3F had the lowest mean log coliforms count of 1.04 Cfu/ml while SW4B had the highest mean log *Coliforms* count of 4.44 Cfu/ml. Out of the 35 ground water sources analyzed, *Coliforms* were absent in 11.8 % tested samples. The mean log *Coliforms* counts significantly differed ($p \leq 0.05$) among the ground water sources. Only 11.4 % of the ground water samples met the Kenyan standard requirement of zero coliforms for potable.

Table 4.2: Coliforms, Staphylococcus aureus and Clostridium pafrigens (Log Cfu) in Ground water sources

Water sources	Coliforms (log Cfu/ml)	Water source	*Staphylococcus aureus(log Cfu/ml)*	Water source	*Clostridium pafrigens (log Cfu/ml)*
BH3F	1.04±0.15a	SW2E	3.61±0.47c	SW2E	3.84±0.49e
SW2E	1.39±0.29a	SW2N	3.57±0.67c	SW2N	2.35±0.39a
SW2N	1.58±0.25a	SW2H	4.03±0.68f	BH4A	3.21±0.57bc
SW2H	1.71±0.16a	BH2G	1.08±0.21a	BH3C	2.22±0.43a
BH2G	2.18±0.19a	BH3C	2.61±0.25a	BH3E	2.10±0.31a
BH4A	2.26±0.26a	SW2L	2.44±0.17a	BH3B	2.61±0.36a
BH3C	2.28±0.43a	BH3D	0.95±0.08a	BH2C	2.77±0.37a
BH3E	2.39±0.31a	BH2A	1.18±0.11a	SW2B	3.39±0.67cd
SW2L	2.41±0.36a	BH3B	1.76±0.23a	BH2B	3.45±0.64d
BH3D	2.57±0.44a	BH2C	3.98±0.51e	SW2A	3.83±0.57e
BH2E	2.58±0.39a	SW2B	1.04±0.09a	BH1A	3.03±0.59ab
BH2A	2.72±0.37a	SW2D	2.09±0.13a	SW2F	2.30±0.19a
BH3B	2.94±0.43ab	BH2D	2.44±0.39a	SW4B	3.43±0.46d
BH2C	3.08±0.64abc	SW2D	1.61±0.22a	**Mean**	**3.16**
SW2B	3.13±0.53abcd	SW2C	1.40±0.9a	**cv %**	**22.2**
BH2B	3.18±0.51abcde	BH1A	1.45±0.13a		
BH1A	3.34±0.37bcdef	SW2F	3.98±0.78e		
SW2G	3.35±0.25bcdef	BH4C	1.08±0.11a		
SW2A	3.39±0.31cdef	SW2M	1.08±0.09a		
BH4D	3.44±0.33cdef	SW4B	3.73±0.66d		
BH2D	3.48±0.24def	**Mean**	**3.12**		
SW2D	3.51±0.41ef	**cv %**	**20.0**		
BH3A	3.54±0.44f				
SW2C	3.57±0.49f				
BH1A	3.86±0.57g				
SW2F	4.16±0.87h				
BH4C	4.18±0.79h				
SW2M	4.37±0.73i				
SW4B	4.44±0.62j				
Mean	**3.55**				
cv %	**21.5**				

1. Values are means of two determinations ± standard deviations

2. Values with the same letters on the same column are not significantly different at 5 % level of significance.

Clostridium pafrigens was absent in 54.29 % of ground water samples. BH3E had the lowest mean log *Clostridium pafrigens* count of 2.1 Cfu/ml while BH1A had the highest mean log *Clostridium pafrigens* count of 4.22 Cfu/ml. The samples contaminated with *Clostridium pafrigens* were mainly from Leparua, and Ngare Mara areas which are remote areas far of the urban area. Significant mean difference ($p \leq 0.05$) occurred among the means mean log *Clostridium pafrigens* counts.

Majority of the ground water sources samples were contaminated with *Staphylococcus aureus*. *Staphylococcus aureus* was absent in 35.29 % of the ground water sources. BH3D had the lowest mean log *Staphylococcus aureus* count of 0.95 Cfu/ml while SW2H had the highest mean log count of 4.03 Cfu/ml. Mean log *Staphylococcus aureus* counts differed significantly ($p \leq 0.05$) among the ground water sources.

4.2.2.2. *Escherichia coli* counts (Log Cfu) in Ground water sources

The mean log *Escherichia coli* counts in the ground water sources is presented in Table 4.3. *Escherichia coli* was present in 22.9 % of the ground water samples. SW2A had the lowest mean log *Escherichia coli* count of 0.95 Cfu/ml while BH2A had the highest mean log *Escherichia coli* count of 2.31 Cfu/ml. The mean log *Escherichia coli* significantly ($p \leq 0.05$) differed among the ground water sources.

Table 4.3: *Escherichia coli* counts (Log Cfu) in Ground water sources

Water sample	*Escherichia coli (log Cfu/ml)*
SW2A	0.95±0.11a
SW2N	1.09±0.16a
BH3E	1.15±0.22a
BH3C	1.24±0.25ab
SW2C	1.54±0.29bc
SW4A	1.69±0.21c
SW2G	2.13±0.41d
BH2A	2.31±0.52e
Mean	**1.77**
cv %	**12.3**

1. Values are means of two determinations ± standard deviations

2. Values with the same letters on the same column are not significantly different at 5 % level of significance.

4.2.3 *Escherichia coli, Staphylococcus aureus* and *Clostridium pafrigens* contamination in Surface water sources

Escherichia coli, Clostridium pafrigens and *Staphylococcus aureus* mean log counts in the surface water sources are as shown in Table 4.4.

Table 4.4: ***Escherichia coli, Staphylococcus aureus and Clostridium pafrigens*** **(Log Cfu) contamination in Surface water sources**

Sample	*Escherichia coli* (log Cfu/ml)	Sample	*Clostridium pafrigens* (log Cfu/ml)	Sample	*Staphylococcus aureus* (log Cfu/ml)
R1C	1.08±0.23a	SPR1C	1.34±0.36a	R4B	1.04±0.14a
PAN2B	1.09±0.46a	R3C	1.58±0.18a	PAN2A	1.18±0.16a
SPR3A	1.09±0.26a	R1A	2.10±0.57a	SPR1D	1.35±0.23a
SPR1D	1.11±0.20a	SPR1D	2.38±0.76a	SPR3A	1.40±0.34a
SPR1B	1.18±0.08a	R4B	2.53±0.11a	R4A	1.69±0.42a
R3C	1.54±0.11a	RAIN2	3.18±0.15a	SPR1B	1.97±0.25a
SPR1A	1.60±0.40ab	R1C	3.19±0.49a	TROUGH2	2.94±0.37b
SPR3B	1.74±0.15bc	R3A	3.27±0.82a	TROUGH4	3.19±0.18c
SPR1C	1.90±0.26c	PAN2A	3.54±0.69a	SPR3B	3.24±0.39c
R3A	2.16±0.72d	TROUGH2	3.85±0.24b	RAIN2	3.39±0.37d
RAIN2	2.20±0.19d	SPR1B	3.86±0.57b	SPR1A	3.54±0.45e
R4A	2.22±0.13d	SPR1A	4.62±0.37c	R3A	3.57±0.78e
Mean	**1.59**	**Mean**	**3.53**	**Mean**	**2.87**
cv %	**23.3**	**cv %**	**46.1**	**cv %**	**26.5**

1. Values are means of two determinations ± standard deviations

2. Values with the same letters on the same column are not significantly different at 5 % level of significance.

Escherichia coli, Staphylococcus aureus and *Clostridium pafrigens* mean log counts differed significantly ($p \leq 0.05$) among the surface water sources. *Escherichia coli, Staphylococcus aureus* and *Clostridium pafrigens* were absent in only 36.8 % of the surface water sources. However, *Escherichia coli, Staphylococcus aureus* and *Clostridium pafrigens* were present in 63.2 % of the surface water sources. R1C had the lowest mean log *Escherichia coli* count of 1.08 Cfu/ml while the highest mean log *Escherichia coli* was 2.22 Cfu/ml in R4A. SPR1A had the highest mean log *Clostridium pafrigens* count of 4.62 Cfu/ml and the lowest was 1.34 Cfu/ml in SPR1C. Similarly, highest mean log *Staphylococcus aureus* count of 3.57 Cfu/ml was in R3A whereas the R4B had the lowest mean log *Staphylococcus aureus* count of 1.04 Cfu/ml was in.

4.2.3.1 Coliforms counts (Log Cfu) in surface water sources

Total coliforms log counts significantly differed (p≤0.05) among the surface water sources. R1A had the lowest mean log total coliforms count of 1.26 Cfu/ml while Trough2 had the highest mean log Coliforms count of 4.44 Cfu/ml. The coliforms counts in the surface water sources were higher than the recommended minimum limit for potable water standard in Kenya. The total coliforms counts in the surface water sources are as shown in Table 4.5.

Table 4.5: Coliforms count (Log Cfu) in the surface water sources

Sample	Coliforms (log Cfu/ml)	Sample	Coliforms (log Cfu/ml)
R1B	1.26±0.17a	SPR1C	2.99±0.22ab
R4B	1.45±0.21a	SPR3B	3.08±0.13ab
R1C	1.58±0.28a	PAN2A	3.49±0.72abc
SPR1B	1.98±0.46a	R4A	3.61±0.54bc
SPR1A	2.04±0.36a	R3A	3.74±0.56c
PAN2B	2.08±0.13a	R3C	3.74±0.18c
R1A	2.78±0.15ab	SPR3A	3.80±0.28c
R3B	2.64±0.89ab	SPR1D	4.32±0.36d
TROUGH4	2.72±0.16ab	TROUGH2	4.44±0.87e
Mean	**3.61**	**Mean**	**3.61**
cv %	**18**	**cv %**	**18**

1. Values are means of two determinations ± standard deviations

2. Values with the same letters on the same column are not significantly different at 5 % level of significance.

4.2.3.2 *Escherichia coli, Clostridium pafrigens, Coliforms and Staphylococcus aureus* counts Association in surface water sources

Mean log count Correlation among the *Escherichia coli, Clostridium pafrigens, Coliforms and Staphylococcus aureus* in surface water sources is shown in Table 4.6.

Staphylococcus aureus had a significant positive association with *Clostridium pafrigens* and *Escherichia coli* count (r = 0.52 and 0.472) respectively. *Clostridium pafrigens, Staphylococcus* *aureus* and *Escherichia coli* are all pathogenic and their occurrence is a likely indicator of primary contamination of the water sources with feacal matter. Total coliforms counts had a negative association to all the three pathogens.

Table 4.6: *Escherichia coli, Clostridium pafrigens*, Coliforms and *Staphylococcus aureus* counts correlation in surface water sources

	Staphylococcus	*Coliforms*	*Clostridium*	*Escherichia coli*
Staphylococcus	1	-0.053	0.52**	0.472**
Coliforms	-0.053	1	-0.032	-0.095
Clostridium	0.52**	-0.032	1	-0.018
E. coli	0.472**	-0.095	-0.018	1

**Correlation is significant at the 0.01 level (2-tailed).

4.2.4 Level of microbial contamination in Chlorinated urban water sources

Total coliforms in treated urban water supply at household level is shown in Table 4.6. *Escherichia coli*, *Staphylococcus* and *Clostridium pafrigens* were absent in 60 % of the chlorinated urban water sources. Only 40 %of the chlorinated urban water sources from the households had *Clostridium pafrigens*. Tap1 had 2.89 mean log Cfu/ml while Tap2 had 1.10 mean log Cfu/ml *Clostridium pafrigens* counts which significantly differed ($p \leq 0.05$). Coliforms were present in 80 % of the chlorinated urban water sources. Tap2 had the highest mean log coliforms count of 4.18 Cfu/ml that significantly differed ($p \leq 0.05$) from those of Tap3, Tap4 and Tap5 as shown in Table 4.7.

Table 4.7: Level of microbial contamination in Chlorinated urban water sources

Sample	*Coliforms (Log Cfu/ml)*	*Escherichia coli (Log Cfu/ml)*	*Clostridium pafrigens (Log Cfu/ml)*	*Staphylococcus aureus (Log Cfu/ml)*
TAP5	2.31±0.69a	0.0±0.0a	1.10±0.12b	2.68±0.67c
TAP4	2.63±0.18a	1.36±0.67c	0.75±0.05a	1.89±0.22a
TAP3	2.85±0.56a	1.11±0.09b	1.65±0.73c	2.09±0.79b
TAP2	4.18±1.66b	0.0±0.0a	1.02±0.11a	1.88±0.12a
Mean	**3.51**	**1.24**	**1.13**	**2.14**
cv %	**19.5**	**16.7**	**10.7**	**6.4**

1. Values are means of two determinations ± standard deviations
2. Values with the same letters on the same column are not significantly different at 5 % level of significance

Staphylococcus aureus was present in 60 % of the chlorinated urban water sources. The mean log *Staphylococcus aureus* counts in the chlorinated urban water sources significantly differed ($p \leq 0.05$). The highest and lowest mean log *Staphylococcus aureus* counts were 2.68 Cfu/ml and 1.88 Cfu/ml. *Escherichia coli* was present in 40 % of the chlorinated urban water sources. The highest and lowest mean log *Escherichia coli* were 1.11 Cfu/ml and 1.36 Cfu/ml respectively. The mean log *Escherichia coli* counts in significantly differed ($p \leq 0.05$) among the chlorinated urban water sources.

4.2.5 Parasitic cysts in the water sources

All the water samples collected from surface, ground and treated water sources were analyzed for *Trichuris trichura*, *Amoeba cyst*, *Giardia lamblia*, *Cryptosporidium oocysts*, hook worm, *Ascaris ova*, hookworm Larvae and *Blastocystis hominis.*

Spring water had three *Trichuris trichura* cysts per milliliter, one *Ascaris ova* and hook worm larvae each per milliliter. River water had one cysts of *Trichuris trichura*. *Blastocystis hominis* cysts was only detected in open shallow well water. *Giardia lamblia* cysts was found in open trough water. River water tested positive for one hook worm and Ascaris ova per milliliter each.

Generally, it was only the surface water sources that indicated parasitic contamination, while all ground water sources were negative for the tested cysts.

4.3. Discussion

4.3.1 Level of Coliforms, *Escherichia coli, Clostridium pafrigens and Staphylococcus aureus* in ground water quality

Ground water is a major source of drinking water (Rod *et al.,* 2008*;* Olaleye and Ogunbajo, 2015; Megha *et al*., 2015). Its pollution by pathogens and elevated concentrations of dissolved solids is of concern due to its use for drinking and its effect on the quality of surface water bodies into which groundwater discharges. Concentrations of total coliforms, *Escherichia coli, Clostridium pafrigens and Staphylococcus aureus* in the ground water samples were higher indicating the extent of contamination of the water sources making them unsafe for drinking (Rod *et al*., 2008; Kalpana *et al*., 2014).

The presence of *Escherichia coli*, total coliforms and *Clostridium pafrigens* in higher counts in ground water indicates contamination by potentially dangerous faecal matter and other pathogens that compromises the safety of such water sources (Kalpana *et al*., 2014). Total coliform presences in the water is therefore useful for monitoring the microbial quality of drinking water from time to time (Gangil *et al*., 2013). To minimize health risk resulting from the consumption of such contaminated ground water, appropriate treatment processes should therefore be utilized for disinfection of ground water for quality and safe drinking water (Oyedeji *et al*., 2010). Contamination of ground water by coliforms and *Escherichia coli* counts that exceed zero colony forming units per milliliter recommended for standard drinking water has been report by Mahananda *et al*. (2010) and Manhokwe *et al*. (2013). The level of microbiological contamination in the ground water exceeded the limits regarded as safe by East African standard for drinking water.

Groundwater sources are very important resource for drinking purpose because it has been found to contain over 90 % of the fresh water recharge over the world (Sabahi, 2009). It is partially or severely polluted depending on the level of vulnerability to pollution sources. Poor microbiological quality of groundwater sources is of concern at the point of use considering the health risk and the handling conditions at the household level where unhygienic practices dominates the handling operations (Olaleye and Ogunbajo, 2015). There exist incessant microbial contamination of ground water among rural communities and Isiolo County is not an exception shown by the level of microbial count (Razzolini *et al*., 2011; Moyo, 2013; Lavanya and Ravichandran, 2013). Consumption of untreated ground water could therefore be a root cause of diarrheal conditions and deaths reported among the rural population of Isiolo County (Megha *et al.*, 2015). Contamination of some ground water sources result from poorly designed latrines and inappropriately maintained septic systems within the rural areas that have been implicated in many water borne epidemics (Megha *et al*., 2015)

4.3.2 Level of Coliforms, *Escherichia coli, Clostridium pafrigens and Staphylococcus aureus* in Surface water sources

Surface water covers a wide area of the Earth surface (Ahiablame *et al*., 2012). Springs, rivers, pans and dams are the predominant surface waters in the rural areas of developing nations (Kuta *et al*., 2014; Muhammad *et al*., 2017). These sources are susceptible to diverse contaminants given their open exposure to the environment (Oludairo and Aiyedun, 2015; Gangil *et al*., 2013; Muhammad *et al*., 2017). The population of Isiolo County that uses these water sources for drinking and food processing are therefore exposed to higher health risk as shown by higher counts of coliforms, *Escherichia coli*, *Clostridium pafrigens* and *Staphylococcus aureus* that exceeded the recommended Kenyan standard for drinking water of zero colony forming units per milliliter (Opara and Nnodim, 2014).

Escherichia coli and coliforms presences in the surface water sources points out the possibility of contamination by other pathogenic microorganisms that further renders such water unsafe for drinking and food processing (Anyamene and Ojiagu, 2014). All the surface water sources samples tested positive for total coliforms. The counts exceeded the limits regarded as safe for drinking water by Kenyan Standards. Such level of contamination exposes the end user community members to higher health risk and the prevalence of diarrheal conditions and other water borne infections in Isiolo can be explained by the continued use of untreated surface water (Olaleye and Ogunbajo 2015; Megha *et al*., 2015;Kirianki *et al*., 2017).

4.3.3. Level of Microbial contamination in the Chlorinated urban water sources

About 80 % of the treated urban water supply samples tested positive for total coliforms. Similarly notable proportion of the samples tested positive for *Escherichia coli*, *Clostridium pafrigens* and *Staphylococcus aureus*. The mean values significantly differed ($p \leq 0.05$) indicating the variation in household handling practices. Unhygienic handling practices at household level results into cross contamination of the already treated water with pathogenic organism thereby compromising the safety of the water (Kirianki *et al*., 2017). Inadequate sewerage system along the water supply chain and septic systems are implicated for leakages that pollutes the water with pathogenic bacteria (Olaleye and Ogunbajo, 2015; Megha *et al*., 2015). Some of the water samples tested negative for Coliforms, *Escherichia coli*, *Clostridium pafrigens* and *Staphylococcus aureus* indicating the adequacy of treatment and the observed contamination was as a result of inappropriate handling post treatment.

Despite the treatment given to water re-growth and re-contamination of treated water has been a trend of concern (Anyamene and Ojiagu, 2014). Lack of proper cleaning for the storage and handling containers have also been implicated in cross contamination of water with pathogenic bacteria (Kiruki *et al.,* 2011)

4.3.4 Microbial contamination of water sources in Isiolo County Kenya

Generally, surface water sources were more contaminated than the ground water sources. In most cases, surface water sources are contaminated by waste, sewage, chemicals, hydrocarbons, medicine, hormones, antibiotics, bacteria, and fertilizers (Kumar and Lee, 2012; Oludairo and Aiyedun, 2015; Gangil *et al*., 2013; Muhammad *et al*., 2017). The ground water passes through a bed of soil and rock as the surface water run-off infiltrates and percolates through the earth crust (Wang *et al*., 2014; Kirianki *et al*., 2017). Inappropriate tillage operations on arable lands on the slopes of mount Kenya the sources of river Isiolo, Ayana River and all the springs in Isiolo is a significant contributor to greater extent of surface water pollution as similarly reported by Wang et al. (2014). In most cases the residents water their animals directly into the surface water sources. The animals urinate and defecates in the water. The animal's waste therefore forms the sources of feacal contamination noted by high coliforms, *Escherichia coli* and *Clostridium pafrigens*. During sample collection, goats were observed grazing on riparian vegetation growing on the banks and surface of river Ngare Ndare one of the surface water sources for most locals in Leparua area of Isiolo County. As the goats grazed, they urinate and drop their feacal matter on the surface of River Ngare Ndare hence the eventual observable contamination (Kirianki *et al*., 2015).

4.3.5 Parasitic cysts in water

Most of the water borne pathogens are zoonotic (Kiruki *et al*., 2011; Kirianki *et al*., 2015). *Giardia lamblia, Ascaris ova, Hook worm,* and *Trichuris trichura* are shed into the surface water sources from the skins of the animals and as well as the urine and feacal matter when the animals are watered directly into the surface water sources (Kumar and Lee 2012). Inadequate hygiene facilities in most rural set-ups of Isiolo promotes open human waste disposal (Muhammad *et al*., 2017). The cysts of the gastrointestinal origin find their way into the surface soils. During precipitations the cysts are carried along in the surface run-offs to the open surface waters from where they thrive withstanding the dynamic environmental conditions (Kalpana *et al*., 2014). Cysts contributes to malnutrition in children as they suck nutrients from the gastro-intestinal tract of the host victims and their presences compromises the entire water safety (Anyamene and Ojiagu, 2014).

4.4 Conclusion

Surface, ground and chlorinated urban water sources in Isiolo were contaminated with bacteria and cysts to levels regarded as unsafe as per the standards for potable water. This makes the water sources unsafe for direct drinking and use in food processing. Point of use water disinfection is needed. Solar water disinfection which uses clean and cheap solar energy to induce germicidal effect would be appropriate in the area owing to the high solar intensity of about 800 Wm^{-2} in Isiolo. Acceptability of solar use in powering boreholes pumps and solar drying of agricultural produce has increased in the recent past and solar water disinfection technologies might not be an exception. This would minimize health risk associated with other chemical disinfection methods and as well save on biofuel consumption in the form of firewood for boiling water.

CHAPTER FIVE

Physico-Chemical Characteristics of Water used for Drinking and Processing in Isiolo County in Kenya

Abstract

Water quality, wholesomeness and palatability is usually influenced by the level of dissolved minerals as well as the physical appearance of color, turbidity and suspended matter. Climatic conditions and changes in the hydrological cycles have been reported to alter the physico-chemical attributes of water exposing the end users to health risks. Forty four water samples were purposively sampled aseptically and analyzed as per ASTM-D1125, ISO 7887, 10523, 6059, and 7027 for electrical conductivity, color, pH, hardness, and turbidity respectively. Means and Pearson correlation were compared at 5 % level of significance. Results show that highest and lowest total hardness values were 638.5 mg/l and 138.5 mg/l for borehole and tap water respectively. Calcium and magnesium ions mean values were 33.92 mg/l and 68.43 mg/l. Pan Water had the highest turbidity of 3026 NTU while borehole water had the lowest turbidity of 0.8 NTU. Mean value range for electrical conductivity and color were 139 µS/cm to 454 µS/cm and 13 TCU to 280 TCU respectively. Physico-chemical properties significantly differed ($p \leq 0.05$) across the water sources. Most of the surface and ground water sources had mean values of carbonate hardness, color, pH, electrical conductivity and turbidity that exceeded the minimum requirements for potable water as per WHO and KS EAS 12 guidelines. Point of use treatment is required for safe use in food processing and drinking.

Key words: Physico-chemical; Water Sources; food processing; drinking water; water turbidity, water hardness, Water pH, water color.

5.0 Introduction

Water is a natural resource that is required in all aspects of life (Hanasaki *et al*., 2013; Omar *et al*., 2017; Ferreira *et al*., 2017). Only 1 % of the total water coverage is available for use, 99 % of which are ground water sources (Ferreira *et al.,* 2017). Ground water while in the aquifers interacts with both beneficial and toxic components of soil and rocks and changes its physical and chemical properties (Peh *et al*., 2010; Nair *et al*., 2015). Pollution and modification of the hydrological cycle due to fluctuating climatic conditions tremendously alters the water quality characteristics (Nair *et al.,* 2015).

Water scarcity and pollution of surface and ground water sources not only cause immediate effect on public health but can prove fatal to the continuous users in the long run (Shen and Chen, 2010; Simpi *et al*., 2011; Juneja and Chaudhary, 2013). Pollution by heavy metals from industrial wastes renders the available water sources unsafe for drinking and food processing, some of these metals raises the physical and chemical properties of the water to unacceptable levels (Juneja and Chaudhary, 2013).

Climatic changes and the trending global warming especially in the arid and semi-arid areas increase the rate of evaporation in surface water sources and hence the concentration of dissolved solutes (Simpi *et al*., 2011; Hanasaki *et al*., 2013; Wang *et al*., 2014; Bada *et al*., 2017). Water PH, electrical conductivity, turbidity, alkalinity and water hardness among other chemical properties are greatly influenced by seasons and location (Simpi *et al*., 2011). Agricultural activities along the river banks also contributes to high water alkalinity (Pradesh *et al*., 2012). The agricultural inputs on the farms are washed off by surface run-off into the surface water sources where they accumulate (Shen and Chen, 2010). Leaching through the soil occurs as rain water percolates and infiltrates through the soil profile (Pradesh *et al*., 2012).

Rural dwellers rely on surface and ground water for drinking and food processing (Malik *et al.*, 2010; Ahmad *et al.*, 2012; Muhammad *et al.*, 2013; Muhammad *et al.*, 2017). Due to contamination, majority of the human population do not have access to potable water and are therefore exposed to water borne health risks (Muhammad *et al*., 2013). High alkalinity and pH of most of these water sources induces unpalatable taste as well as high salt intake that is implicated in high blood pressure and kidney stones (Anwar *et al*., 2011; Muhammad *et al*., 2017). However, fluoride in optimal concentration in the drinking water is beneficial for strong teeth formation (Muhammad *et al*., 2013).

Meat and milk are the major items of trade from the pastoral communities in Kenya. The initial processing that involve cleaning of milk cans, carcass and mixing ingredients require water. The quality and safety of the available water sources in Isiolo County is unknown given their diversity. This study therefore, sought to establish the physico-chemical quality of water sources utilized by the residents for food processing and drinking as an informed basis for development of appropriate water treatment technology.

5.1 Materials and methods

5.1.1 Study setting

The study was conducted in Isiolo, an expansive County covering an area of 25, 336.1 square kilometers in the Northern Kenya classified as Arid and Semi-Arid land. Isiolo County is located within: 00°21′N 37°35′E / 0.350°N 37.583°E / 0.350; 37.583 and about 285 kilometers north of Nairobi. Administratively Isiolo County consists of six divisions namely Central, Garbatulla, Sericho, Merti, Oldonyiro and Kinna. The plains gradually rise from an altitude of 200 -300 m above sea level. The main water sources includes river Ngare Mara, Ngare Ndare river, river Ewaso Nyiro, Leparua spring, Boreholes, Shallow wells, Pans and Dams and treated urban water supply in Isiolo town among others.

5.1.2 Sample collection

Exhaustive sampling based on the available water sources distributed across the three locations of Ngare Mara, Burat and Wabera in Isiolo central was used to collect 44 water samples. All the laboratory apparatus and polyethylene sampling bottles were pre-cleaned sanitized and sterilized. This procedure was very crucial to remove any contaminants before the analysis (APHA, 2012).

The sterile sampling bottles were opened at the point of sampling to allow aseptic water sampling. Afterwards, the collected samples were stored in the cooler box at approximately 4˚C to minimize any activity that might alter the physico-chemical property of the water (APHA, 2012). During sampling, the polyethylene sample bottles were normalized with sampled water. Triplicate samples were collected and homogenized from each sampling station in order to obtain an average value for the analysis. Each bottle was labeled with corresponding sampling station and the time of sampling was recorded. The samples were then transported to the laboratory for analysis within 48 hrs of sampling owing to the long distance between sampling points and analysis station.

5.1.3 Sample size

Forty four (44) 100 ml water samples based on exhaustive sample were collected aseptically from eight water sources. Samples from each water source were then mixed aseptically to obtain a randomized homogenous representative sample for analysis. Sampling was done in October, 2016.

5.1.4 Analytical methods

5.1.4.1 pH determination

pH was determined as per ISO 10523:2017. Water pH was determined, using HACH pH meter (E-08328 Crisson Instruments, South Africa). The pH meter was calibrated using buffers 4.01 followed by 7.01 and 10.01 at 25 ˚C, then the electrode probe rinsed with distilled water. 50 ml of each water sample was placed in a beaker, then stirred for 15 seconds on the titrator using magnetic stir bar. pH values were then read off without stirring, the probe was rinsed between each sample determination.

5.1.4.2 Turbidity determination

Turbidity of the water samples was determined as per IS0 7027: 2016, using HACH Turbidity meter (2100 Q01-2010- USA). About 5 ml of each water sample was placed in the Turbidi meter and the turbidity read out in NTU.

5.1.4.3 Determination of total hardness

The total hardness of the water samples was determined as per ISO 6059. About 50 ml of the water samples were placed in conical flask. About 1 ml of buffer solution was added to each sample. To the sample buffer solution, 3 drops of Eriochrome black T indicator was added then the solution titrated against Ethylenediaminetetraacetic acid (E.D.T.A) solution to end point. Total hardness was calculated using the formula:

Total hardness = titre volume (ml)*20mg/l. Total hardness was expressed as mg/L.

5.1.4.4 Determination of calcium and magnesium hardness

Calcium hardness was determined as per ISO 6059. About 50 ml of water samples were placed in conical flask, 2mls of normal sodium hydroxide was added followed by Addition of 1ml hydroxynaphthol blue indicator, and the solution titrated against E.D.T.A without magnesium chloride to end point. The calcium and magnesium hardness was calculated using the following formulas based on titre volume of E.D.T.A:

Calcium hardness (mg/l) = titre volume (ml)*8mg/l

Calcium carbonate hardness (mg/l) = calcium hardness (mg/l)*2.4975

Magnesium carbonate hardness (mg/l) = total hardness – calcium carbonate hardness

Magnesium hardness (mg/l) = magnesium carbonate hardness/4.116

5.1.4.5 Determination of electrical conductivity

Electrical conductivity of the water samples was determined as per ASTM-D1125 (2014). Standard test method for electrical conductivity and resistivity of water using H1 9033 Multi range conductivity meter. Electrical conductivity were reported in µS/cm

5.1.4.6 Determination of color

Color of the water samples was determined as described by ISO 7887: (2011). Color values were recorded in TCU units.

5.1.4.7 Data analysis

Analysis of variance (ANOVA) at 5 % level of significance was used to compare means of the physico-chemical water quality among all the sampled sources; river, spring, borehole, pans and shallow wells, using statistical analysis software (SAS) version 9.0. Least significant difference (Lsd) was used to separate the means. Significant differences were indicated by different letters.

Pearson correlation was used to establish the relationship among the chemical quality aspects of the sampled water at 5 % and 1 % levels of significance.

5.2 Results

5.2.1 Water hardness

Magnesium and calcium carbonates hardness and total hardness of ground water sources analyzed are shown in Table 5.1.

Table 5.1: Total hardness, Magnesium and Calcium Carbonates Hardness of the water sources

Water source	Total Hardness (mg/l)	Magnesium Carbonate Hardness (mg/l)	Calcium Carbonate Hardness (mg/l)
Tap	138.5±2.1a	125.0±1.4a	13.5±2.1a
River	225.5±0.7b	145.0±1.4a	80.5±0.7cd
Open Shallow well	274.5±30.4c	210.0±7.1b	46.0±1.8ab
Spring	362.0±1.4d	269.5±0.7c	91.0±1.6d
Pan	478.0±4.2e	381.0±1.4d	93.0±1.4d
Shallow well	579.0±25.5f	448.5±24.7e	119.5±13.4e
Borehole	638.5 ±3.5g	467.0±32.5e	170.5±28.9f
Mean	**354.4**	**270.4**	**84.7**
cv%	**4.0 %**	**5.4 %**	**13.4 %**
L.S.D	**32.72**	**33.89**	**26.18**

1. Values are means of ten determinations ± standard deviations

2. Values with the same letters on the same column are not significantly different at 5% level of significance.

Mean total hardness significantly differed ($p \leq 0.05$) across the water sources. Borehole water had mean total hardness that was higher than 600 mg/l recommended for potable water by KS EAS 12: 2014. Tap water had the lowest mean total hardness of 138.5 mg/l. Mean magnesium carbonate hardness significantly differed ($p \leq 0.05$) among pan, spring and open shallow well water. Tap and river as well as borehole and spring water insignificantly differed ($p \leq 0.05$) in their mean magnesium carbonate hardness. The highest and lowest mean magnesium carbonate hardness were 467 mg/l and 125 mg/l in borehole and Tap water respectively. Grand magnesium hardness mean was 270.4 mg/l.

Calcium carbonate mean hardness significantly differered ($p \leq 0.05$) across the water sources except between spring and pan water. Calcium carbonate mean hardness values range was 13.5 mg/l to 170.5 mg/l and an average mean of 84.7 mg/l. Borehole water had the highest calcium carbonate concentration of 170.5 mg/l.

5.2.2 Magnesium and calcium ions concentration in the water sources

Mean magnesium ions concentrations varied from 8.45 mg/l to 108 mg/l. Across the water sources significant differences occurred ($p \leq 0.05$) except between pan and River water. Grand magnesium ions concentration was 68.43 mg/l as shown in Table 5.2.

Calcium ions concentration significantly differered across the water sources ($p \leq 0.05$). Grand calcium ions concentration mean was 33.92 mg/l. Higher calcium ions concentrations were found in borehole and shallow well water than the other water sources.

Insignificant differences occurred among the mean pH values. Spring and borehole water mean pH values significantly differed ($p \leq 0.05$). The grand pH mean was 7.24 which is within the acceptable limit of 6.5 to 9.5 for naturally potable water by KS EAS 12: 2014 standards.

Table 5.2: Magnesium and Calcium Ions concentration and Water pH

Water source	**Ca^{2+} concentration (mg/l)**	**Mg^{2+}concentration (mg/l)**	**pH**
Tap	22.0 ±1.2b	31.0 ±1.4b	7.4±0.21b
Open shallow well	18.5±1.7b	49.5±0.7c	7.6±0.1b
Spring	35.0±3.2c	67.0±2.1d	8.1±0.04c
Pan	36.0±1.4c	90.0±2.4e	7.7±0.21b
River	34.0±2.8c	91.0±2.8e	7.7±0.07b
Shallow well	53.0±1.4d	102.0±2.8f	7.6±0.04b
Borehole	66.0±2.3e	108.0±1.4g	8.7±0.1d
Mean	**33.92**	**68.43**	**7.24**
cv%	**4.5 %**	**2.7 %**	**1.7 %**
L.S.D	**3.51**	**4.24**	**0.29**

1. Values are means of ten determinations ± standard deviations

2. Values with the same letters on the same column are not significantly different at 5% level of significance.

5.2.3 Water turbidity, electrical conductivity and color

Ground water sources of borehole, open shallow well and shallow well had low mean turbidity values compared to surface water sources of pan, spring and river whose mean turbidity exceeded the 25 NTU for naturally potable water by KS EAS 12: 2014 standards. Significant differences ($p \leq 0.05$) in mean turbidity values only occurred in the surface water sources. Ground water sources insignificantly differed in their turbidity mean values. Table 5.3 shows the mean values of water turbidity, electrical conductivity and color of the various water sources analyzed.

Table 5.3: Water turbidity, electrical conductivity and color

Water source	Turbidity (NTU)	Electrical conductivity (µS/cm)	Color (TCU)
Borehole	0.8±0.14a	454.0±2.8g	13.0±1.41a
Tap	1.7±0.14a	251.0±2.83b	39.0±5.65c
Shallow well	1.8±0.1a	310.5±2.1e	124.0±2.82ab
Open shallow well	2.2±0.35a	299.5±2.1d	133.0±2.34bc
River	35.5±0.71c	317.5±2.1e	238.5±4.95e
Spring	40.3±1.9d	272.5±4.9c	80.0±5.66d
Pan	3026±4.2e	437.0±4.2f	280.0±9.9f
Mean	**389.74**	**310.1**	**603.1**
cv%	**0.4 %**	**1.4 %**	**0.8**
L.S.D	**3.89**	**9.78**	**11.54**

1. Values are means of ten determinations ± standard deviations

2. Values with the same letters on the same column are not significantly different at 5% level of significance.

Electrical conductivity mean values significantly differed ($p \leq 0.05$) across the water sources. Borehole water had the highest electrical conductivity of 454 µS/cm while spring water had the lowest electrical conductivity of 272 µS/cm. Mean electrical conductivity values for the water sources were lower than 1500 µS/cm limit for treated potable water.

The water sources significantly differed ($p \leq 0.05$) in their color. Pan water had the highest mean color value of 280 TCU which was higher than 50 TCU limit for naturally potable water. Most of the water sources had un-desirable color except borehole and urban treated water from the taps.

5.2.4 Pearson Correlation matrix for the physico-chemical water attributes

The relationships among the physical and chemical characteristics of the water samples analyzed are shown in Table 5.4.

Table 5.4: Pearson correlation for the physico-chemical characteristics of the water sources

	Total hardness	Ca^{2+}	Mg^{2+}	pH	Turbidity	EC	Color
Total hardness	1	0.903**	0.843**	0.58*	0.254	0.77**	0.134
Calcium ions	0.903**	1	0.904**	0.713**	0.043	0.77**	0.041
Magnesium ions	0.843**	0.904**	1	0.755**	0.244	0.83**	0.341
pH	0.58*	0.713**	0.755**	1	0.104	0.77**	0.157
Turbidity	0.254	0.043	0.244	0.104	1	0.507*	0.913**
EC	0.77**	0.773**	0.839**	0.77**	0.507*	1	0.499**
Color	0.134	0.041	0.341	0.157	0.913**	0.49**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Water electrical conductivity and pH were greatly influenced by concentration of magnesium and calcium ions as shown in Table 5.4. Turbidity and color had a significant positive relationship (r = 0.913). Similarly an increase in water turbidity results into more dissolved minerals that significantly induces the electrical conductivity (r = 0.507).

5.3 Discussion

5.3.1 Water hardness

Reported values of 161 mg/l to 183 mg/l present study but have a much lower upper hardness range value (Pradesh *et al.,* 2012). Ground water had higher hardness values than surface water.

Environmental pollution and deforestation have led to climatic changes that have resulted in high rate of water evaporation from the surface waters and increased concentration of carbonates in the water (Simpi *et al*., 2011; Hanasaki *et al*., 2013; Wang *et al*., 2014; Bada *et al*., 2017). Given the harsh prevailing conditions of arid and semi-arid regions of Kenya of which Isiolo County form part, modification of the hydrological cycle occurs as rate of replacement of evaporated water is intermittent (Nair *et al*., 2015; Ferreira *et al*., 2017).

Majority of the rural population relies on ground water held in aquifers during dry seasons which occur most of the year (Olaleye and Ogunbajo, 2015; Megha *et al*., 2015; Muhammad *et al*., 2017). Water hardness is season dependent with higher values in the months of April – July (Simpi *et al*., 2011). Lithology, ground velocity and recharge greatly impact on the calcium and magnesium ions concentration (Ferreira *et al.,* 2017). During these dry seasons the population utilizing these water sources are therefore exposed to high health risk as they have to bear with the highly saline water for drinking.

As the ground water infiltrates and percolates through the Earth crust after precipitation it carriers dissolved minerals in the form of calcium ions and magnesium ions from the surface bed rock through which the water flows into the aquifers (Bada *et al*., 2017; Ferreira *et al.*, 2017). Similarly surface run-offs to the surface water sources flow through the farming regions on the slopes of Mount Kenya, the source of springs and rivers utilized in Isiolo County. In these areas application of chemical inputs on farms is the normal practice. Some of the carbonates applied in the farms therefore contribute to the observed levels in the analyzed samples.

Calcium ions values ranged from 6.85 mg/l to 66.0 mg/l which were within the acceptable limit of less than 150 mg/l recommended by East African as well as WHO standard for potable water (WHO, 2014; KS EAS12, 2014). Similarly magnesium ions concentration values were in the range of 6.85 mg/l to 120.04 mg/l, only few water samples had mean magnesium values greater than 100 mg/l limit recommended for potable water (WHO, 2014; KS EAS 12, 2014). Borehole and shallow well water sources had the highest magnesium and calcium hardness. The bed rocks through which the underground water rises and the surface water flows, is weathered and the carbonates that constitute these rocks dissolve in water delivering the minerals of calcium and magnesium into the water (Mokhtar *et al*., 2009). Boreholes and shallow wells are always enclosed by the earth crust rocks and therefore the concentration is greater as the constant contact provide adequate time for more of the rocks carbonates to dissolve into the water enhancing the concentration of the carbonates (Mokhtar *et al*., 2009). Rate of contaminations depends on the aquifer lithology, ground velocity and recharge replacement (Ferreira *et al*., 2017).

Water with high concentration of calcium and magnesium carbonates causes formation of scales in steam and boiler pipes if used in steam generation at industrial level, thereby inducing heat resistance and increased fuel consumption leading to extra cost of food processing (Talabi *et al*., 2013; Singh *et al*., 2013). Hard water does not lather well with soap and thus more detergent consumption when used for cleaning food handling equipment (Karikari *et al*., 2011; Sigh *et al*., 2013).

5.3.2 Water pH

pH values of the water samples ranged from 7.4 to 8.7 and are favorable for the growth of planktons that are useful for breeding of fish that is food to the population (Pradesh *et al*., 2012). Alkaline skewed pH values have been reported in various studies in different environments pointing towards the trend extent of environmental and water pollution (Simpi *et al*., 2011; Pradesh *et al*., 2012; Muhammad *et al*., 2013). The pH values differered significantly ($P \leq 0.05$) from one water source to another. Majority of the pH values were within the range of 6.5 to 8.5 standard specification for potable water (WHO, 2004; KS EAS 12, 2014).

As the rain falls, it dissolved the exhaust gases within the atmosphere forming weak carbonic acid thereby the low pH. The low pH also indicates that there is heavy pollution in the environment and possibility of acid rains was high (Simpi *et al*., 2011; Hanasaki *et al*., 2013; Wang *et al*., 2014; Bada *et al*., 2017). Similar acidic skewed pH values were observable in most surface water sources, acidity arises from the soil through which the water flows washing off-acidic farm inputs into the surface water reservoirs.

The alkaline condition normally indicates the presence of carbonates of magnesium and calcium in the water (Begum *et al*., 2009; Reza and Singh 2010). The concentrations of calcium and magnesium were moderate and the pH mean values were skewed to neutral. The significant positive relationship (r = 0.713) explains the close association of water pH to dissolved ions. Higher concentration of calcium ions in water induces higher pH values that are skewed to the alkaline extremes (Begum *et al*., 2009; Reza and Singh 2010). Water with extreme pH is not suitable for use in industrial food processing as well as for drinking due to their unpalatable taste (Simpi *et al*., 2012; Ferreira *et al*., 2017). Close association of pH to dissolved ions can then be used to gauge the level of contamination of the water source (Pradesh *et al*., 2011).

5.3.3 Water turbidity

Pan water had the highest turbidity mean values that were greater than 25 NTU maximum limit for potable water (WHO, 2004; KS EAS 12, 2014). Turbidity was highest in pan water, followed by river water and spring water respectively. Borehole and protected shallow wells had the lowest turbidity values.

Urban treated tap water also had lower values of turbidity but this differed significantly ($P \leq 0.05$) from one sampling location to another depending on the household handling. Turbidity of borehole water, shallow wells and urban treated water were within the acceptable limits of less than 25 NTU East African standard for potable water. Generally, water turbidity significantly ($P \leq 0.05$) differed across all the water sources.

Surface run-off as well as dredging at the sites carried sediments into the pan (Ashraf *et al*., 2011). Turbidity has high association with total suspended solid that makes the water un-clear and higher cost to purify for use in food processing (Bada *et al*., 2017; Ferreira *et al*., 2017). The suspended solids observed in turbid water includes organic matter and consequently higher microbial load that dominates such water making them unsafe (Simpi *et al*., 2011; Bada *et al.,* 2017). Riparian vegetation cover on at some points of the river bed served to purify the water trapping most of the suspended solids. As the water flows over uncovered river surface greater siltation occur hence the higher value turbidity (Ashraf *et al*., 2011). At the town center through which river Isiolo traverses pollution emanates from the settlement around the river as the population channel their wastes directly into the river as surface run-offs that wash the top soil on their way and consequently cause siltation of the river (Pradesh *et al*., 2012, Simpi *et al.*, 2011; Muhammad *et al*., 2013). Spring water that emerges from the earth crust similarly had higher turbidity value but this is from the soil through which the spring emerges (Balke and Zhu, 2008; Momba *et al*., 2012). Shallow well, borehole and urban treated water had low turbidity levels that are within acceptable limits of less than 25 NTU for potable water (WHO, 2004; KS EAS 12, 2014).

5.3.4 Water electrical conductivity

Electrical conductivity is influenced by the presences of dissolved minerals in the water (Begum *et al*., 2009; Reza and Singh 2010). Concentration of calcium and magnesium ions in the water acts as electrolyte to promote the current passage (r = 0.773 and 0.839). The electrical conductivity of the utilized water sources were within the acceptable limit of 2500 µS/cm for potable water (WHO, 2004; KS EAS 12, 2014). Despite the pollution that increases the concentrations of calcium and magnesium ions in water, the increase requires longer period of time to negatively impact on electrical conductivity.

5.3.5 Water color

The presences of dissolved minerals such as ferrous among other ions such as manganese have been reported to be responsible for the off color of water (Simpi *et al*., 2011). As the turbidity of the water rises due to dissolved and suspended solids the water loses its clarity and becomes non-pleasant (Ashraf *et al*., 2011). The close association of color and turbidity (r = 0.913) implicates discharge of solid wastes and soil erosion occurring on bear soil on which surface run-off occurs as well as the eroded river bed and banks with little riparian vegetation in the observable poor color of surface water sources (Bada *et al*., 2017; Ferreira *et al*., 2017). Ground water passes through a bed of soil, rocks, gravel, fine and course sand that traps most of the dissolved and suspended solids as the water infiltrates and percolates through the earth crust and hence the low turbidity and clear color.

Colored water reduces the associated aesthetics and as such minimized consumption. The end users thus endures occasional dehydration implicated in renal failure. Polluted water contains unknown substances with adverse health implications that compromises the active life of the residents in Isiolo.

5.4. Conclusion

Surface and ground water sources had hardness, Color, turbidity and pH values that exceeded the recommended limits for potable water. These water sources are unsafe for direct use in food processing and drinking. Therefore, point of use treatment is necessary. The electrical conductivity of water sources in Isiolo county were within the acceptable limit of <1500 µS/cm. the observable levels of physico-chemical characteristic of the water sources are pollution related and can be addressed through environmental awareness campaigns by the ministry of Environment conservation and Public health at county level.

CHAPTER SIX

Performance of a Continuous Solar Water Disinfection System (SODIS) in Isiolo County, Kenya

Abstract

Safe drinking water is important for a healthy community. In addition, access to adequate potable water is essential for sanitation and hygiene. Frequent disease outbreaks in Arid and Semi-arid Lands (ASALs) in Kenya are water related. These challenges can be reduced by a cost effective solar water disinfection system (SODIS). A SODIS prototype was designed, installed and tested in Isiolo town, Kenya. Two flat-plate solar collectors were used for water heating. Water circulation through the system at various flow rates was facilitated by a controlled photovoltaic pumping system. Temperature and solar radiation intensity were measured using digital temperature sensors and a pyranometer respectively. Microbiological and physico-chemical attributes of the water were determined using ISO analytical procedures.

Results showed a significant positive ($r = 0.87$) logarithmic change in solar radiation with time of the day. Temperature of disinfected water significantly differed with time of the day ($p \leq 0.05$). The mean log reduction for coliforms, *Escherichia coli*, *Staphylococcus aureus* and total viable counts were; 3.08, 2.071, 1.368 and 3.474, respectively. Despite the difference in temperatures of the day the microbial log reduction insignificantly differed ($p \leq 0.05$) for most parts of the day. Flow rate was a significant exponential function of disinfection temperature ($r = 0.9738$). Significant ($P \leq 0.05$) change in pH was achieved at temperature above 70˚C. In all the temperature regimes under review, Color changes were significant ($p \leq 0.05$). The turbidity and electrical conductivity changes significantly differed ($p \leq 0.05$) at all temperature regimes. Effective solar water

disinfection can be enhanced extensively through optimized flow rates, disinfection temperature, holding time and solar radiation intensity.

Key words: Temperature, holding time, flow rate, disinfection, logarithmic reduction, solar intensity, water quality.

6.0. Introduction

Access to adequate water is essential for drinking, food processing, sanitation and hygiene (Borde *et al*., 2016). Frequent cholera outbreaks in most rural and peri-urban settlements of Kenya are water related (Ssemakalu *et al.*, 2014). Heavy pollution of open surface water sources and limited water supply during drought have been implicated in incidences of water related diseases. Consequently, interventions such as rehydration therapy, the use of antibiotics, vaccination, the provision of chlorine tablets and hygiene sensitization drives have been used to mitigate water borne. The implementation of these interventions remains a challenge due to constraints associated with the cost, ease of use and technical knowhow (Somani and Ingole, 2011). These challenges can be reduced by Solar Water Disinfection (SODIS) (Ssemakalu *et al*., 2014). Other water disinfection methods such as boiling and chlorination have been implicated in deforestation and induced genotoxicity respectively (McGuigan *et al.*, 2012).

Disinfection of drinking water using solar energy is not a recent development but has been practiced in ancient cultures for centuries (Kean *et al*., 2014). Historical developments of solar water disinfection in the recent past has been reviewed (McGuigan *et al*., 2012). Solar water disinfection (SODIS) is one of the most practical and low-cost techniques to reduce the load of pathogenic microorganisms in water at households in low-income areas (Borde *et al*., 2016; Castro-Alferez *et al*., 2016).

Successful use of SODIS in projects in Uganda and Vietnam have led to the UN description of SODIS as a 'sustainable' and 'transferrable' technology (Kean *et al*., 2014). Some of the steps employed to increase effectiveness of SODIS as a procedure for drinking and food process water treatment include the use of reflective or black surfaces, shaking the bottle to increase dissolved oxygen and filtering prior to filling the bottle (McGuigan *et al*., 2012). However, batch SODIS systems are limited by the long time of six hours taken to fully disinfect the water, limited volume of water treated per batch and variation in disinfection time (Byrne *et al*., 2011; Kean *et al*., 2014; Borde *et al*., 2016).

SODIS in large vessels could be used as a simple method to meet water requirements in low income and disaster affected populations. However, some concerns associated with the conventional SODIS method are cold or cloudy weather; the fear of leaching in plastic bottles, water turbidity, and community acceptance.

Continuous solar water disinfection systems have been recommended as a solution to the limitations of the batch systems (Kean *et al*., 2014; McGuigan *et al*., 2012). Components of the continuous SODIS systems have been reviewed for improved disinfection effect (Malato *et al*., 2016).

Solar pasteurization has been used for water disinfection and in areas with high solar incidence (Onyango *et al*., 2009; Konersmann and Frank, 2011). A continuous-flow gravity-fed system with flat reflectors that used simple solar oven to heat incoming water to pasteurization temperature (70°C) in seven minutes was reported by Anthony *et al*. (2015). Similarly, a two log unit reduction in coliforms to complete disinfection was achieved using single pass continuous flow reactor in 20 minutes at 0.12 kgs^{-1} (Gill and Price, 2010). A 2 log reduction in *Escherichia coli* in a 50 liters continuous pilot scale flow reactor on grey water was reported by Pansonato *et al*. (2011). In another study, CPC reflector of 1.89 concentration factor in a continuous single pass flow reactor, produced a reduction in residence time required for disinfection and a higher volume of disinfected water (Polo-lopez *et al*., 2011). Hot water at 70 ˚C and a flow rate of 0.0475 kgs^{-1} was produced per square meter of flat reactor for every kWh incident radiation as reported by El-Ghetany and El-Seesy. (2005). Thermo siphon solar water heating system with a single flat plate solar collector produced hot water at 80 ˚C and 0.06 kgs^{-1} flow rate per square meter of the flat plate reactor for each kWh of incident solar energy (Bansal *et al*., 1988). El Ghetany and Dayem. (2012) reported a single 2.34 m^2 solar collector in a continuous solar water disinfection system operated at 0.0185 kgs^{-1} flow rate with an output of hot water at 60 ˚C. Flow rate and solar radiation intensity influence the temperature and volume of the disinfected water (El Ghetany and Dayem, 2012).

The effectiveness and efficiency of SODIS procedures are influenced by the solar radiation intensity, water turbidity and the effective disinfection area influenced by the type of reactor. Even though continuous SODIS systems have shown improvement from the conventional systems, there is need for further improvement and to establish the effectiveness under different environmental and operating conditions. In the present study the impact of holding time and solar radiation intensity against *coliforms, Escherichia coli, staphylococcus aureus*, water pH, color and turbidity were determined in Isiolo County using Isiolo river water. This study aimed at providing a basis for scaling up SODIS as alternative means for provision of potable water thereby enhancing public health standards in the rural set-up.

6.1. Materials and Methods

6.1.1. Study setting

The study was conducted in Isiolo County. The system was set-up at Ewaso Nyiro North Development Authority (ENNDA) premises in Isiolo town. Water used for experiments was sourced from Isiolo, a few kilometers from the research site. Laboratory analysis was done at the Department of Food Science, Nutrition and Technology, University of Nairobi.

6.1.2. Sample collection

Before sampling, all the laboratory apparatuses and polyethylene sampling bottles were pre-cleaned sanitized and sterilized as per APHA (2012).

The sterile sampling bottles were opened at the point of sampling to allow aseptic water sampling. Afterwards, the collected samples were stored in the cooler box at approximately 4 ˚C to minimize microbial activity in the water (APHA, 2012). During sampling, the polyethylene sample bottles were normalized with sampled water. Triplicate samples were collected and homogenized from each sampling station in order to obtain an average value for the analysis (APHA, 2012). Each bottle was labeled with its corresponding Code. The samples were then transported to the laboratory for analysis within 24 hrs of sampling owing to the long distance between sampling points and analysis station. Thirty trials were carried out between October and November 2017 using the system. About 1Lof raw water used in each of the trials was collected each day of the experiments and coded based on a composite sample prepared from the three weeks as R1, R2 and R3 to represent the weekly mean quality values.

6.1.3. Components of the designed solar water disinfection system

The system consisted of shell and tube heat exchanger, two flat collectors, Photovoltaic pumping system and two 500 ml water tanks.

6.1.3.1. Heat exchanger

Shell and tube heat exchanger was used. Modelled shell of 25 cm diameter and 28 inner tubes each 2 cm in diameter and length of 1m. Using the hot and cold side inlet temperatures and flow rates, the heat recovery efficiency was calculated as described by Dewitt and Incropera, 1996.

6.1.3.2. Flat solar collector

Two flat-plate solar collectors (model ST 230, Turkey), each having a gross area of 2.3 m^2 were used in both series and parallel arrangements of the experiments.

6.1.3.3. Pump

Solar panel (model YL125P-17b6/7, Davis and Shirtliff) power rating of 125 W and 17.9 V was used to drive a photovoltaic SHURflo Diaphragm Pump 3.5 GPM, 45 PSI pressure setting, 12 VDC voltage, Model 2088-443-144. The SHURflo pump was used for circulating the water through the system at different flow rates.

6.1.3.4. Water tanks

Two 500 l galvanized steel tanks painted on the inside surface to prevent corrosion (using an epoxy paint "Epilac") were fabricated and installed. Each was used for storage of raw and disinfected water.

6.1.3.5. Determination of solar radiation intensity

A thermopile pyranometer of type Kipp and Zonen (model CM5-774035), for measuring the instantaneous value of the total solar radiation intensity (IT) incident on the collector surface with an output voltage of 6.09 x 10^{-3} mV/Wm^{-2} for a resistance range of 10 Ohm. It was connected to a data logger that recorded the voltage and hence the corresponding solar radiation intensity.

6.1.3.6. Thermometers

Six digital temperature sensors were used to determine the temperature of raw water, hot water leaving collector one and two as well as temperature of the water at two entry and exit points of the shell and tube heat exchanger. An industrial mercury-in-glass thermometer was inserted in the disinfected water storage tank for measurement of water temperature (range: 0 -100 ˚C).

6.1.4. Analytical methods

6.1.4.1. Enumeration of *Escherichia coli*

Enumeration of *Escherichia coli* was done as described in ISO 16649-3. About 28.1 g of *Brilliance Escherichia coli*/coliform selective media was suspended in 1 litre of distilled water. The media was gently boiled to completely dissolve, then cooled to 45 ˚C, the molten media was then transferred to sterile plates. About 1ml of each serial dilution of 10^{-1} to 10^{-3} was transferred to spread plates aseptically in duplicates and the plates incubated at 37 ˚C for 24 hrs. Purple colonies on the selective media typical of *Escherichia coli* were enumerated.

6.1.4.2. Enumeration of coagulase positive *Staphylococcus aureus*

Colony counts of *Staphylococcus aureus* in water were enumerated as described by ISO 6888-2. About 28 g of Baired parker selective media was suspended in 1 litre of distilled water, the mixture was then autoclaved at 121 ˚C for 15 minutes, allowed to cool to 45 ˚C and 50 ml of egg yolk tellurite emulsion was added. About 1 ml of each serial dilution of 10^{-1} to 10^{-3} was transferred to spread plates aseptically in duplicates and the plates incubated at 37 ˚C for 24 hrs. Coagulase positive black colonies on the selective media typical of *Staphylococcus aureus* were enumerated.

6.1.4.3. Enumeration of *Clostridium pafrigens*

Colony counts of *Clostridium pafrigens* was done as per ISO 7937. About 38 g of differential reinforced clostridia media was suspended in 1L of distilled water, boiled to dissolve, autoclaved at 121 ˚C for 15 minutes and cooled to 45 ˚C. About 50 ml of egg yolk emulsion was added. About 1ml of each serial dilution of 10^{-1} to 10^{-3} was transferred to spread plates aseptically in duplicates and the plates incubated anaerobically at 44 ˚C for 48 hrs. At this temperature other Clostridia species are inhibited. The egg yolk was to induce lecithinace activity typical of *Clostridium pafrigens,* motile rod shaped black colonies developed on the selective media and were enumerated.

6.1.4.4. Determination of total coliforms

Total coliforms were determined as described in ISO 9308-1.About 28.1 g of *Brilliance* E. coli/coliform Selective media was suspended in 1 litre of distilled water. The media was gently boiled to completely dissolve, then cooled to 45 ˚C, the molten media was then transferred to sterile plates. About 1ml of each serial dilution of 10^{-1} to 10^{-3} was transferred to spread plates aseptically in duplicates and the plates incubated at 37 ˚C for 24 hrs. All typical pink colonies on the selective media were enumerated.

6.1.4.5. pH determination

pH was determined as per ISO 10523:2017. Water pH determination was done using HACH pH meter model E-08328 Crisson Instruments, South Africa. The pH meter was calibrated using buffers 4.01 followed by 7.01 and 10.01 at 25 ˚C, then the electrode probe rinsed with distilled water. 50 ml of each water sample was placed in a beaker, then stirred for 15 seconds on the titrator using magnetic stir bar. pH values were then read off without stirring. The probe was rinsed between each sample determination.

6.1.4.6. Turbidity determination

Turbidity of the water samples was determined as per IS0 7027: 2016, using Turbidi meter (HACH model 2100 Q01-2010- USA). About 5 ml of each water sample was placed in the Turbidity meter and the turbidity read out in NTU.

6.1.4.7. Determination of Color

Color of the water samples was determined as described by ISO 7887: (2011). Color values were recorded in True Color Units (TCU) units.

6.1.4.8. Determination of electrical conductivity

Electrical conductivity of the water samples was determined as per ASTM-D1125 (2014), standard test method for electrical conductivity and resistivity of water, using H1 9033 Multi range conductivity meter (USA). Electrical conductivity was reported in µS/cm.

6.1.4.9. Data analysis

Analysis of variance (ANOVA) at 5 % level of significance to compare means of the logarithmic reduction in microbial counts in the disinfected water samples using statistical analysis software (SAS) version 9.0. Least significant difference (Lsd) was used to separate the means. Significant differences was indicated by letters.

Pearson correlation was used to establish the relationship among the quality aspects of the sampled disinfected and raw water at 5 % and 1 % levels of significance.

6.2. Results

6.2.1. Raw water quality

Each day of the experiment water samples were taken from the new batch loaded into the raw water reserve tank. The quality of Isiolo river water sampled on different days of the experiments is shown in Table 6.1.

Table 6.1: Raw water quality

Characteristic	R1	R2	R3	MEAN	L.S.D	cv%
PH	7.15±0.7a	7.55±0.7b	7.38±0.35b	7.36	0.19	0.8
Color (TCU)	10.00±.14a	9.25±0.21a	13.3±1.56b	10.85	2.8	8.4
Turbidity (NTU)	399.4±1.56a	453.5±4.67b	385±6.65a	412.6	15.9	1.2
EC (µS/cm)	286.5±1.91b	310.9±1.70c	250.9±1.9a	282.8	5.86	0.7
E. coli (Cfu/ml)	32.5±3.54a	89.0±5.66b	260.0±14.14c	127.2	2.73	7.1
Coliforms (Cfu/ml)	3350±70.71b	920±14.14a	905±7.07a	1725	33.1	2.4
Total counts(Cfu/ml)	9250±353.6b	2350±212a	12650±70.71c	8083	78.6	3.0
Staphylococcus (Cfu/ml)	90.0±4.24b	36±5.66a	47.5±3.54a	57.8	4.53	7.9

1. Values are means of two determinations ± standard deviations.
2. Values with the same letters on the same row are not significantly different at 5% level of significance.

The three water samples were analyzed for *Clostridium pafrigens* and all tested negative. From the preliminary analysis of the raw water, it was not therefore necessary to determine the disinfection effect on *Clostridium pafrigens*. Electrical conductivity significantly differed ($p \leq 0.05$) across the three raw water samples. Electrical conductivity depends on the dissolved minerals which change with prevailing environmental conditions that influence the ionic concentration in the river bed (Begum *et al*., 2009; Reza and Singh 2010). The pH, color, and electrical conductivity were within the acceptable limits of 6.5 -9.5, < 50 TCU and 2500 µS/cm respectively (WHO, 2014; KS EAS 12, 2014).Turbidity had a significant positive relationship to electrical conductivity ($r = 0.9$). The water flow through the surface of the river bed contain suspended soil particles washed off from agricultural farms on the slopes of Mount Kenya, the source to river Isiolo (Ashraf *et al*., 2011; Bada *et al*., 2017; Ferreira *et al*., 2017). *Escherichia coli*, coliforms, *Staphylococcus aureus* and total aerobic counts in the water were satisfactory for the experiments and as well pointed the extent of pollution of river Isiolo water at the point of sampling (Oludairo *et al*., 2015, Muhammad *et al*., 2017).The physico-chemical characteristics had no significant association to the microbiological characteristics.

6.2.2. Change in solar radiation intensity with time of the day

The intensity of the solar radiation varied from day to day depending on the prevailing weather conditions. Figure 6.1 shows the change in solar radiation intensity at different times of the day recorded on different days of the experiments. The intensity of the solar radiation assumed a polynomial increase from around 0900 hrs to peak at 1300 hrs beyond which the solar radiation exhibits a logarithmic decline. The intensity of the solar radiation on day 2 of the experiments was moderately lower than on day 1 due to the greater cloud cover most of the day. Solar radiation intensity is significantly (r =0.87, 0.78 and 0.64) influenced by time of the day and prevailing weather condition (Zell *et al*., 2015).

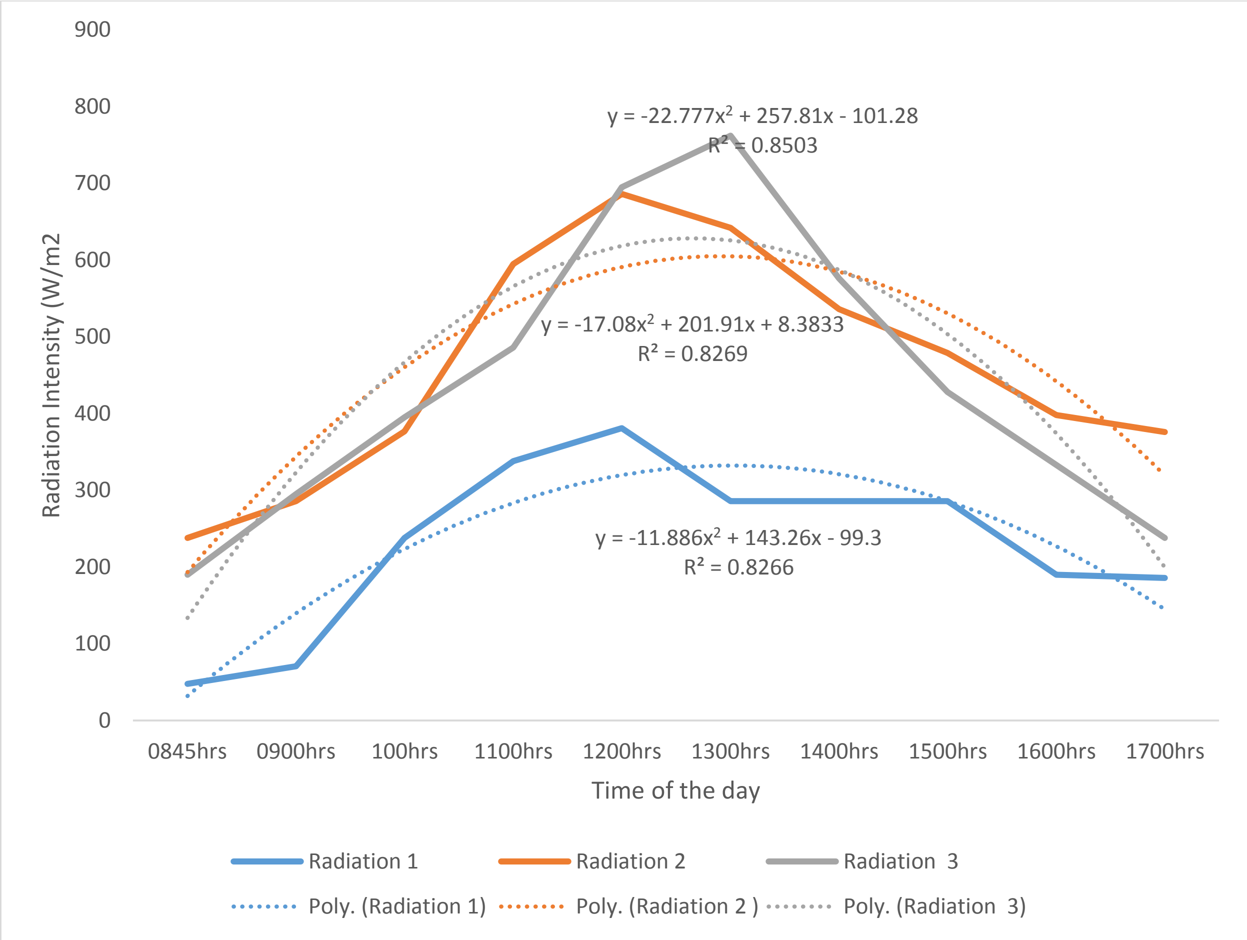

Figure 6.1: Change in solar Radiation with time of the day

6.2.3. Change in heated water temperature with time of the day

The change in solar radiation intensity with time of the day influences the quantity of heat absorbed by the flat plate collector. The absorbed energy is transferred to the circulated water causing a corresponding change in the water temperature. The changes in temperature with time of the day for the three experimental set-ups are shown in Table 6.2.

Table 6.2: Mean hot water temperature (˚C) at different times of 5 day trials

Time (hrs)	Series arrangement (no heat exchanger) (˚C)	Parallel arrangement (no heat exchanger) (˚C)	Series arrangement (heat exchanger)(˚C)
0800 h	38.3±0.99a	30.4±0.85a	37.1±0.28a
0900 h	43.3±0.96a	38.45±0.78b	45.8±1.69b
1000 h	51.2±1.13b	46.8±0.28de	57.25±1.77c
1100 h	60.6±0.85cd	47.85±0.21de	65.65±0.91d
1200 h	62.65±0.45d	49.2±0.28e	68.65±0.49de
1300 h	63.3±0.57d	49.65±0.92e	71.8±0.28e
1400 h	64.75±1.06d	47.8d±1.13e	70.9±1.27e
1500 h	61.45±2.05d	45.15±1.62cd	68.1±1.56de
1600 h	55.05b±2.33c	42.2±0.57c	58.65±0.49c
1700 h	40.1±0.71a	34.95±0.35b	39.05±1.06a
Mean	**54.07±9.98**	**43.25±6.46**	**58.29±12.9**
cv %	**2.3**	**1.9**	**2.75**
L.S.D	**2.801**	**1.83**	**2.508**

1. Values are means of two determinations ± standard deviations.
2. Values with the same letters on the same column are not significantly different at 5% level of significance.

Water temperatures for the three experimental set-ups gradually increased from 0800 hrs at the onset of the experiments to a peak between 1100 h to 1500 h after which the temperature decreases to almost the temperature in the reserve water tank towards sunset at 1700 h.

Series arrangement of the flat plate solar thermal collectors coupled by a shell and tube heat exchanger produced water at more elevated temperatures than both parallel and series arrangement without the heat exchanger.

6.2.4. Mean microbial log reduction for parallel solar collector's disinfection system

The two flat-plate solar collectors were connected in parallel and the water circulated at a flow rate of 0.018 kgs^{-1} without using heat exchanger. Table 6.3 shows the effectiveness of the water disinfection process.

Table 6.3: Reduction in Coliforms, E.coli, S.aureus and TPC for parallel solar disinfection system

Time of Day	Coliforms	*E.coli*	*S.aureus*	Total plate counts
1000 h	1.84±0.085bcd	1.92±0.021c	0.0±0.0a	2.15±0.21b
1100 h	1.78±0.25bcd	1.9±0.071c	0.15±0.21a	3.29±0.078d
1200 h	2.02±0.03cd	2.17±0.01d	1.1±0.021b	3.46±0.042d
1300 h	2.12±0.113d	2.19±0.021d	1.09±0.12b	3.50±0.05d
1400 h	1.45±0.21bc	2.0±0.21cd	0.45±0.64a	2.73±0.18c
1500 h	1.39±0.55b	1.65±0.064b	0.0±0.0a	2.39±0.13b
Mean	**1.513±0.72**	**1.687±0.74**	**0.397±0.52**	**2.5±1.18**
cv %	**16.4**	**5.3**	**4.9**	**4.8**
L.S.D.	**0.059**	**0.21**	**0.061**	**0.28**

1. Values are means of two determinations ± standard deviations.
2. Values with the same letters on the same column are not significantly different at 5% level of significance.

The log mean reduction in *coliforms*, *Escherichia coli*, and *Staphylococcus aureus* and total plate counts in the water significantly differed ($p \leq 0.05$) across different times of the day. However, between 1100 h and 1300 h the mean log reduction in the microbial load in the water were insignificantly different. *Staphylococcus aureus* was not inactivated at 1000 h and 1500 h when the temperatures were below 48 ˚C (Table 6.2). Complete disinfection of the raw water was not achieved with this arrangement owing to higher contamination of the raw water shown in Table 6.1. This system produced the low temperatures shown in Table 6.2 consequently low log reductions in microbial.

6.2.5. Water disinfection effectiveness of series arrangement with heat exchanger

The two flat-plate solar collectors were installed in series coupled with the use of the shell and tube heat exchanger for heat recovery and water circulated at constant flow rate of 0.18 kgs^{-1} between 0900 h and 1600 h. Table 6.4 shows the log reduction in microbial load in the test water.

Table 6.4: Logarithmic disinfection using series arrangement and Shell and tube heat exchanger

Time of day	*Escherichia coli*	*Coliforms*	*Staphylococcus*	*Total plate counts*
1000 h	2.295±0.01c	3.505±0.01b	1.485±0.01b	3.95±0.014b
1100 h	2.385±0.01d	3.510±0.014b	1.6±0.0c	3.975±0.01c
1200 h	2.4±0.0e	3.53±0.0d	1.6±0.0c	3.97±0.0c
1300 h	2.4±0.0e	3.53±0.0d	1.6±0.0c	3.98±0.0c
1400 h	2.4±0.0e	3.53±0.0cd	1.6±0.0c	3.98±0.0c
1500 h	2.4±0.0e	3.53±0.0cd	1.6±0.0c	3.965±0.01c
1600 h	2.285±0.01b	3.515±0.01bc	1.46±0.04b	3.97±0.0c
Mean	**2.071±0.81**	**3.08±1.2**	**1.368±0.54**	**3.4737±1.36**
cv%	**0.2**	**0.2**	**1.1**	**0.2**
L.S.D	**0.01**	**0.0142**	**0.03507**	**0.01412**

1. Values are means of two determinations ± standard deviations.
2. Values with the same letters on the same column are not significantly different at 5% level of significance.

The logarithmic reduction in microbial load did not differ significantly ($p \leq 0.05$) with the time of the day. Complete disinfection was achieved between 1200 h and 1400 h. The mean log reduction for coliforms, *Escherichia coli*, *Staphylococcus aureus* and total plate counts were 3.08, 2.071, 1.368 and 3.474 respectively when the temperatures were about 70 ˚C. Despite the difference in temperatures in the course of the day, the disinfection effect did not differ significantly ($p \leq 0.05$) for most parts of the day.

Logarithmic microbial disinfection had a significant positive relationship ($p \leq 0.05$) with the outlet water temperature; r = 0.799, 0.827, 0.848 and 0.798 for *coliforms*, *Escherichia coli*, *Staphylococcus aureus* and total plate counts respectively.

6.2.6. Effect of flow rate on hot water temperature

The experiment was carried out between 1100 h and 1400 h when the average solar radiation was 800 – 1100 Wm^{-2} using series arrangement of the two flat-plate solar collectors without using the shell and tube heat exchanger. The flow rates were varied as shown in Figure 6.2.

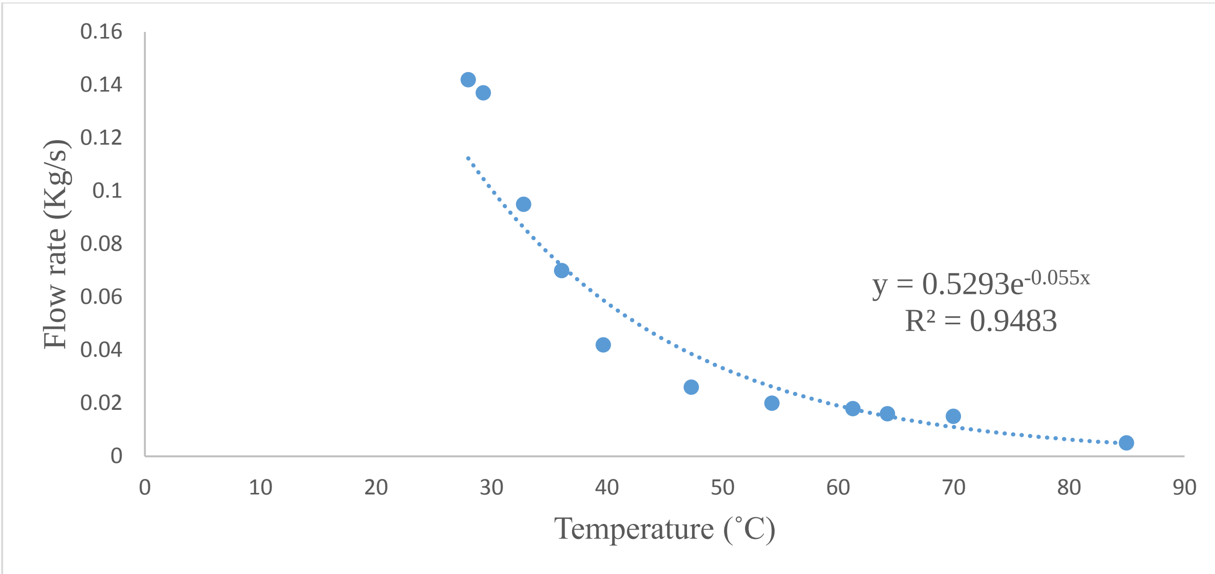

Figure 6.2: Effect of flow rate on hot water temperature

The change in solar radiation intensity between 1100 h to 1400 h was insignificant (Figure 6.1). Flow rate and temperature of the disinfected water exhibited an exponential relationship ($y = 0.5293e^{-0.055x}$). Flow rate significantly influenced the temperature of the disinfected water ($r = 0.9738$).

Disinfection temperature was attained at flow rates below 0.02 kgs^{-1}. At flow rate of 0.142 kgs^{-1} the water temperature did not increase. Higher temperature was attained at a flow rate of less than 0.005kgs^{-1} though exhibiting pulsating flow.

6.2.7. Effect of holding time on coliforms

Holding time was investigated between 1000 h and 1300 h and a constant flow rate of 0.02kgs^{-1} by varying the length of the water pipe connecting the last collector in a series arrangement and the disinfected water tank. Table 6.5 shows the effect of holding time on the reduction of coliforms.

Temperature and log reduction in coliforms insignificantly differed ($p \leq 0.05$) at different holding times. However, the holding time resulted into temperature drop as heat is lost by the disinfected water along the holding pipe.

Table 6.5: Effect of holding time on hot water temperature and mean coliform log reduction

Time of day (hrs)	Holding time (minutes)	Temperature (˚C)	Log coliform reduction
1100hrs	6	56.2±2.26a	3.415±0.01a
1200hrs	2	58.3±4.24a	3.435±0.01a
1230hrs	1	62.85±1.06a	3.44±0.0a
1300hrs	5	57.6±0.99a	3.435±0.01a
Mean		**58.78±3.2711**	**3.4313±0.011**
cv %		**4.3**	**0.2**
L.S.D		**6.972**	**0.017**

1. Values are means of two determinations ± standard deviations.
2. Values with the same letters on the same column are not significantly different at 5% level of significance.

6.2.8. Variation of change in hot water temperature with change in solar radiation intensity

This experiment was carried out at constant flow rate of 0.015 kgs^{-1} between 0800 h and 1300 h. Average temperatures of the water flowing from the tank to the collector, the water flowing from collector one to collector two and the disinfected water leaving collector two for the disinfected water tank were recorded against the solar radiation intensity at various times. Figure 6.3 shows the log change in temperatures with log change in solar radiation intensity.

The log change in temperatures of the water leaving the two flat-plate solar collectors are equal at 2.125 log change in solar radiation intensity. At higher solar radiation intensity experienced between 1100 h to 1300 h the log change in solar radiation stabilizes and the log change in temperature at collector one and two exhibit insignificant differences. The overall log change in temperature of the raw water after disinfection also exhibits a constant change at higher log changes in solar radiation intensity at greater than 2.55.

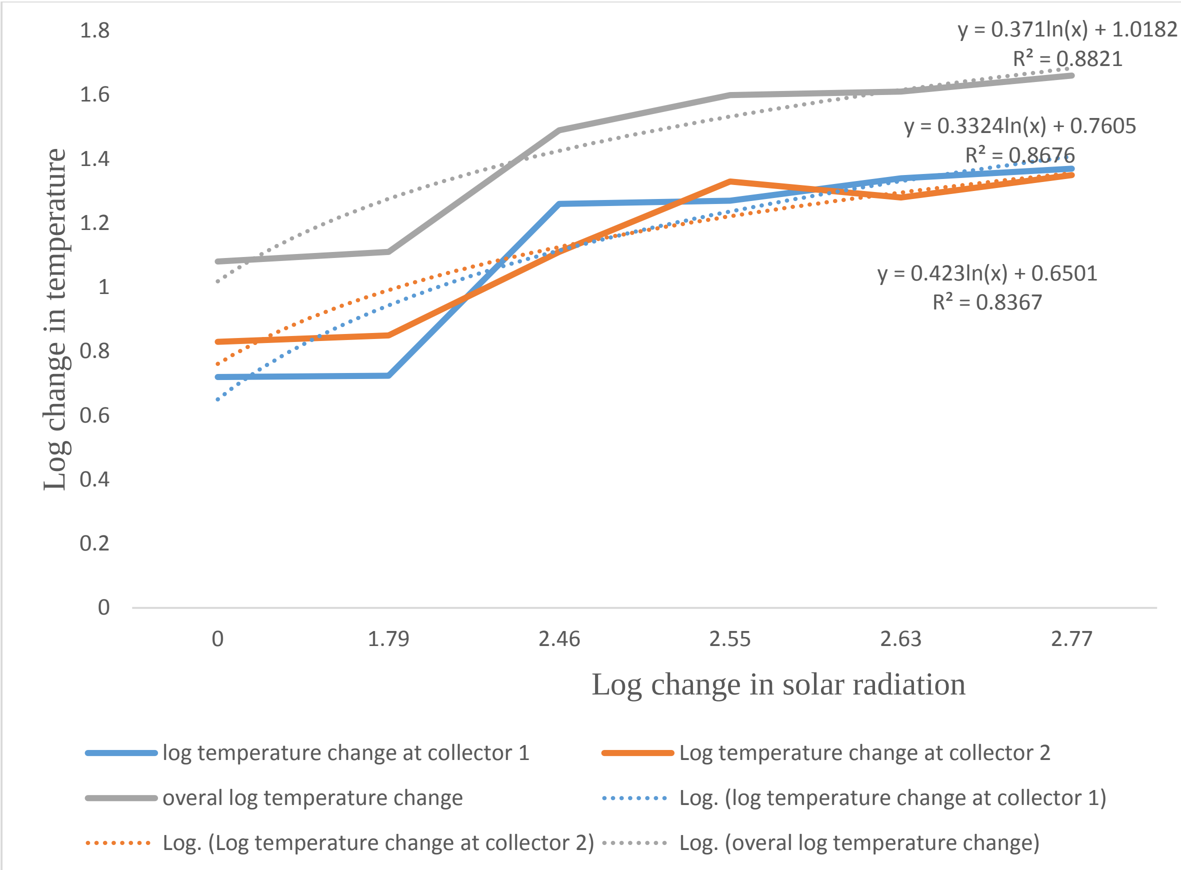

Figure 6.3: Log change in temperatures vs. log change in solar radiation

6.2.9. Effect of disinfection temperature on physico-chemical characteristics

This experiment was carried out at constant flow rate of 0.015 kgs^{-1} between 0900 h and 1530 h. Effects of disinfection temperature on pH, electrical conductivity, turbidity and color are shown in Table 6.6. Temperature significantly changed with time of the day. pH Significantly ($P \leq 0.05$) changed at temperature above 70 ˚C. Significant difference ($p \leq 0.05$) in color occurred at temperatures below 60 ˚C, at 60 - 70 ˚C, and above 70 ˚C, similar trend was exhibited by the turbidity and electrical conductivity of the disinfected water.

Table 6.6: Effect of disinfection temperature on physico-chemical characteristics of disinfected water

Time	Temperature (˚C)	pH	Color (TCU)	Turbidity (NTU)	Electrical conductivity (μS/cm)
0915 h	43.65±0.49a	7.32±0.028b	10.88±0.035c	374.5±2.61a	287.3±2.4c
1030 h	57.25±1.77b	7.3±0.01b	10.83±0.042c	368.0±0.57a	279.3±0.57bc
1115 h	65.65±0.92c	7.25±0.07b	9.72±0.17b	382.2±1.06b	278.6±3.32b
1230 h	68.65±0.49de	7.29±0.01b	9.45±0.35b	387.9±2.19bc	253.5±4.71a
1330 h	71.8±0.28f	7.14±0.05a	8.14±0.02a	395.5±2.69d	248.5±1.61a
1430 h	70.9±1.27ef	7.14±0.03a	8.9±0.57ab	390.2±1.13cd	254.4±4.17a
1500 h	68.1±1.56cd	7.31±0.01b	9.4±0.99b	372.8±6.64a	279.5±4.38bc
Mean	**63.71±9.71**	**7.25±0.08**	**9.62±1.01**	**381.59±10.01**	**268.74±15.47**
cv%	**1.7**	**0.5**	**4.7**	**0.8**	**7.92**
L.S.D	**2.618**	**0.08642**	**1.079**	**7.25**	**1.2**

1. Values are means of two determinations ± standard deviations.
2. Values with the same letters on the same column are not significantly different at 5% level of significance.

6.2.10. Effect of solar radiation intensity on flow rate

The solar radiation intensity reaching the earth surface influences the quantity of energy absorbed and transduced to electrical energy by the photovoltaic pumping system. The quantity of energy absorbed and transduced directly correlates to the pumping efficiency determined by maximum flow rates when all valves are fully opened. Figure 6.4 shows the flow rate output of the photovoltaic pumping system at different solar intensity recorded at different times of the day.

The polynomial positive relationship between solar radiation intensity and flow rate was significant (r = 0.985). As the solar intensity increased the pump power increased resulting into a significant increase in volume of disinfected water.

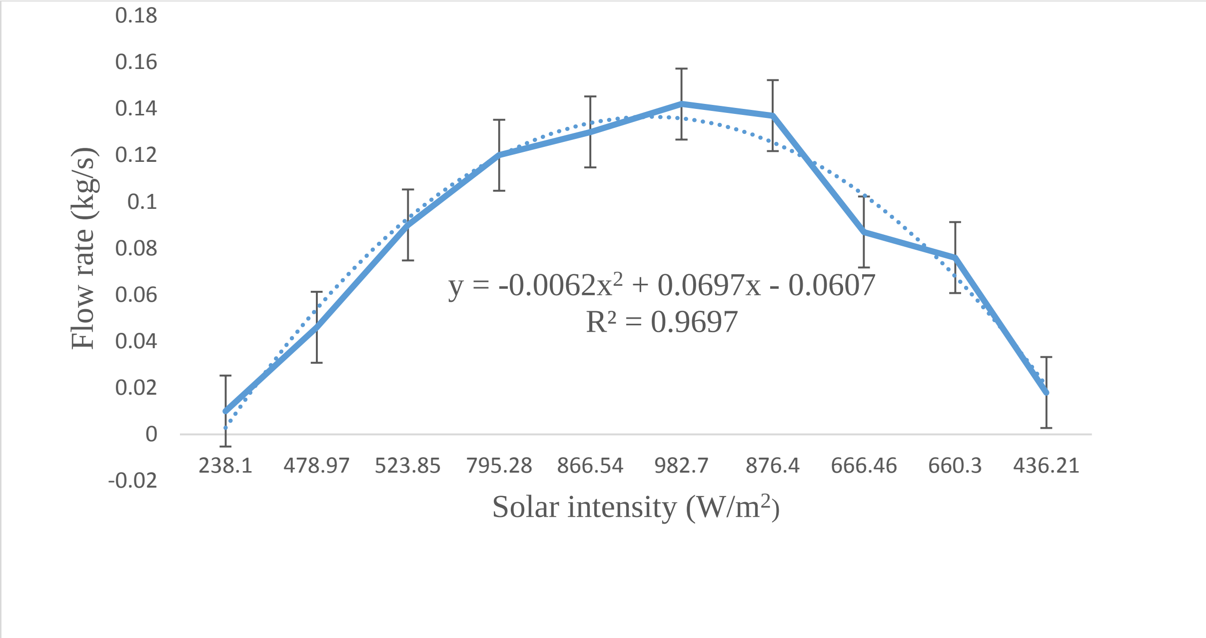

Figure 6.4: Change in flow rate with change in solar radiation intensity

6.3. Discussion

6.3.1. Quality of river water used

Electrical conductivity of river water depends on the dissolved minerals which change with prevailing environmental conditions that influence the ionic concentration in the river bed (Begum *et al*., 2009; Reza and Singh 2010). The pH, color, and electrical conductivity were within the acceptable limits of 6.5 -9.5, < 50 TCU and 2500 µS/cm respectively (WHO, 2014; KS EAS 12, 2014). River Isiolo flows through the river bed surface containing suspended soil particles washed off from agricultural farms on the slopes of Mount Kenya. The suspended and silted soil particles increase the turbidity of the water (Ashraf *et al*., 2011; Bada *et al*., 2017; Ferreira *et al*., 2017).

Escherichia coli, coliforms, *Staphylococcus aureus* and total aerobic counts in the water were satisfactory for the experiments and as well indicated the extent of pollution of River Isiolo water at the point of sampling (Oludairo *et al*., 2015; Muhammad *et al*., 2017).

Contamination of River Isiolo water by coliforms, aerobic plate counts, *Staphylococcus aureus* and *Escherichia coli* exceeded zero colony forming units per milliliter recommended for standard drinking water as reported by Mahananda *et al*. (2010) and Manhokwe *et al*. (2013), Hence the need for appropriate water disinfection methods.

6.3.2. Effect of time of the day on solar radiation intensity

The solar radiation incident on the Earth surface is divided into two parts; the first part used to generate electricity in the photovoltaic cell while the second part used to raise its temperature (Chaichan and Kazem, 2015; Chaichan and Kazem, 2016). The sun emits 1360Wm^{-2} of solar radiation out which 1120 Wm^{-2} reaches the earth surface (McGuigan *et al*., 2012). As the weather conditions of the day keeps on changing the solar intensity detected by the pyranometer also change as influenced by light reflectivity on the cell surface, the angle at which the solar radiation is falling on the pyranometer cell (Jeng *et al*., 2009; Makrides *et al*., 2009; Chaichan and Kazem, 2016). Wavelengths of the sunrays falling on the earth surface vary (Chow, 2010; Chakraborty et al., 2014). Similar trend was reported by Chaichan and Kazem. (2016), in their experiments based in Oman the solar intensity rose from about 200 Wm^{-2} at 7.00am to 800 Wm^{-2} peak at 1.00 pm beyond which the intensity declined to about 100 Wm^{-2} at 7.00 pm in summer. In winter the solar radiation hours were reduced to 9 hours with the highest insolation of 500 Wm^{-2}. The ambient temperatures in Oman are as higher as 50 ˚C (Chaichan Kazem, 2016), and the average ambient temperatures in Isiolo Kenya is about 37 ˚C with lower solar radiation intensity.

As at the time of the experiments there was a lot of cloud cover following the light showers experienced in October 2017 in Isiolo. Consequently, solar radiation intensity was low on some days. On other days when the clouds were clear, the solar intensity rose to 800 Wm^{-2} at 1.00 pm.

The variation in solar intensity was significant (r = 0.64) indicating the effect of weather conditions on absorption of solar radiation by the earth surface (Zell *et al*., 2015).

6.3.3. Temperature of disinfected water at different times of the day

As the intensity of the solar radiation changes with time of the day the quantity of heat absorbed also changes (Chaichan and Kazem, 2016). The flat-plate solar collector absorbs most of the solar radiation incident on the collector surface raising its temperature and transfers the heat to the circulating water (McGuigan *et al.,* 2012). Similar reports by El Ghetany and Dayem. (2010) showed that the temperature of disinfected water changed with time of the day. Desirable pasteurization temperature of 60 ˚C was attained at 1000 h (Pejack, 2011; Birzer *et al*., 2014). From this experiment it was observed that the effective pasteurization temperature could only be attained between 1000 h and 1600 h for series arrangement of collectors with and without the shell and tube heat exchanger (El Ghetany and Dayem, 2010). The temperatures of the parallel arrangement could not reach pasteurization temperatures of greater than 55 ˚C (Ciochetti and Metcalf, 1984; Safapour and Metcalf; 1999; El Ghetany and Dayem, 2012; Birzer *et al*., 2014). Despite the temperatures attained by the parallel arrangement of the two collectors in the present study being low between 1000 h and 16 h the temperatures were greater than 45˚C and were therefore sufficient to effect disinfection (Wegelin *et al*., 1994; McGuigan *et al*., 1998; Konersmann and Frank, 2011; McGuigan *et al*., 2012; Birzer *et al*., 2014). Recirculation of the water in the parallel system is therefore necessary to enhance the temperatures (El Ghetany and Dayem, 2010).

Alternatively, the parallel arrangement system could be fitted with control units with thermostats and valves such that the water leaves the collectors at the set disinfection temperature (El Ghetany and Dayem, 2010; Pejack, 2011; Birzer *et al.*, 2014).

6.3.4. Disinfection of water in parallel arrangement of solar collectors

The log reduction of coliforms, staphylococcus aureus, Escherichia coli and total viable counts did not differ significantly at 1000 h, 1100 h and 1500 h. At times the disinfection temperatures were just about 45 ˚C, the disinfection induction temperature (Wegelin *et al*., 1994; McGuigan *et al*., 1998; Konersmann and Frank, 2011; McGuigan et al., 2012; Birzer *et al*., 2014). Consequently, the log reduction in coliforms, *Staphylococcus aureus, Escherichia coli* and total viable counts were lower than would be expected at higher temperatures. At 1300 h the temperatures of the water leaving the system were at about 50 ˚C, causing better pasteurization disinfection effect (Ciochetti and Metcalf, 1984; Safapour and Metcalf; 1999; El Ghetany and Dayem, 2012; Birzer *et al*., 2014). The best germicidal effect is achieved between 1200 h and 1400 h (Vivar *et al*., 2015). For the parallel arrangement no water samples were collected for analysis before 1000hrs and after 1500hrs since the water temperatures were below 40˚C, the water disinfection induction temperature (Vivar *et al*., 2015).

Staphylococcus aureus was not destroyed at temperatures below 48 ˚C thus requiring longer residence time at low temperatures to induce disinfection. To achieve better disinfection effect, the temperature, holding time, flow rate and initial load combination have to be optimized for synergistic effect.

6.3.5. Reduction in micro-organisms in series solar collector's arrangement with heat exchanger

Water samples for this arrangement were collected between 1000 h and 1600 h where the temperatures were above 50 ˚C. Before and after the time range considered in this study, the temperatures were lower than 45 ˚C considered as disinfection induction temperature (Wegelin et al., 1994; McGuigan *et al*., 1998; Konersmann and Frank, 2011; McGuigan *et al*., 2012; Birzer *et* *al*., 2014). Complete disinfection *of Escherichia coli* and *Staphylococcus aureus* was achieved at temperatures exceeding 65 ˚C. Similar reports indicate that pathogenic micro-organisms are disinfected at temperatures exceeding 60 ˚C (Birzer *et al*., 2014). Greater than 2 Log reduction in Escherichia coli was produced by the system as similarly reported in other studies (Gill and Price, 2010; Pansonato *et al*., 2011).

Complete disinfection of coliforms was realized between 1200 h and 1400 h when the temperatures were at about 70 ˚C. This disinfection temperature and solar radiation of 700 Wm^{-2} has been reported by Anthony *et al*. (2015) though with low flow rate of 0.0025 kgs^{-1} using solar oven box. The log reduction in coliforms was less than 4 reported by Caslake *et al*., (2004) and greater than 2 reported by Ubomba-Jaswa *et al*. (2010) and Gill and Price. (2010). The final coliforms count during disinfection depends on the initial load in the raw water.

Total viable count is not a common indicator of disinfection effectiveness in most studies since it contains a group of microorganisms with different disinfection dynamics. Complete elimination of total viable counts was not achievable even at temperatures of 70 ˚C. Effectiveness of disinfection is a function of microbial load in the raw water as well as the disinfection temperature.

6.3.6. Effect of flow rates on temperature of disinfected water

The experiment was carried out between 1100 h and 1400 h when the average solar radiation intensity was 800 Wm^{-2}, considered as the best disinfection times based on results in Table 2, 3 and 4. In other studies, SODIS was investigated at 500 -1150 Wm^{-2} (Felix *et al*., 2009). In the present study, temperature of disinfected water is a significant exponential function of disinfected water flow rate (r = 0.9738). The quantity of accumulated disinfected water is higher at higher flow rates, though at lower temperatures (El Ghetany and Dayem, 2010). A continuous gravity fed SODIS system achieved a temperature of 70 ˚C at 0.0025 kgs^{-1} (Anthony *et al*., 2015). In the current study the highest temperature of 85 ˚C at a flow rate of 0.005 kgs^{-1} was realized using series solar water disinfection system.

6.3.7. Effect of holding time on coliforms disinfection

Coliforms are more susceptible to disinfection temperatures and are thus used as indicators in the experiments (Felix *et al*., 2009; Gill and McLoughlin, 2007). The log reduction in coliforms insignificantly differed ($p \leq 0.05$) at different holding times. The holding time depended on the length of the pipe through which the disinfected water flows after exiting the reactor. Further the water exited the system at a temperature of about 60 ˚C, adequate for complete disinfection of coliforms (Felix *et al*., 2009; El Ghetany and Dayem, 2012; Gill and price, 2010, Pansonato *et al*., 2011; Birzer *et al*., 2014).

The temperature of the disinfected water as it exited the holding pipe insignificantly differed ($p \leq 0.05$). As the length of the holding pipe increased, the surface area exposure for energy loss to the environment increased, the result was the drop in temperature of disinfected water with increase in holding time. Significant effect of holding time is influenced by changes in flow rates (Khaled *et al*., 2008; El Ghetany and Dayem, 2010; Anthony *et al*., 2015).

6.3.8. Effect of solar radiation intensity on temperature of disinfected water

The two flat-plate solar collectors absorbed equal amount of energy and consequently the rise in temperature of water flowing out of them were insignificantly different ($r = 0.9147$). Log change in temperature was a function of log change solar radiation intensity. Solar radiation intensity increased with the time of the day consequently the energy absorbed by the flat plate solar collectors increased with the time of the day resulting in increase in temperature of disinfected water (Jeng *et al*., 2009; Makrides *et al*., 2009; Chaichan and Kazem, 2016). Despite the change in temperature of disinfected water with change in solar radiation intensity, insignificant changes in temperature of disinfected water occurred at log change in solar radiation intensity greater than 2.55.

6.3.9. Effect of disinfection temperature on Physico-chemical characteristics of water

Significant differences in pH and color of the disinfected water occurred at 1200 hrs and 1300 hrs when higher temperatures of 70 ˚C were attained. Generally, insignificant changes occur in the physico-chemical characteristics of the water during disinfection (Felix *et al*., 2009). The turbidity of the water increases during disinfection resulting from debris of microbial cells destroyed in the disinfected water (Felix *et al*., 2009). However, as temperatures of the water tends to 70 ˚C the turbidity reduces. The higher temperatures induce vaporization in the collectors, consequently some of the dissolved solids in the water are deposited in the collector tubes lowering the turbidity of water. Synergistic desalination and disinfection occurs at higher temperatures. The desalination of water occurs as temperature of disinfection increase with time of the day. Most of the dissolved minerals remains in the solar collector's tubes as the water vaporizes. Dissolved minerals influence the electrical conductivity in water (Begum *et al*., 2009; Reza and Singh 2010). Despite the changes, the physico-chemical characteristics were within the acceptable limits (WHO, 2014; KS EAS 12, 2014).

6.3.10. Effect of solar radiation intensity on flow rate

The intensity of solar radiation rises from as low as 48 Wm^{-2} (McGuigan *et al*., 2006) to peak of 800 Wm^{-2} -1120 Wm^{-2} (Felix *et al*., 2009; Chaichan and Kazem, 2016) at noon. The peak of solar radiation intensity is attained at 1300 h corresponding to highest flow rate when the pump valve is fully opened. The flow rate is a significant positive polynomial function of the solar radiation intensity (r = 0.9847). Similar reports indicate significant positive relationship between solar radiation intensity and flow rate (El Ghetany and Dayem, 2010). Increase in solar intensity increases the power input to the pump and hence increases the flow rate. Photovoltaic pumping system attained 63.11 % efficiency at 982.7 Wm^{-2}.

6.4. Conclusion

There exists a significant logarithmic relationship between the solar radiation intensity and time of the day. Solar radiation intensity in Isiolo is sufficient to facilitate water disinfection.

Parallel arrangement of the flat-plate solar collectors is only effective at noon when the solar radiation intensity is at its peak. On the contrary, series arrangement of the flat plat thermal solar collectors coupled with shell and tube heat exchanger achieves better results of enhanced temperatures as well as disinfection effect.

Solar radiation intensity is a polynomial function of flow rate. Similarly, the output flow rate resultant from the conversion of solar energy reaching the earth surface by the photovoltaic pumping system exhibits a significant exponential relationship with the disinfection temperature. It's therefore established that effective solar water disinfection can be enhanced extensively through optimized flow rates, disinfection temperature, holding time and solar radiation intensity.

CHAPTER SEVEN

General Conclusions and Recommendations

7.1. Conclusions

Isiolo County has diverse surface and ground water sources. The utilization of these water sources depends on seasons and location. Spring water is mainly used in Leparua areas of Burat location. Borehole and shallow well water are predominantly utilized in Ngare Mara location. Urban Treated water from Isiolo Water and Sewerage Company (IWASCO) is only the population residing in Wabera location. The water sources are located at a distance of greater than 1 km that compromises the accessibility by the users. Boiling is the main water disinfection technique employed by the residents of Isiolo. However, water guard tablets are occasionally distributed by the public health to the households for water disinfection. Solar water disinfection technique is not common among the residents of Isiolo County, but, solar energy is used for powering boreholes as well as drying of meat among other food products. Water and food borne prevalence is high in Isiolo. There is thus need to improve potable water supply in Isiolo County through cost effective water disinfection techniques.

Carbonate hardness, alkalinity, pH and turbidity and color of ground and surface water sources in Isiolo exceeded the recommended WHO maximum limits for potable water. These, water sources are thus unsuitable for direct use in food processing and drinking. Point of use desalination and treatment is necessary.

Ground and surface water sources in Isiolo are contaminated with Clostridium pafrigens, Coliforms, Staphylococcus aureus, Escherichia coli and total plate counts to levels regarded as unsafe by WHO guidelines for potable water. To enhance the safety of processed products and drinking water, point of use disinfection of these water sources is necessary.

Solar radiation intensity in Isiolo is in the range 48 -1120 Wm^{-2} with the peak at 1300 h in September and October and is sufficient to facilitate solar water disinfection. Series arrangement of the flat plate solar collectors coupled with shell and tube heat exchange achieves better results of enhanced temperatures as well as disinfection effect. Complete solar water disinfection is achieved a flow rate of 0.02 kgs^{-1}, 70 ˚C and solar radiation intensity of about 700 Wm^{-2}.

The flow rate of water delivered by a solar photovoltaic pump increases with increase in the solar radiation intensity and follows a polynomial function. The system in this study works better at lower flow rates of less than 0.01 kgs^{-1} and temperatures above 60 ˚C when the radiation intensity average is about 700 Wm^{-2}. This is only attainable between 1100 h and 1400 h.

Solar water disinfection has a potential to eliminate all pathogenic and coliforms as well hygiene indicator organism with enhanced flow rates, holding time and disinfection temperatures. This thereby minimizes the reliance on alternative disinfection methods such as boiling and chlorination that are costly.

7.2. Recommendations

Boiling is the most preferred water disinfection of majority of the population, however, this impacts negatively on the environment as trees are cut down for firewood. There is need for alternative energy sources. The ministry of energy and the county government should fast tract the rural electrification program to reach each household and facilitate the water disinfection operations.

Chlorination as a water disinfection method is only adopted by 21.7 % of the population. This is attributed to the low level of literacy among the population and thus lack of technical skills in application. The County government and community based organizations should thus enact policies to promote education and create awareness on water treatment. Technical trainings and follow up activities on the use of chlorine and chlorine compounds for water treatment to be routinely carried out by the Public health.

Young children aged below ten years are the most adversely affected group. This is attributed to high levels of microbiological contaminations of most of the surface water sources and the treated IWASCO water supply is limited to the urban residence. To achieve Sustainable Development goal 6, the National government in collaboration with the County government and Non-governmental organization should allocate resources geared towards construction of water treatment plants for potable water accessibility in all villages.

Use of traditional herbs is a dying technology that can be revived to suit use in water treatment in most rural areas in Isiolo County. Moringa among other medicinal herbs have naturally grown in most parts of the County. Trainings on safety and technical application of such plant extracts to be carried out by the public health department.

Use of renewable energy is not a widely accepted and adopted technology among the population. Only few households have solar and wind powered boreholes. The piloting results should be reviewed by the development agencies especially Ewaso Nyiro North Development Authority as basis for strategic development planning. In addition, promotion of renewable energy use should be the focus of every stakeholder in the County given the abundance of solar radiation intensity and wind in the region.

Most of the rivers in Isiolo County are polluted upstream especially Mount Kenya regions as a result non-conservative farming practices. The National Environmental Management Authority and the ministry of agriculture to promote environmental conservation and conservative agricultural practices in the water catchment areas.

The turbidity of the river water varies with seasons. Higher turbidity is exhibited during rainy seasons. However, solar water disinfection insignificantly affects the water turbidity. Thus, a pre-filtration is necessary for such water to minimize clogging of the disinfection water pipes and resistance to flow. Pre-filtration enhances water clarity and thermal capacity and resultant disinfection effect. Filtration through screens, sand filters and charcoal bed reduces the microbial load and enhances the water color.

The system was operated using 6.48 m^2 solar collector area at a flow rate of less than 0.01kgs^{-1} when operated between 1100 h and 1400 h yielding about 200 litres of water. To enhance the volume of disinfected water and the effectiveness of disinfection, the solar water disinfection system should be optimized in design and operation.

In this study the effect of solar water disinfection was investigated using river water during a particular season, to effectively establish the efficiency of the system, investigation using the river water should be carried out throughout the year.

References

Abok, E.O., Okoth, M.W., and Kunyanga, C.N. (2018). Microbiological Quality and Contamination Level of Water Sources in Isiolo County in Kenya. *Journal of Environmental and Public Health*, 2018: 1 – 18. https://doi.org/10.1155/2018/2139867.

Abok, E.O., Okoth, M.W., and Kunyanga, C.N. (2018). Profiling of Physico-chemical properties of Water Sources in Isiolo County Kenya. *Asian Journal Science and Technology*, 9(2): 7452 – 7258.

Acra, A., Jurdi, M., Mu'Allem, H., Karahagopian, Y., and Raffoul, Z. (1989). Sunlight as disinfectant. *Lancet*, 1: 280.

Adegoke, O.O., Bamigbowu, E.O., Oni, E.S., and Ugbaja, K.N. (2012). Microbiological examination of sachet water sold in Aba, Abia State, Nigeria. *Global Research Journal of Microbiology,* 2: 62 – 66.

Admassu, M.M., Wubshet, M., and Gelaw, B. (2004). A survey of Bacteriological quality of drinking water in North Gondar. *Ethiopian Journal of Health Development*, 18 (2): 112 – 115.

Ahiablame, L., Engel, B., and Venort, T. (2012). Improving Water Supply Systems for Domestic Uses in Urban Togo: The Case of a Suburb in Lomé. *Water Journal,* 4: 123 – 134.

Ahmad, I., Bahadar, K., Hussain, U., Rehman, A., Iqbal, H., Wahab, A., Haq, A. U., Khan, M. A., and Ijaz, F. (2012). Physico-Chemical Analysis of Drinking Water Sources at Sampling Point of Billitang, Kda, Nasrat khel and Chongee of District Kohat, K.P.K., Pakistan. *International Journal of Science Innovations and Discoveries*, 2(6): 598 – 609.

Ahmed, K.K.M., Rana, A.C., and Dixit, V.K. (2005). Calotropis procera (Ascle pediaceae): A comprehensive review. *Pharmacology*. *Maga*. 1:48 – 52.

Ahmed, U.A.M., S. Zuhua, N.H.H. Bashier, K. Muafi, H. Zhongping and Yuling, G. (2006). Evaluation of insecticidal potentialities of aqueous extracts from *Calotropis procera* (Ait) against *Henosepilachnaelateriirossi*. *Journal of Applied Science*, 6(1): 2466 – 2470.

Ahmed, W., Neller, R., and Katouli, M. (2005). Host Species specific metabolic finger print Database for Enterococci and Escherichia coli and its application to identify source of faecal contamination in surface waters. *Journal of Applied and Environmental Microbiology,* 71 (8): 4461 - 4468.

Akinde, S.B., Nwachukwu, M.I., and Ogamba, A.S. (2011). Storage effects on the quality of sachet water produced within Port Harcourt metropolis. *Nigeria. Journal of Biological Sciences*, 4: 157 – 164.

Almas, H., Yaqub, G., Sadiq, Z., Tahir, A. and Noor ul Ain. (2013). Intensive report on total analysis of drinking water quality in Lahore. *Journal of Environmental Science*, 3(6): 2161 – 2171.

Anthony, A., Clayton, T., William, S., Justin, P., and Alexandre, T.F. (2015). Simple continuous flow device for combined solar thermal pasteurisation and solar disinfection for water sterilisation. *Journal of Humanitarian Engineering*, 3 (1): 1 – 7.

Anunobi, C.C., Onajole, A.T., and Ogunnowo, B.E. (2006). Assessment of the quality of packaged water on sale in Onitsha metropolis. *Nigerian Quarterly Journal of Hospital Medicine*, 16: 56 – 59.

Anwar, M. M., and Bureste, J. (2011). Water Management and Conservation Practices in Arid Zone: A Case Study of Bahawalpur, Pakistan. *Sindh University Research Journal (Science Series)*, 43(2): 169 – 172.

Anyamene, N.C., and Ojiagu, D.K. (2014). Bacteriological Analysis of sachet water sold in Akwa Metropolis, Nigeria. *International Journal of Agriculture and Biosciences*, 3: 120 - 122.

APHA, AWWA and Water Environment Federation. (2012). Standard Methods for the Examination of Water and Waste Water. 14th Edition, *American Public Health Association, Washington DC*, 9:110-9:112.

Aroh, K.N., Eze, E.M., Ukaji, D., Nwachukwu, C.K., Gobo, A.E., Abbe, S.D., Teme, S.C. and Igoni, A.H. (2013). Health and environmental components of sachet water consumption and trade in Aba and Port Harcourt. *Nigeria. Journal of Chemical Engineering and Material Science*, 4: 13 - 22.

Arouna, A., and Dabbert, S. (2010). Determinants of domestic water use by rural households without access to private improved water sources in Benin: A seemingly unrelated Tobit approach. *Water Resources Management*, 24:1381 – 1398.

Ashraf, M. A., Maah, M. J., Yusoff, I., and Mehmood, K. (2010). Effects of Polluted Water Irrigation on Environment and Health of People in Jamber, District Kasur, *Pakistan. International Journal of Basic & Applied Sciences*, 10(3): 37 – 57.

Aste, N., Chiesa, G., and Verri, F. (2008). Design, development and performance monitoring of a photovoltaic-thermal (PVT) air collector. *Renewable Energy Journal*, 33:914 – 927.

ASTM-D1125 (2014). Standard test method for electrical conductivity and resistivity of water.

Bada, A. M., Malou, R., Kodi, M.M., Souk, A.W. (2017). Study of the Dynamics of Quaternary Aquifers by Infiltration of Rainwater and/or Lake Chad. *American Journal of Water Resources*, 5(2): 41 – 53.

Bakos, G.C. (2006). Design and construction of a two-axis Sun tracking system for parabolic trough collector (PTC) efficiency improvement. *Renewable Energy Journal*, 31:2411 – 2421.

Balke, K. D., and Zhu, Y. (2008). Natural water purification and water management by artificial groundwater recharge. *Journal of Zhejiang University SCIENCE B, 9*(3): 221–226.

Baloch, M. K., Jan, I. U., and Ashour, S. T. (2000). Effect of Septic Tank Effluents on Quality of Groundwater. *Pakistani Journal of Food Science*, 10 (3-4): 25 – 31.

Balogun, S.A., Akingbade, A.O., Oyekunle, M.A., and Okerentugba, P.O. (2014). Physiochemical and Microbiological profile of drinking water sold in Abeokuta, Ogun State. Nigeria. *Nature and Science*, 12: 103 – 105.

Bansal, N.K., Sawhney, R.L., and Misra A. (1988). “Solar Sterilization of Water”. *Solar Energy Journal*, 1: 35 – 39.

Battleson, K.W. (1981). Solar power tower design guide: solar thermal central receiver power systems. *Sandia National Labs, Report SAND81-8005*.

Begum, A., Harikrishna, S., and IrFanulla, K. (2009).Analysis of Heavy metals in Water, Sediments and Fish samples of Madivala Lakes of Bangalore, Karnataka. *International Journal of Chemical and Technology Research*, 1(2): 245 – 249.

Berney, M., Weilenmann, H.U., Ihssen, J., Bassin, C., and Egli, T. (2006). Specific growth rate determines the sensitivity of Escherichia coli to thermal, UV-A, and solar disinfection. *Journal of Applied Environmental Microbiology*, 72: 2586 – 2593.

Bhagwatula, A., Temburkar, A.R., Gupta, R. (2000). Method of Disinfection other than chlorination, *Proceeding- All India Seminars on Disinfection of Rural & Urban Water Supplies, the Institution of Engineers (India*), 85 – 89.

Binayke, R.A., and Jadhav, M.V. (2013). Application of natural coagulants in water purification. *International Journal of Advanced Technology in Civil Engineering*, 2(1): 118 – 123.

Birzer C, Kalt P, Evans H, Liew A, Padovan M, and Watchman M. A. (2014). Solar disinfection water treatment system for remote communities. *Journal of Procedia Engineering*; 78: 250 – 258.

Borde, P., Elmusharaf, K., McGuigan, K. G., and Keogh, M. B. (2016). Community challenges when using large plastic bottles for Solar Energy Disinfection of Water (SODIS). *BMC Public Health*, 16(1): 931. https://doi.org/10.1186/s12889-016-3535-6

Bosshard, F., Bucheli, M., Meur, Y., and Egli, T. (2010). The respiratory chain is the cell's Achilles' heel during UVA inactivation in Escherichia coli. *Journal of Microbiology*, 156: 2006 – 2015.

Boubetra, A., Allaert, C.C., and Feinberg, M. (2011). Validation of alternative methods for the analysis of drinking water and their application to Escherichia coli. *Applied Environmental Microbiology*, 77: 3360 – 3367.

Brahmi, M., and Hassen, A. (2012). Ultraviolet Radiation for Microorganism Inactivation in Wastewater. *Journal of Environmental Protection*, 3: 194 – 202.

Brogren, M. (2001). Low-concentrating photovoltaic systems with parabolic reflectors. *Licentiate Thesis, Division of Solid State Physics, Uppsala University*.

Brogren, M., Nostell, P., and Karlsson, B. (2000). Optical efficiency of a PV-thermal hybrid CPC module. In: *Proceedings of the Eurosun 2000-ISES Europe Solar conference. Copenhagen*.

Byrne, J. A., Fernandez Ibanez, P. A., Dunlop, P. S. M. Alrousan D. M. A., and. Hamilton, J. W. J. (2011). *International Journal of Photo energy*, 1(1): 1 – 10.

Canonica, S., Kohn, T., Mac, M., Real, F.J., Wirz, J., and von Gunten, U. (2005). Photosensitizer method to determine rate constants for the reaction of carbonate radical with organic compounds. *Journal of Environmental Science and Technology,* 39: 9182 – 9188.

Caslake, L. F., Connolly, D. J., Menon, V., and Duncanson, C.M., Rojas, R.., and Tavakoli, J. (2004). Disinfection of Contaminated Water by Using Solar Irradiation. *Journal of Applied and Environmental Microbiology*, 70 (2): 1145 – 1150.

Castro-Alferez, M., Polo-López, M.I., and Fernandez-Ibáñez, P. (2016). Intracellular mechanisms of solar water disinfection *Scientific Reports*, 6:38145, DOI: 10.1038/srep38145.

Chaichan, M.T., and Kazem, H. A. (2016). Experimental analysis of solar intensity on photovoltaic in hot and humid weather conditions. *International Journal of Scientific and Engineering Research*, 7 (3): 91 – 96.

Chakraborty, S., Sadhu, P.K., and Pal, N. (2014). "New Location Selection Criterions for Solar PV Power Plant," *International Journal of Renewable Energy Research,* 4(4): 1020 – 1030.

Cheesbrough, M. (2000). District Laboratory Manual for Tropical Countries. Cambridge University press, U.K, 143 – 147.

Chow, T.T. (2010). "A Review on Photovoltaic/Thermal Hybrid Solar Technology," *Journal of Applied Energy*, 87(2): 365 – 379.

Clark, M., and Mano, R.S. (1998). Predicting Chlorine Residuals and Formation of TTHMs in drinking Water. Journal of Environmental Engineering, 124 (12): 1203 – 1210.

Clasen, T., Cairncross, S., Haller, L., Bartram, J., and Walker, D. (2007). Cost-effectiveness of water quality interventions for preventing diarrheal disease in developing countries. *Journal of Water Health*, 5: 599 – 608.

Cleark, M.O. (2010). Microbiology and physiochemical analysis of different sources of drinking water in Nigeria. *Nigerian Journal of Microbiology*, 15:57 – 61.

Cramer, S., Jasch, K., McIntyre, S., O'Malley, K., Ragozzino, B., Reed, J., Xiong. J., and George, C. (2006). Solar Powered Water Pasteurizer, University of St. Thomas, http://courseweb.stthomas.edu/cmgeorge/projects/english/solarwaterpasteurizer/solarWaterPas eurizer.htm.

Danso-Boateng, E., and Frimpong, I.K. (2013). Quality analysis of plastic sachet and bottled water brands produced or sold in Kumasi, Ghana. *International Journal of Development and Sustainability*, 4: 2222 – 2232.

Dev, R., and Tiwari, G. N. (2011). Solar Distillation, In Drinking Water Treatment, Chitttaranjan R, *Springer Verlag* 1: 159 – 210.

Dhir, V.K. (2006). Mechanistic prediction of nucleate boiling heat transfer – Achievable or a hopeless task. *Journal of Heat Transfer,* 128: 1 – 12.

Diersing, N. (2009). Water Quality. *Journal of Environmental Protection*, 6(4): 1 – 4.

Downes, A., and Blunt, T.P. (1877). Researches on the effect of light upon bacteria and other organisms. *Proceedings of the Royal Society of London*, 26: 488 – 500.

Duff, W.S., and Hodgson, D.A. (2005). A simple high efficiency solar water purification system. *Journal of Solar Energy*, 79 (1): 25 – 32.

Dunlop, P.S.M., Byrne, J.A., Manga, N., and Eggins, B.R. (2002). The photocatalytic removal of bacterial pollutants from drinking water. *Journal of Photochemical and Photobiology*, 148: 355 – 363.

Dunlop, P.S.M., Byrne, J.A., Manga, N., and Eggins, B.R. (2002). The photocatalytic removal of bacterial pollutants from drinking water. *Journal of Photochemical and Photobiology*, 148: 355 – 363.

Dunlop, P.S.M., Ciavola, M., Rizzo, L., and Byrne, J.A. (2011). Inactivation and injury assessment of Escherichia coli during solar and photo catalytic disinfection in LDPE bags. *Chemosphere*, 85: 1160 – 1166.

Edbert, D. C., Sandra, A. U., and Ebere, E. C. (2017). Storage and its Effect on Chemical Quality Indicators in Sachet Water Brands Sold in Owerri Municipal, Imo State, Nigeria. *Journal of World News of Natural Sciences*, 12: 73 – 81.

Edema, M.O., Omem, A.M., and Fapetu, O.M. (2001). Microbiology and physiochemical analysis of different sources of drinking water in Abeokuta. *Nigeria. Nigerian Journal of Microbiology,* 15: 57 – 61.

El-Ghetany, H., and Dayem, A. (2007). Mathematical modeling and experimental investigation of a controlled flow solar water disinfection system using flat plate solar collector. *Proceedings of ISES Solar World Congress 2007: Solar Energy and Human Settlement.*

El-Ghetany, H.H., and Dayem, A. A. (2010). Numerical simulation and experimental validation of a controlled flow solar water disinfection system. *Journal of Desalination and Water Treatment*, 20 (1-3): 11 – 21.

El-Ghetany, H.H., and EL-Seesy, I.E. (2005). Performance evaluation of an overflow thermo-syphon solar water heating system, Engineering Research Journal, Helwan University, 101: M1 – M16.

Essumang, D.K., Senu, J., Fianko, J.R., Nyarko, B.K., Adokoh, C.K., Boamponsem, L. 2011. Groundwater Assessment: A physicochemical properties of drinking water in a rural setting of developing countries. *Canadian Journal of Science and Industrial Research,* 2(4): 171 – 180.

Fadhil, M.S. (2003). Formulation of a mathematical model to predict solar water disinfection, *Journal of water Research,* 37: 3921 – 3927.

Faisal, I.M. and Kabir, M.R. (2005). An Analysis of Gender-Water Nexus in Bangladesh. *Journal of Developing Societies,* 21(1-2): 175 – 194.

Falegan, C.R., Odeyemi, A.T., and Ogunjobi, L.P. (2014). Bacteriological and Physico-chemicals studies of sachet water in locations at Ado- Ekiti, Ekiti State. *Aquatic Biology Journal*, 2: 55 – 61.

Fane, A.G., Tang C.Y., and Wang, V. (2011). Membrane Technology for Water: Microfiltration, Ultrafiltration, Nano filtration, and Reverse osmosis. *Treatise on Water Science,* 4(11): 301 – 335.

Ferreira, C. A., Helena, E.L.P., Maria-Angelade, B.C.M., and Lucia, M.L.A.A. (2017). Hydro chemical Assessment of Spring Waters from the Iron Quadrangle Region, Minas Gerais, Brazil. *American Journal of Water Resources,* 5(2): 29 – 40.

Gagnon, G.A., Rand, J.L., O'Rygel, A.C., Chauret, C., Andrews, R.C. (2005). Disinfectant efficacy of chlorite and chlorine dioxide in drinking water biofilms. *Journal of Water Research*, 39: 1809 – 1817.

Gangil, R., Tripachi, R., Patyal, A., Dutta, P., and Mathur, K.N. (2013). Bacteriological evaluation of packaged bottled water sold at Jaipur city and its public health significance. *Veterinary World*, 6: 27 – 30.

Garba, I., Tijjani, M.B., Aliyu M.S., Yakubu, S.E., Wada-Kura, A., and Olonitola, O.S. (2009). Prevalence of Escherichia coli in some public water sources in Gusau municipal, north - western Nigeria. *Bayero Journal of Pure and Applied Sciences*, 2 (2):134 – 137.

Gil, A., Medrano, M., Martorell, I., Lazaro, A., Dolado, P., and Zalba, B. (2010). State of the art on high temperature thermal energy storage for power generation. Part 1 concepts, materials and modellization. *Renewable and Sustainable Energy Reviews*; 14: 31 – 55.

Gilg, A., and S. Barr (2006). Behavioral attitudes towards water saving? Evidence from a study of environmental actions. *Journal of Ecology and Economics*, 57: 400 – 414.

Gill, L., and Price, C. (2010). Preliminary observations of a continuous flow solar disinfection system for a rural community in Kenya. *Journal of Energy*, 35: 4607 – 4611.

Goel, P.K. (2006). Water pollution: causes effect and control. *Macmillian Publishers, London*, 154 – 232.

Goodsell, D.S. (2002). The molecular perspective: ultraviolet light and pyrimidine dimmers. *Oncologist*, 6: 298 – 299.

Gregory, G.D., and Di Leo, M. (2003). Repeated Behavior and Environmental Psychology: The Role of Personal Involvement and Habit Formation in Explaining Water Consumption. *Journal of Applied Social Psychology*, 33(6):1261 – 1296.

Hamidu, H., Lawal, M., Abdulganiyu, Y., Kwaya, M. Y., Grema, H. M., Ibrahim, H.A.1, Kitha, M.1, and Yelwa, N.A. (2017). Re-evaluation of Shallow Floodplain Aquifers Groundwater Potentials and Storage of Sokoto Basin, Northwestern Nigeria. *American Journal of Water Resources*, 5 (3): 72 – 84.

Hanasaki, N., Fujimori, S., Yamamoto, T., Yoshikawa, S., Masaki, Y., Hijioka, Y., Kainuma, M., Kanamori, Y., Masui, T., Takahashi, K., and Kanae, S. (2013). A global water scarcity assessment under Shared Socio-economic Pathways – Part 2: Water availability and scarcity, *Journal of Hydrological Earth System Science,* 17: 2393 – 2413.

Hassan, A. S. (2009). Seasonal influence on microbial quality of water sources in some rural communities of Zaria, Nigeria. *Science World Journal*, 4 (3): 23 – 27.

Hellstrom, B., Adsten, M., Nostell, P., Karlsson, B., and Wackelgard, E. (2003). The impact of optical and thermal properties on the performance of flat plate solar collectors. *Journal of Renewable Energy* 28: 331 – 344.

Ho, C. D., Yeh, H. M., and Wang, R. C. (2005). Heat-transfer enhancement in double-pass flat plate solar air heaters with recycle. *Journal of Energy* 30 (2): 796 – 817.

Hoerter, J.D., Arnold, A.A., Kuczynska, D.A., Shibuya, A., Ward, C.S., Sauer, M.G., Gizachew, Hotchkiss, A., Fleming, T.M., and Johnson, S. (2005). Effects of sub-lethal UV A irradiation on activity levels of oxidative defense enzymes and protein oxidation in Escherichia coli. *Journal of Photochemical and Photobiology,* 81: 171 – 180.

Huang, B.J., Lin, T.H., Hung, W.C., and Sun, F.S. (2001). Performance evaluation of solar Photovoltaic/thermal systems. *Solar Energy Journal*, 70:443 – 448.

Hughes, J.M., and Koplan, J.P. (2005). Saving lives through global safe water. *Journal of Infectious Diseases*, 11: 1636 – 1637.

Isikwue, M.O., and Chikezie, A. (2014). Quality assessment of various sachet water brands marketed in Bauchi metropolis of Nigeria. *International Journal of Advances in Engineering and Technology*, 6: 2489 – 2495.

Islam, M.F., and Johnston, R.B. (2006). Household Pasteurization of Drinking-water: The Chulli Water treatment System. *International Center for Diarrheal Disease Research*, 23 (3): 356 – 362.

ISO 10523:2017. Water quality -- Determination of pH.ICS:13.060.50. Examination of water for chemical substances

ISO 16649-2: (2001). Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of beta-glucuronidase-positive Escherichia coli. Part 2: Colony-count technique at 44 degrees C using 5-bromo-4-chloro-3-indolyl beta-D-glucuronide, 1-2.

ISO 16649-3: (2015). Microbiology of the food chain, Horizontal method for the enumeration of beta-glucuronidase-positive Escherichia coli. Part 3: Detection and most probable number technique using 5-bromo-4-chloro-3-indolyl-ß-D-glucuronide, 1-10.

ISO 18744. (2016). Microbiology of the food chain. Detection and enumeration of Cryptosporidium and Giardia in fresh leafy green vegetables and berry fruits, 1: 21

ISO 21528-2:2004. Microbiology of food and animal feeding stuffs. Horizontal methods for the detection and enumeration of Enterobactericea, Part 2: Colony-count method, 1-2.

ISO 4832 (2006). Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of coliforms, Colony-count technique, 3-4.

ISO 6059. Determination of Hardness in Water Standard methods for water 18th edition 2.36 2340C.

ISO 6579-1 (2016). Microbiology of the food chain, Horizontal method for the detection, enumeration and serotyping of Salmonella. Part 1: Detection of Salmonella spp, 1-50.

ISO 6888-2 (2010).Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of coagulase-positive Staphylococci (Staphylococcus aureus and other species). Part 2: Technique using rabbit plasma fibrinogen agar medium, 1-3.

ISO 7027-1:2016 .Water quality -- Determination of turbidity -- Part 1: Quantitative methods.

ISO 7887:2011. Water quality. Examination and determination of colour.

ISO 7937. (2016). Microbiology of food and animal feeding stuffs. Horizontal method for the enumeration of Clostridium pafrigens, Colony-count technique, 3: 16.

ISO 9308-1:2014 Water quality -- Enumeration of Escherichia coli and coliform bacteria - Part 1: Membrane filtration method for waters with low bacterial background flora, 3:10.

Jackson, R.B., Carpenter, S.R., Dahm, C.N., McKnight, D.M., Naiman, R.J., Postel, S.L., and Running, S.W. (2001). Water in a changing world. *Ecological Applications Journal*, 11:1027 – 1045.

Jeffrey, P., and Gearey, M. (2006). Consumer reactions to water conservation policy instruments, in Water Demand Management, edited by D. Butler and F. Ali Memon, IWA Publication., London. 303 – 329.

Jeng, M.J., Lee. Y.L., and Chang, L.B. (2009). "Temperature Dependences of lnxGa1_xN Multiple Quantum Well Solar Cells," *Journal of Physics D: Applied Physics*, 42: 105 – 111.

Juneja, T., and Chaudhary, A. (2013) Assessment of Water Quality and Its Effects on the Health of Residents of Jhunjhunu District, Rajasthan: A Cross Sectional Study. *Journal of Public Health and Epidemiology*, 5: 186 – 191.

Kacira, M., Simsek, M., Babur, Y., and Demirkol, S. (2004). Determining optimum tilt angles and orientations of photovoltaic panels in Sanliurfa, Turkey. *Renewable Energy Journal*, 29:1265 – 1275.

Kalogirou, S.A. (2004). Solar thermal collectors and applications. *Progressive Energy Combustion Journal*, 30:231 – 295.

Kalpana, D.V., Monica, B., and Kalavathy, V. (2014). Microbiological analysis of packaged drinking water sold in Chennai. *International Journal of Medical Science and Public Health*, 3(4): 472 – 476.

Kareem, S.O., Akpan, I. and Osho, M.B. (2003). Calotropis procera (Sodom apple) – A potential material for enzyme purification. *Journal of Bioscience Technology,* 87:133 – 135.

Karikari, O. D., Amoako, J., and Ansa-Asare, A. Y. (2011). Physico-chemical quality of boreholes in Densu Basin of Ghana. *Journal of Applied Water Science*, 1: 41 – 48.

Keane, D., McGuigan, K., Ibáñez, P., Polo-López, M., Byrne, J., Dunlop, P., O'Shea, K., Dionysiou, D., and Pillai, S. (2014). Solar photo catalysis for water disinfection: materials and reactor design. *Catalysis Science and Technology Journal*, 5(4): 2 – 33.

Kehoe, S.C., Joyce, T.M., Ibrahim, P., Gillespie, J.B., Shahar, R.A., and McGuigan, K.G. (2001). Effect of agitation, turbidity, aluminium foil reflectors and container volume on the inactivation efficiency of batch-process solar disinfectors. *Water Research Journal*, 35: 1061 – 1065.

Khaled, A.E., Ali, E., and Anan, A.K. (2008). Disinfecting Contaminated Water with Natural Solar Radiation Utilizing a Disinfection Solar Reactor in a Semi-arid Region. *Jordan Journal of Biological Sciences*, 1 (2): 47 – 53.

Khaniki, G.R.J., Zarei, A., Kamkar, A., Fazlzadehdavil, M., Ghaderpoori, Marei, A. (2010). Bacteriological evaluation of bottled water from domestic brands in Tehran markets, Iran. *World Applied Sciences Journal,* 8: 274 – 278.

Khoukhi, M., and Maruyama. S. (2005). Theoretical approach of a flat plate solar collector with clear and low-iron glass covers taking into account the spectral absorption and emission within glass covers layer. *Journal of Renewable Energy* 30 (11): 77 – 94.

Kirianki, P.R., Othira, J.O., and Kiruki, S. (2017). Analysis of Microbial Quality of Drinking Water in Njoro Sub-county, Kenya. *Journal of Environment Pollution and Human Health*, 5(1): 15 – 21.

Kiruki, S., Limo M, Njagi, M, and Okemo, P. (2011). Bacteriological quality and diarrhoeagenic pathogens in River Njoro and Nakuru Municipal water, Kenya. *International Journal for Biotechnology and Molecular Biology Research*, 2 (9), 150-162.

Konersmann, L., and Frank, E. (2011). Solar Water Disinfection: Field Test Results and Implementation Concepts. *Viewed 10 august, 2015. <http://swisswaterkiosk.org/wp-content/ uploads/2011/08/110817.*

Koning, J., and Thiesen, S. (2005). Aqua Solaris- an optimised small-scale desalination system with 40 litres output per square meter based upon solar-thermal distillation. *Journal of Desalination* 182 (1-3):503 – 509.

KS EAS. (2014). Kenya Standard potable water specification. *ICS 13.060.20 Second Edition*, 2: 11 – 27.

Kumar Reddy, D.H., and Lee, S.M. (2012). Water Pollution and Treatment Technologies. *Journal of Environmental and Analytical Toxicology*, 2 (5): 1 – 2.

Kumar, K. R., and Reddy, K. S. (2009). Thermal analysis of solar parabolic trough with porous disc receiver. *Journal of Applied Energy* 86: 4 – 12.

Kuta, G.I., Emigilati, M.A., Hassan, A.B., and Ibrahim, I. (2014). Domestic water sources and its health implication in Lapai local Government area, Niger state. Nigeria. *Ethiopian Journal of Environmental studies and Management*, 7 (6): 686 – 694.

Lam, S. (2006), Predicting intention to save water: Theory of planned behavior, response efficacy, vulnerability, and perceived efficiency of alternative solutions. *Journal of Applied Sociology and Psychology*, 36(11): 2803 – 2824.

Lambert, A. A., and Cuevasa, S. (2006). Enhanced heat transfer using oscillatory flows in solar collectors. *Journal of Solar Energy* 80 (1): 296 – 302.

Lamuka, P.O., Njeruh, F.M., Gitao, G.C., and Abey, K.A. (2017). Camel health management and pastoralists' knowledge and information on zoonoses and food safety risks in Isiolo County, Kenya. *Pastoralism: Research, Policy and Practice*, 7:20.

Lavanya, V., and Ravichandran, S. (2013). Microbial contamination of drinking water at the source and household storage level in the peri-urban area of southern Chennai and its implication on health. *Indian Journal of Public Health* 21: 481 – 488.

Lee, S. H., and Kim, S. J. (2002). Detection of Infectious Enteroviruses and Adonoviruses in Tap water in Urban Areas in Korea. *Journal of Water Research*, 36 (1): 248 – 256.

Maduka, H.C.C., Chukwu, N.C., Ugwu, C.E., Dike, C.C., Okpogba, A.N., Ogueche, P.N., and Maduka, A.A. (2014). Assessment of commercial bottled table and sachet water commonly consumed in Federal University of Technology, Owerri (FUTO), Imo State, Nigeria using Microbiological indices. *Journal of Dental and Medical Sciences,* 13: 86 – 89.

Makrides, G., Zinsser, B., Georghiou, G.E., Schubert, M., and Werner, J.H. (2009). "Temperature Behavior of Different Photovoltaic Systems Installed in Cyprus and Germany," *Solar Energy Materials and Solar Cells,* 93: 1095 – 1099.

Malato, S., Maldonado, M.I., Fernandez-Ibáñez, P., Oller, I., Polo, I., and Sánchez-Moreno, R. (2016). Decontamination and disinfection of water by solar photo catalysis: The pilot plants of the Plataforma Solar de Almeria. *Materials Science in Semiconductor Processing.* doi:10.1016/j.mssp.2015.07.017.

Malik, M. A., Azam, M., and Saboor, A. (2010). *Water Quality Status of Upper KPK and Northern Areas of Pakistan.* Pakistan Council of Research in Water Resources (PCRWR). Water Resources Research Centre, Peshawar, Pakistan.

Mallick, B., and Rojas, L.F.R. (2015). Social Stratification in the Drinking Water Scarcity Context: Empirical Evidence of Coastal Bangladesh. *American Journal of Water Resources*, 3(3): 92 – 99.

Manhokwe, S., Matiashe, I., and Jombo, T. Z. (2013). An analysis of the water quality of groundwater sources in selected high density areas in Gweru urban, Zimbabwe. *Journal of Environmental Science and Water Resources*, 2(9): 302 – 309.

Mani, S. K., Kanjur, R., Bright, I. S., and Reed. R. H. (2006). Comparative effectiveness of solar disinfection using small-scale batch reactors with reflective, absorptive and transmissive rear surfaces. *Journal of Water Research* 40: 721 – 727.

Manickam, S. and Dhir, V.K. (2012). "Holographic interferometry study of heat transfer to a sliding vapor bubble. *International Journal of Heat and Mass Transfer*, 55(4): 925 – 940.

Martin-Dominguez, A., Alarcon Herrera, M. T., Martin-Dominguez, I. R., and Gonzalez-Herrera, A. (2005). Efficiency in the disinfection of water for human consumption in rural communities using solar radiation. *Journal of Solar Energy* 78: 31 – 40.

Maynard, C., Berthiaume, F., Lemerchand, K., Harel, J., Payment, P., Masson, L., and Brousseau, R. (2005). Water borne pathogen detection by use of oligonucleotide base microarrays. *Journal of Applied and Environmental Microbiology*, 71 (12): 8548 – 8557.

Mberekpe, P.B., and. Eze, N.M. (2014). Effect of preservation on the quality of sachet water consumed by households in Nsukka zone. *International Institute for Science Technology and Education Journal*, 6(7): 25 – 30.

McGuigan, K. G., Joyce, T. M., Conroy, R. M., Gillespie, J. B., and Elmore-Meegan, M. (1998). Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation process. *Journal of Applied Microbiology* 84: 1138 – 1148.

McGuigan, K.G., Conroy, R.M., Mosler, H.J., Preez, M.D., Ubomba-Jaswa, E., and Ibanez, P.F. (2012). Solar water disinfection (SODIS): A review from bench-top to roof-top. *Journal of hazardous materials*, 7: 53 – 55.

Medrano, M., Gil, A., Martorell, I., Potou, X., and Cabeza, L. F. (2010). State of the art on high temperature thermal energy storage for power generation. Part 2 Case studies. *Renewable and Sustainable Energy Reviews* 14: 56 – 72.

Megha, P.U., Kavya, P., Murugan, S., Harikumar, P.S. (2015). Sanitation Mapping of Groundwater Contamination in a Rural Village of India. *Journal of Environmental Protection*, 6: 34 – 44.

Memon, M., Soomro, M. S., Akhtar, M. S., and Memon, K. S. (2011). Drinking Water Quality Assessment in Southern Sindh (Pakistan). *Environmental Monitoring and Assessment*, 177, 39 – 50.

Min Cho, Yunho, L., Wonyong, C., Hyenmi, C., and Jeyong, Y. (2006). Study of Fe (VI) species as a disinfectant: Quantitative evaluation and modeling for inactivating E- Coli. *Journal of water Research*, 40: 3580 – 3586.

Mokhtar, M.B., Aris, A.Z., Abdullah, M.H., Yusoff, M.K., Abdullah, M.P., Idris, A.R. and Raja Uzir, R.I. (2009). A pristine environment and water quality in perspective: Maliau Basin, Borneo's mysterious world. *Water and Environment Journal*, 23(3): 219 – 228.

Momba, M.N.B., Mamba, B.B., and Mwabi, J.K. (2012). Removal of waterborne bacteria from surface water and groundwater by cost-effective household water treatment systems (HWTS): A sustainable solution for improving water quality in rural communities of Africa. *Environmental water and Earth science, Water South Africa*, 39 (4); 1 – 12.

Moyo, B., Masika, P. J., Hugo, A., and Muchenje, V. (2013). Nutritional characterization of Moringa (Moringa oleifera Lam.) leaves. *African Journal of Biotechnology*, 10(60): 12925 – 12933.

Muhammad M., Samira S., Farrukh J., and Faryal A. (2013). Assessment of Drinking Water Quality and its Impact on Residents Health in Bahawalpur City. *International Journal of Humanities and Social Science*, 3(15): 114 – 128.

Muhammad, I., Anas, F., and Ahmad, S. (2017). Determinants of Safe Drinking Water Supply in Nowshera District of Khyber Pakhtunkhwa. *American Journal of Water Resources*, 5(3): 63 – 71.

Muslih, I. M., Abdallah, S. M., and Husain, W. A. (2010). Cost comparative study for new water distillation techniques by solar energy. *Journal of Applied Solar Energy* 46 (1): 8 – 12.

Nacoulima, G., Piro, J., and Bayane, A. (2000). *Journal of Sociology*. Ouest-Af Chim 9: 43 – 57.

Nair, H.C., Padmalal, D., and Joseph, A. (2015). Hydrochemical assessment of tropical springs - a case study from SW India. *Journal of Environmental Monitoring and Assessment*, 187(48): 1 – 24.

Namu, P., Raude, J.M., Mutua, B.M., and Wambua, R.M. (2017). Prediction of Water Turbidity using Artificial Neural Networks: A Case Study of Kiriku-Kiende Settling Basin in Embu County, Kenya. *American Journal of Water Resources*, 5 (3): 54 – 62.

Navntoft, C., Ubomba-Jaswa, E., McGuigan, K. G., and Fernandez-Ibanez, P. (2008). Enhancement of batch solar disinfection (SODIS) using non-imaging reflectors. *Journal of Photochemical and Photobiology* 93: 155 – 161.

Nicki, P., Kate, S., Stefan, W., and Jeannie, D. (2004). UV Disinfection in a model distribution system, biofilm growth and microbial community. *Journal of Water Research*, 38: 3083 – 3091.

Nwosu, J.N., and Ogueke, C.C. (2004). Evaluation of sachet water samples in Owerri metropolis. *Nigeria Food Journal*, 22:164 – 170.

Olaleye, O.N., and Ogunbajo, A.H. (2015). Microbiological risk assessment of groundwater sources in Ikorodu- a peri-urban Lagos settlement. *Journal of Environmental Science and Water Resources*, 4(4): 112 – 116.

Oludairo, O.O., and Aiyedun, J.O. (2015). Contamination of commercially packaged sachet water and the public health implications: An overview. *Bangladesh Journal of veterinary medicine*, 13(2): 73 – 81.

Oludairo, O.O., and Aiyedun, J.O. (2015). Contamination of commercially packaged sachet water and the public health implications: An overview. *Bangladesh Journal of veterinary medicine*, 13(2): 73 – 81.

Oludairo, O.O., Kwaga, J.K.P., Dzikwi, A.A., and Kabir, J. (2013). The genus Salmonella, isolation and occurrence in wildlife. *International Journal of Microbiology and Immunology Research,* 1: 47 – 52.

Olukosi, O.M., Ameh, J.B., and Abdullahi, I.O. (2008). The prevalence of Escherichia Coli O157:H7 in well water source in Zaria metropolis, Kaduna state Nigeria. *Journal of Biological and Environmental Sciences for the Tropics*, 5 (4): 32 – 37.

Omalu, C.I., Eze, G.C., Olayemi, K., Gheri, S., Adeniran, L.A., Ayanwale, A.V., Mohamed, A.Z., and Chukwuemeka, V. (2010). Contamination of sachet water in Nigeria: Assessment and health impact. *The Online Journal of Health and Allied Sciences,* 9: 15 – 20.

Omar, Y.Y., Parker, A., Smith, J.A. and Pollard, S.J.T. (2017). Risk management for drinking water safety in low and middle income countries - cultural influences on water safety plan (WSP) implementation in urban water utilities. *Journal of Science of the Total Environment*, 576: 895 – 906.

Onilude, A.A., Adesina, F.C., Oluboyede, O.A., and Adeyemi, B.I. (2013). Microbiological quality of sachet packaged water vended in three local government of Oyo State, Nigeria. *African Journal of Food Science and Technology,* 4: 195 – 200.

Onuh, J.O., and Isaac, V.U. (2009). Physiochemical and microbiological quality of water sources from some major towns in Igala land. *Nigerian Food Journal,* 2: 66 – 72.

Onyango, E.A., Thoruwa, T.F.N., Maingi, S.M., and Njagi, E.M. (2009). Performance of a 2 Element Plane Reflector Augmented Galvanized Pipe Flat Plate Collector for Solar Water Pasteurisation. *Journal of Food Technology*, 7 (1): 12 – 19.

Opara, A.U., and Nnodim, J. (2014). Prevalence of Bacteria in bottled and sachet water sold in Owerri metropolis. *International Journal of Science Innovations and Discoveries*, 4: 117 – 122.

Oparaku, N.F., Mgbenka, B.O. and Ibeto, C.N. (2011). "Waste Water Disinfection Utilizing Ultraviolet Light". *Journal of Environmental Science and Technology*, 4(1): 73 – 78.

Oyedeji, O., Olutiola, P.O., and Moninuola, M.A. (2010). Microbiological quality of packaged drinking water brands marketed in Ibadan metropolis and Ile-Ife city in South Western Nigeria. *African Journal of Microbiology Research*, 4: 096 – 102.

Oyedeji, O., Olutiola, P.O., and Moninuola, M.A. (2010). Microbiological quality of packaged drinking water brands marketed in Ibadan metropolis and Ile-Ife city in South Western Nigeria. *African Journal of Microbiology Research*, 4: 96 – 102.

Oyelude, E.O. and Ahenkorah, S. (2012). Quality of sachet water and bottled water in Bolgatanga Municipality of Ghana. *Research Journal of Applied Sciences, Engineering and Technology*, 4: 1094 – 1098.

Paavola, J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro. Tanzania. *Environmental Science and Policy*, 11(7): 642 – 654.

Pansonato, N., Afonso, M.V., Salles, C.A., Boncz, M.A., and Paulo, P.L. (2011). Solar disinfection for the post-treatment of grey water by means of a continuous flow reactor. *Journal of Water Science and Technology*, 64: 1178 – 1185.

Pavithra, S., Saranya, D., Sankar, P., and Murugesan, S. (2012). "Effect of Tulsi as a water Treatment" Hitek. *Journal of Biology and Bioengineering*, 1(1): 1 – 7.

Peh, Z., Sorsa, A., and Halamic, J. (2010). Composition and variation of major and trace elements in Croatian bottled waters. *Journal of Geochemical Exploration*, 107: 227 – 237.

Pejack E. (2011). Solar Pasteurization. *Springer*; Chapter 3: 37 – 54.

Polo-Lopez, M.I., Fernandez-Ibanez, P., Ubomba-Jaswa, E., Navntoft, C., McGuigan, K.G., Dunlop, P.S.M., and Byrne, J.A. (2011). Elimination of water pathogens with solar radiation using an automated sequential batch CPC Reactor. *Journal of Hazardous Materials*, 196: 16 – 21.

Postel, S. L. (2000). Entering an era of water scarcity: The challenges ahead. *Journal of Applied Ecology*, 10(4): 941 – 948.

Pradesh, A., Medudhua, T., Samatha, C., Sammajah, C. (2012). Analysis of water quality using physico-chemical parameters in lower manair reservoir of Karimnagar district. *International Journal of Environmental Sciences*, 3(1): 179 – 187.

Razzolini, M.T.P., Gunther, W.M.R., Peternella, F.A., Martone- Rocha, S., Bastos, V. K., Santos, T.F., Cardoso, M.R.A. (2011). Quality of Water Sources Used As Drinking Water in a Brazilian Peri-Urban Area. *Brazilian Journal of Microbiology*, 42: 560 – 566.

Reed, R.H. (2004). The inactivation of microbes by sunlight: solar disinfection as a water treatment process. *Journal of Applied Microbiology*, 54: 333 – 365.

Reed, R.H., Mani, S.K., and Meyer, V. (2000). Solar photo-oxidative disinfection of drinking water: preliminary field observations. *Journal of Applied Microbiology*, 30:432 – 436.

Reza, R., and Singh, G. (2010). Assessment of Ground Water Quality Status by Using Water Quality Index Method in Orissa, India. *World Applied Science Journal*, 9 (12): 1392 – 1397.

Robles-Ocampo, B., Ruíz-Vasquez, E., Canseco-Sánchezb, H., Cornejo-Mezac, R.C., Trápaga-Martínezd, G., and García-Rodrigueza, F.J. (2007). Photovoltaic/thermal solar hybrid system with bifacial PV module and transparent plane collector. *Solar Energy Materials and Solar Collectors Journal*, 91:1966 – 1971.

Rod, D., Murray, C., Andrew, B., Ruth, P., Marion, S., and Zella, S. (2008). Microbial groundwater quality and its health implications for a border-strip irrigated dairy farm catchment, South Island, New Zealand. *Journal of Water and Health*, 6 (1): 83 – 98.

Sabahi, E.A.l., Rahim, S.A., Zuhairi, W.Y.W., Nozaily, F.A.l., Alshaebi, F. (2009). The characteristics of leachate and groundwater pollution at municipal solid waste landfill of Ibb City, Yemen. *American Journal of Environmental Science*, 5: 256 – 266.

Safapour, N., and Metcalf, R.H. (1999). "Enhancement of solar water pasteurization with reflectors". *Applied and Environmental Microbiology Journal*, 65(2):859 – 861.

Saitoh, T.S., and El-Ghetany, H.H. (2002). A pilot solar water disinfecting system: performance analysis and testing. *Journal of Solar Energy*, 72: 261 – 269.

Schwartzenbach, R.P., Gschwend, P.M, and Imboden, D.M. (2003). *Environmental Organic Chemistry, 2nd Edition, John Wiley and Sons, Hoboken, NJ,* ISBN 0-47 1- 35750 – 2.

Sharma, A., Tyagi, V. V., Chen, C. R., Buddhi, D. (2009). Review on thermal energy storage with phase change materials and applications. *Renewable and Sustainable Energy Reviews* 13: 318 – 320.

Shen, Y., and Chen, Y. (2010). Global perspective on hydrology, water balance, and water resources management in arid basins, *Hydrological Process Journal*, 24: 129 – 135.

Shibu, K., Mani, R.K., Isaac, S., Bright, S., and Reed, R.H. (2006). Comparative effectiveness of solar disinfection using small-scale batch reactors with reflective absorptive and transmissive rear surfaces. *Journal of water Research*, 40: 721 – 722.

Silva, G., Luis, A. G., Karina, R., and Teresa, L.M. (2006). A practical demonstration of water disinfection using TiO2 films and sunlight. *Journal of water Research*, 40: 3274 – 3280.

Simpi, B., Hiremath, S.M., Murthy, K.N.S., Chandrashekarappa, K.N., Patel, A. N., and Puttiah, E.T. (2011). Analysis of Water Quality Using Physico-Chemical Parameters Hosahalli Tank in Shimoga District, Karnataka, India. *Global Journal of Science Frontier Research*, 11 (3): 31 – 34.

Singh, A.K., Raj, B., Tiwari, A.K. and Mahato, M.K. (2013). Evaluation of hydro geochemical processes and groundwater quality in the Jhansi district of Bundelkhand region, India. *Journal of Environmental Earth Sciences*, 70 (3): 1125 – 1247.

Sinton, L.W., Hall, C.H., Lynch, P.A., and Davies-Colley, R.J. (2002). Sunlight inactivation of fecal indicator bacteria and bacteriophages from waste stabilization pond effluent in fresh and saline waters. *Journal of Applied Environmental Microbiology*, 68: 1122 – 1131.

Slaman, M., and Griessen, R. (2009). Solar collector overheating protection. *Journal of Solar Energy* 83: 2 – 7.

Somani, S. B., and Ingole N. W. (2011). Alternative approach to chlorination for disinfection of drinking water an overview. *International Journal of Advanced Engineering Research and Studies*, 1 (1): 47 – 50.

Sommer, B., Marino, A., Solarte, Y., Salas, M. L., Dierolf, C., Valiente, C., Mora, D., Rechsteiner, R., Setter, P., Wirojanagud, W., Ajarmeh, H., A. L., Hassan, A., and Wegelin, M. (1997). Solar water disinfection (SODIS) an emerging water treatment process. *Journal of Water Research* 46: 127 – 137.

Ssemakalu, C.C., Ubomba-Jaswa, E., Motaung, K.S., and Pillay, M., (2014). Influence of solar water disinfection on immunity against cholera - A review. *Journal of Water and Health.* doi:10.2166/wh.2014.158.

Steg, L., and Vlek, C. (2009). Encouraging pro-environmental behavior: An integrative review and research agenda. *Journal of Environment and Psychology*, 29: 309 – 317.

Sunada, K., Watanabe, T., and Hashimoto, K. (2003). Water Quality. *Journal of Photochemistry and Photobiology*, 156: 227 – 233.

Talabi, A.O. and Tijjani, M.N, (2013). Hidrochemical and stable isotopic characterization of shallow groundwater system in the crystalline basement terrain of Ekiti area, southwestern Nigeria. *Journal of Applied Water Science*, 3: 229 – 245.

Tanushree, B., Gidde, M.R., and Bipinraj, N.K. (2013). Disinfection of Drinking Water in Rural Area Using Natural Herbs. *International Journal of Engineering Research and Development*, 5(10): 7 – 10.

Tavakolpour, A.R., Zomorodian, A., and Golneshan, A.A. (2008). Simulation, construction and testing of a two-cylinder solar Stirling engine powered by a flat-plate solar collector without regenerator. *Renewable Energy Journal*, 33:77 – 87.

Thliza, L.A., Khan, A.U., Dangora, D.B., and Yahaya, A. (2015). Study of some bacterial load of some brands of sachet water sold in Ahmadu Bello University (Main Campus), Zaria, Nigeria. *International Journal of current Science*, 14: 91 - 97.

Tian, Y., and Zhao, C. Y. (2011). A numerical investigation of heat transfer in phase change materials (PCMs) embedded in porous metals. *Journal of Energy* 36 (55): 39 – 46.

Tina, G.M., Rosa-Clot, M., Rosa-Clot, P., and Scandura, P.F. (2012). Optical and thermal behavior of submerged photovoltaic solar panel: SP2. *Energy Journal*, 39:17 – 26.

Tortora, J.G., Funke, R.B., and Case, L.C. (2002). An introduction 7th edition. *Daryl Fox Publishers*, 258 – 260.

Tripanagnostopolous, Y., Souliotis, M., and Nousia, T. (2000). Solar collectors with colored absorbers. *Journal of Solar Energy* 68 (3): 43 – 56.

Ubomba-Jaswa, E., Fernandez-Ibanez, P., Navntoft, C., Polo-Lopez, M.I., and McGuigan, K.G. (2010). Investigating the microbial inactivation efficiency of a 25 litre batch solar disinfection (SODIS) reactor enhanced with a compound parabolic collector (CPC) for household use. *Journal of Chemical Technology and Biotechnology*, 85: 1028 – 1037.

Ubomba-Jaswa, E., Navntoft, C., Polo-Lopez, M.I., Fernandez-Ibanez, P., and McGuigan, K.G. (2009). Solar disinfection of drinking water (SODIS): an investigation of the effect of UV-

A dose on inactivation efficiency. *Journal of Photochemical and Photobiology Science,* 8, 587 – 595.

Umoh, V.J., Agbogu, V.N., Okuofu, C.A., Smith, S.I., and Ameh, J.B. (2006). Study of the bacteriological and physicochemical indicators of pollution of surface waters in Zaria. *Nigerian African Journal of Biotechnology*, 5:10 – 11.

Vidal, A., and Diaz, A.I. (2000). High-performance, low-cost solar collectors for disinfection of contaminated water. *Journal of Water and Environmental Research*, 72, 271 – 276.

Vivar, M., Fuentes, M., Castro, J., and Garcia-Pacheco, R. (2015). Effect of common rooftop materials as support base for solar disinfection (SODIS) in rural areas under temperate climates. *Solar Energy Journal*, 115: 204 – 216.

Vorsmarty, C. J., Green, P., Salisbury, J., and Lammers, R. B. (2000). Global water resources: Vulnerability from climate change and population growth, *Journal of Science* 289: 284 – 288.

Walker, D.C., Len, S.V., and Sheehan, B. (2004). Development and evaluation of a reflective solar disinfection pouch for treatment of drinking water. *Journal of Applied Environmental Microbiology,* 70 (4): 2545 – 2550.

Wang, K., Deng, J., Gu, Q., Lin, Y., Li, J., Gan, M., Ma, L., and Hong, Y. (2014). Identification and Assessment of Potential Water Quality Impact Factors for Drinking-Water Reservoirs. *International Journal of Environmental Research and Public Health,* 11: 6069 – 6084.

Wang, K., Deng, J., Gu, Q., Lin, Y., Li, J., Gan, M., Ma, L., and Hong, Y. (2014). Identification and Assessment of Potential Water Quality Impact Factors for Drinking-Water Reservoirs. *International Journal of Environmental Research and Public Health,* 11: 6069 – 6084.

Wang, R.Z., and Zhai, X.Q. (2012). Development of solar thermal technologies in China. *Energy Journal*, 35:4407 – 4416.

Warrier, G.R., and Dhir, V.K. (2006). Heat transfer and wall heat flux partitioning during sub-cooled flow nucleate boiling - A review. *Journal of Heat Transfer*, 128: 1243 – 1256.

Watete, P.W., Kogi Makau, W., Njoka, J.T., AderoMacOpiyo, L., and Mureithi, S.M. (2016). Are there options outside livestock economy? Diversification among households of northern Kenya. Pastoralism: *Research, Policy and Practice* 6: 3.

Wayua, F.O., Okoth, M.W., and Wangoh, J. (2012). Survey of postharvest handling, preservation and processing practices along the camel milk chain in Isiolo district, Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, 12(7): 6897 – 6912.

Wazwaz, J., Salmi, H., and Hallak, R. (2002). Solar thermal performance of a nickel pigmented aluminium oxide selective absorber. *Journal of Renewable Energy* 27 (2): 77 – 92.

Wegelin M, Canonica S, Mechsner K, Fleischmann T, Pesaro F, and Metzler A. (1994). Solar water disinfection: scope of the process and analysis of radiation experiments. *Journal of Water SRT Aqua*; 43: 154 – 169.

Wegelin, M., Canonica, A., Alder, A., Suter, M., Bucheli, T. D., Haefliger, O. P., Zenobi, R., McGuigan, K. G., Kelly, M. T., Ibrahim, P., and Larroque, M. (2001). Does sunlight change the material and content of PET bottles? *Journal of Water* 50: 125 – 135.

Wei, X. D., Lu, Z. W., Wang, Z. F., Yu, W. X., Zhang, H. X., and Yao, Z .H. (2010). A new method for the design of the heliostat field layout for solar tower power plant. *Journal of Renewable Energy* 35 (19): 5 – 10.

World Health Organization WHO (2014). Water sanitation and hygiene links to health: *Facts and figures updated. Accessed on 14/8/2017.*

Wright, J.A., Yang, H., Rivett, U. and Gundry, W. S. (2012). Public perception of drinking water safety in South Africa 2002–2009. *Journal of Public Health*, 12:556.

Yang, H., Vinopal, R.T., Grasso, D., and Smets B.F. (2004). High diversity among environmental Escherichia coli isolates from a bovine feed lot. *Journal of Applied and Environmental Microbiology,* 70 (1): 1528 – 1536.

Zalba, B., Marin, J. M., Cabeza, L. F., and Mehling, H. (2003). Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. *Journal of Applied Thermal Engineering* 23 (2): 51 – 83.

Zell, E., Krizan, Z., and Teeter, S.R. (2015). Global gender differences can be operationalized and tested. *American psychologist Journal*, 70(7): 664 – 665.

Zhang, Y., Lin, B., and Chen, J. (2007). Optimum performance characteristics of an irreversible solar-driven Brayton heat engine at the maximum overall efficiency. *Renewable Energy Journal,* 32: 856 – 867.

Zhang, Z., Hu, H., Tian, F., Yao, X., and Sivapalan, M. (2014). Groundwater dynamics under water-saving irrigation and implications for sustainable water management in an oasis: Tarim River basin of western China. *Journal of Hydrology Earth Systems Science*, 18: 3951– 3967.

Zondag, H.A., De Vries, D.W., Van Helden, W.G.J., Van Zolingen, R.J.C., and Van Steenhoven, A.A. (2002). The thermal and electrical yield of a PV-thermal collector. *Solar Energy Journal*, 72: 113 – 28.

Appendices

Appendix. 1: Questionnaire

WATER SOURCES, WATER TREATMENT, WATER QUALITY AND USE IN ISIOLO COUNTY

County……………….. ………………….Sub-county …………………………………………

Location ………………….. ……………...Sub-location ……………………………………..

Name of interviewer……………………………… …….Date of interview………/……../2016

Introduction

This is to introduce you to the study on water sources, treatment, quality and use and their impacts on household food processing and general health at large. The study is being conducted Isiolo County. The aim of the study is to assess the current situation in household water handling and the various water sources within the rural set-ups of Kenya. This information would be used in designing appropriate solar water disinfection system prototype with optimized operation systems to enhance accessibility to potable water for various household uses especially food processing operation thereby ensuring proper public health. You are therefore being requested as a key stakeholder, to spare some time to answer questions in this questionnaire. Your responses shall be used in strict confidentiality and shall not be attributed to you without your express permission. Please feel free to end the interview any time if you feel uncomfortable with it. Do you wish to continue with the interview?

I accept to take part in the study: Yes ( ) No. ( )

Personal identification

Respondent's name ………………………………………………………………

Gender ( ) 1= Male, 2= Female

Section A: Demographic and Socio-economic characteristics

1. Age (years) = (   ), Religion-code- (   ), Level of education (   ) and Occupation (   )

Religion	Education	Occupation
1= Christian 2=Muslim 3=Traditionist 4= Others (specify)	1= In Primary 2=Primary drop-out 3=Completed primary 4=Secondary drop-out 5=In secondary 6=Completed secondary 7=Tertiary level 8=University 9=Adult education 10= Other (specify)	1= salaried employee 2=farmer 3=Self employment 4=Casual laborer 5=Student 6=Unemployed 7=Others (specify)

Section B: Source of water.

2a.) where do you get your water for various domestic use from? ……(   )……………………..

1= River, 2 = Pan and Rain, 3 = Urban treated, 4 = springs, 5 = Open Shallow wells 6 = Closed shallow well, 7 = Borehole and 8 = others (specify)………………………..

b.) How far is the water source from the house hold? ....(   )................................

1= < 1km, 2 = 1 – 2km, 3 = 2 – 5 km, and 4 = > 5km

c.) which mean of transport do you use frequently to access the water source… (   ) ……

1 = Wheelbarrow/ Hand cart, 2 = Animal (Donkey), 3 = humans, 4 = Motorbikes and Trucks and 5 = other (specify)……………

Section C: Household water handling

3a.) Do you treat your water fetched from the source prior to use? ……(   ) ………

1 = Yes or 2 = No

b.) If your answer in b. above is yes, which method of treatment do you use? ......(   )..........

1= Boiling, 2 = Chlorination, 3 = both boiling and chlorination, 4= Solar water disinfection, 5 = use of herbs and 6 = other (specify) ………………………

c.) Which vessels do you use for fetching water from the source? ……. (   ) ……

1 = Pots, 2 = Jericans without lids, 3 = Jericans with lids, 4 = Pipe and 5 = other (specify) ………

d.) Which vessels do you use for storing food process water? …… ( ) ……..

1 = Pots, 2 = Jericans, 3 = water tanks, 4 = other (specify) ………………..

Section D: Household hygiene practice

4a.) Do you clean your water storage vessel? ….. ( ) ……….

1 = Yes or 2 = No

b.) If yes, how frequently do you clean the vessel?

1. Daily ( ) 2. 2-3 times a week ( ) 3.weekly ( ) 4.monthly ( ) 5.other (specify)……………….

c.) How do you draw drinking water from the storage vessel? …. ( ) …..

1 = same container for drinking and drawing continuously, 2 = Use different container for drawing and drinking, 3 = both methods and 4 = other (specify)…………………………..

d.) Do you sieve your drinking water? ….. ( ) ………..

1 = Yes or 2 = No

e.) what type of sieve do you use? …… ( )

1 = Cloth, 2 = Clay sieve, 3 = traditional herbs, 4 = other (specify) …………………

Section E: Cases of water borne illnesses

5a.) in the last one year, has anyone in your family fallen sick? ….. ( ) ………

1= Yes and 2 = No

b.) If yes, which age group was affected? …… ( )

1= < 10 years, 2 = 10-18, 3 = 18-35, and 4 = >35

c.) What were the signs and symptoms? ……( ) …..

1 = Vomiting, 2 = Diarrhea, 3 = Abdominal pain, 4 = Fever, 5 = other (specify) …….

d.) What was diagnosed as the cause of the illness? …….( ) ……..

1= Food borne, 2 = water borne, 3 = other (specify)………………