EFFECT OF COMMUNITY HYGIENE AND WATER HANDLING PRACTICES ON DRINKING WATER QUALITY IN MPONDWE LHUBIRIHA TOWN COUNCIL, WESTERN UGANDA

BY

MUMBERE WILFRED

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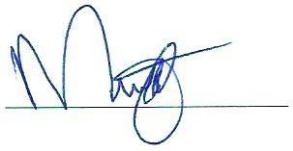
DECLARATION

I, **Mumbere Wilfred,** a student at Kampala International University, declare that this research report is my original work except where references have been made and it has never been submitted for a degree or any award at any University or institution of higher learning that I am aware of.



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APPROVAL

I have read and hereby recommend this thesis report titled "Effect of community hygiene and water handling practices on drinking water quality in Mpondwe Lhubiriha Town Council, Western Uganda" for acceptance by the School of Natural and Applied Sciences in partial fulfillment of the requirements for the award of Master of Science in Environmental Management Degree of Kampala International University, Uganda.

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. **MAIN SUPERVISOR: DR. JULIUS MATSIKO**

Sign: 

Date: 17.10.2023

CO-SUPERVISOR: DR. BARASA BERNARD

Sign: 

Date: 17th October 2023

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LIST OF ABBREVIATIONS

UNBS	Uganda National Bureau of standards.
WQI	Water quality index
WHO	World Health Organization
UNICEF	United Nations International Children's Emergency Fund
ISO	International Organization for Standardization
NWSC	National water and Sewerage Corporation
DRC	Democratic Republic of Congo
WASH	Water, Sanitation and Hygiene
IWRM	Integrated water resource management
NEMA	National Environmental Management Authority
UBOS	Uganda Bureau of statistics
PCR	Polymerase Chain Reaction
RT-PCR	Real Time Reverse Transcription PCR
MPCR	Multiplex PCR
EC	Electro-conductivity
DO	Dissolved oxygen.
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
MPN	Most Probable Number
T.C	Total Coliforms

ABSTRACT

Water safety and quality are fundamental to human development and well-being. The aim of this study was to determine the effect of community hygiene and water handling practices on drinking water quality in Mpondwe Lhubiriha Town Council, Kasese District, Western Uganda. Sixteen samples from different water sources and storage vessels in households were analyzed for physicochemical and microbiological Quality during wet and dry season as described in UNBS Portable water quality analysis guidelines. Characterization of Community hygiene, household drinking water handling practices and risk of water contamination was determined by Qualitative methodology. The study findings revealed that community hygiene and water handling practices had a direct effect on water quality where 97.70% of respondents do not practice household water treatment methods. PH, E.C, TDS, temperature, and total hardness were within permissible limits of WHO standard while there was a variation in Dissolved oxygen and nitrates values. Microbial analysis results showed a variation in Total coli and *Escherichia coli* above UNBS standard this could be due to cross contamination, poor water handling practices where some respondents (41%) had no specific cleaning schedule for water vessels, most respondents (54.00%) were using same vessels for water collection and storage as well as factors from already determined household sanitary risk factor of 39.00-90.00% while Salmonella spp. and Enterococcus bacteria was within limits of WHO standard. This research also revealed that Total coliform and *E. coli* have a strong positive correlation with Nitrate presence in the water samples ($r=0.412$, $p=0.008$) and Nitrates ($r=0.557$, $p=0.000$) respectively. Water from some sources and households in this Town Council is not safe for drinking and domestic use. Therefore, should promote good community hygiene, water handling practices and appropriate household water treatment practices to prevent Drinking water Quality variations from the set WHO standard.

CHAPTER ONE: INTRODUCTION

1.1 Background

Globally, it is approximated that 27% of rural population have no access to sufficient safe water (Ritchie & Roser, 2021). Access to clean and safe water as well as improved sanitation facilities and practices is a key to improved health (WHO, 2015). Goal 6 (Clean water and Sanitation) of United Nations Sustainable Development Goals (SDGs) introduced in 2015, aims to achieve universal and equitable access to safe and affordable water by 2030 (WHO, 2017). To achieve this goal, water should be free from pathogenic micro-organisms, easily accessible, affordable when required (Smiley & Hambati, 2019) and within permissible limits of physicochemical parameters (Hussain, Jamir, & Singh, 2021).

Water quality is affected by microbial pollution and the occurrence of physicochemical parameters and heavy metals above the permissible standards make it unsafe for drinking (Jung *et al*., 2014). Pathogenic agents like viruses, protozoa and bacteria are a leading cause of microbiological contamination of drinking water. This affects human health and can lead to outbreak of water borne diseases like typhoid, cholera, dysentery, acute gastroenteritis, and hepatitis A (WHO, 2009; Sabae & Rabeh, 2007; Gall *et al.*, 2015; Sun *et al*., 2016). Such pathogenic agents are directly transmitted to human beings when faecally contaminated water is used for drinking, preparing food, domestic or recreation purposes (WHO, 2009). Some examples of pathogenic microorganisms present in faecally contaminated water are Salmonella spp., Vibrio cholera, Shigella dysenteriae, *E. coli* and Hepatitis A virus (A-Aljaro, Blanch, Campos, Jofre, & Lucena, 2018; Nouho *et al*., 2018; Omer, 2014). The presence of Escherichia coli in drinking water is a confirmation of faecal matter existence in portable water (Omer, 2014). Contamination of water sources also affects biodiversity more especially, animals that depend on surface waters and unprotected water springs for habitat and drinking like cattle, wild animals and aquatic animals hence affecting the Ecosystem (Sabae & Rabeh, 2007; Olusegun *et al*., 2012). Pollution of water is measured by assessing the physiochemical parameters of water such as NH_4^+, NO_3^-, NO_2, total nitrogen, total phosphorus, dissolved orthophosphates, COD, BOD and total inorganic, organic carbon, EC, pH, DO, turbidity (Dirican, 2015; Lukubye & Andama, 2017).

Microbiological and physicochemical contamination of water sources is a major environmental and public health concern in low developed countries including Uganda since life depends on

water (Cabral, 2010; Lukubye & Andama, 2017). People affected by diseases like typhoid, cholera, dysentery, acute gastroenteritis, and hepatitis A are those with low financial income, poor hygiene, and children under five (Cabral, 2010). In Uganda, 24% of the rural population does not have access to improved water sources (Murduca, 2018). About 3.2 million Ugandans have no latrine thus practice open defecation and 13.8 million share unsanitary latrines; this increases exposure and vulnerability of people to water borne diseases (WSP, 2012). Despite recent improvements in the water and sanitation sectors, some communities still practice open defecation which leads to contamination of water sources through surface run off. This leads to wide spread of diseases like diarrhea, cholera and typhoid (Elliott, 2014).

Mpondwe Lhubiriha Town council has a Gravity flow tap water supply distribution system with pipelines which enables access of water to reach every potential user. Normally, there is a potential opportunity for microbial or physiochemical contamination to exist due to the nature of the distribution system, such as long-distance pipelines, storage tanks, leakages, and interconnections with different users. To control the water quality, water must be microbial safe before entering the distribution system (Bai *et al*., 2022).

Mpondwe Lhubiriha Town council in Kasese District is endowed with various water sources which includes untreated surface waters of River Lhubiriha, River Mpondwe and River Kyanzi, borehole water, open dug wells and protected water springs which is vulnerable and exposed to faecal contamination due to poor municipal waste disposal, surface run off, open defecation and use of unsanitary pit latrines (Parks, 2015; Abdulkadir *et al*., 2018).

1.2 Problem Statement

Mpondwe Lhubiriha is one of the newly created Town Council in Uganda observed with poor sewage system, relies on individual septic tanks and pit latrines for body waste disposal, individual use of designed unsanitary latrines, poor solid waste management, poor hygiene and people still practice open defecation during cross border market days making the water sources and household drinking water in this area liable to microbial and physiochemical contamination. Cholera outbreaks have also been recently reported in this area in 2015, 2017, which predominantly affect communities using the surface water and water springs (Bwire *et al*., 2020).

Furthermore, Government has provided supply of safe domestic water supply through National water and sewerage corporation (NWSC) Grid to Mpondwe Lhubiriha Town Council, this water is for sale leaving the poor community liable to use water from alternative water sources which may be unsafe.

Although studies have been done on waterborne diseases in Mpondwe Lhubiriha Town Council, Kasese District like cholera and typhoid outbreaks (Kwesiga *et al.*, 2017; Neil *et al*., 2012), there is limited information documented on community hygiene, water handling practices and Quality of drinking water in Mpondwe Lhubiriha Town Council. This study therefore investigated sanitary practices, water handling practices, risk of water contamination, level of physiochemical and microbial contamination of selected water sources and household water samples in Mpondwe Lhubiriha Town Council.

1.3 Objectives of the Study

1.3.1 General Objective

The major objective of the study was to determine the effect of community hygiene and water handling practices on the quality of drinking water in Mpondwe Lhubiriha Town Council.

1.3.2 Specific Objectives

1. To characterize community hygiene, water handling practices and risk of contamination in Mpondwe Lhubiriha Town Council.
2. To determine Total Coliforms, *E. coli*, Salmonella spp. and Enterococcus bacteria levels in water samples from selected water sources (protected springs, bore holes, tap water, river) and household water storage vessels in Mpondwe Lhubiriha Town Council.
3. To determine the physio-chemical characteristics of utilized drinking water sources (protected springs, bore holes, tap water, river) and household water storage vessels in Mpondwe Lhubiriha Town Council.
4. To determine water quality Index (WQI) and relationship of water quality parameters.

2. 1.4 Research Questions

1. What is the effect of community hygiene and household drinking water handling practices on the water quality in Mpondwe Lhubiriha Town Council?
2. What is the concentration of Total Coliforms, *E. coli*, Salmonella spp. and Enterococcus faecalis bacteria in water samples from protected springs, boreholes, tap water, surface water (rivers) and household water storage vessels during dry and wet seasons in Mpondwe Lhubiriha Town Council?
3. What is the physio-chemical characteristics of protected springs, boreholes, tap water, surface water (rivers) and household water storage vessels during dry and wet seasons in Mpondwe Lhubiriha Town Council?
4. What is the water quality index (WQI) and the relationship of water quality parameters in Mpondwe Lhubiriha Town Council?

1.5 Significance of the Study

The knowledge generated from this study contributes to the understanding of community hygiene and water handling practices, water microbial and physicochemical contamination status and effect on human health, water pollution prevention, WASH (Water, Sanitation and Hygiene) programs improvement and water resource management. This research will also be valuable from a social-economic and educational point of view since water is a finite resource. Therefore, the outcome of the current study will be a relevant contribution for Mpondwe Lhubiriha Town council decision makers to monitor the rate of water resources exploitation, water pollution and establish possible measures to solve water sources pollution and preventing the spread of waterborne diseases. This will also be used in establishing inter-boundary water resource management measures for sustainable development.

1.6 Scope

This study focused on determining the effect of community hygiene and water handling practices on drinking water quality in Mpondwe Lhubiriha Town Council, Kasese District, Western Uganda. Microbial analyses include Total Coliforms, *E. coli*, Salmonella spp. and Enterococcus bacteria whereas physio-chemical was analyzed for, nitrate, total hardness and On-site measurements like temperature, electric conductivity (EC), TDS, pH, Dissolved Oxygen (DO) and turbidity. The analyses were carried out following the APHA Standard Methods for the Examination of Water and Wastewater (23rd Edition). The study was carried out in Mpondwe Lhubiriha Town Council located in Kasese District, Western Uganda approximately 432km (268 miles) from Kampala City by road.

1.7 Conceptual Framework

Figure 1 presents the conceptual framework for this study and defines the interaction between the independent variables, the process, and dependent variables.

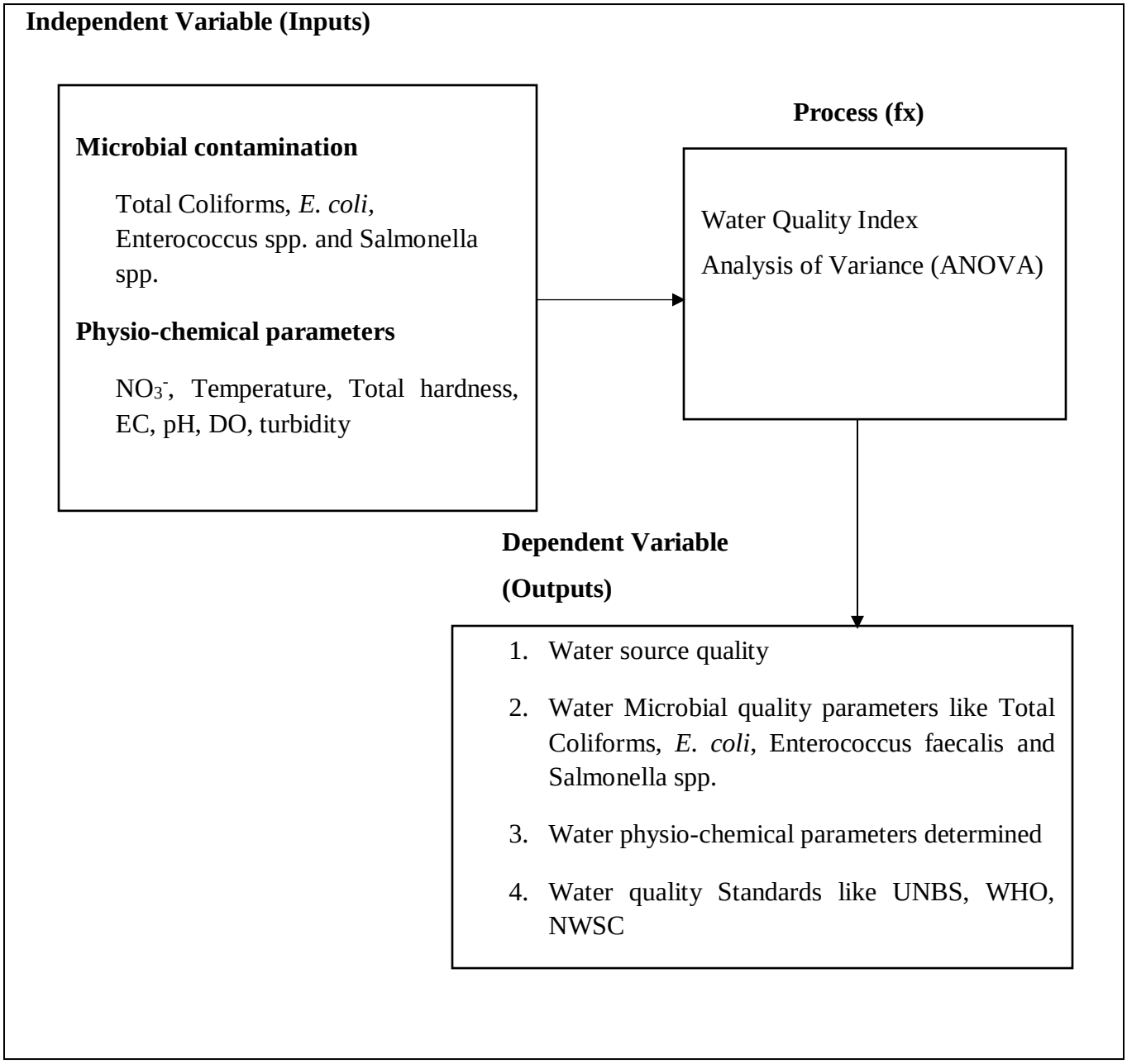

Figure 1: *Conceptual Framework*

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

Adequate safe water availability is essential for water borne diseases like typhoid and cholera prevention. Therefore, access to safe drinking and domestic water in terms of quantity and quality is key to support life (Bwire *et al*., 2020). This literature review has been designed to give a theoretical insight of this research and comprehensive understanding of drinking water microbial contamination and physiochemical properties of water which has guided in the achievement of already set objectives.

2.1 Water Sources

Water is a global and crucial issue. It is an essential need for living things, agriculture and promoting economic development (Nsubuga *et al*., 2014). Sources of water include rivers, lakes, bore holes, tap water, open dug wells, rainwater, and unprotected water springs (Nayebare *et al*., 2014). These water sources are prone to microbiological and physiochemical contamination due to population growth and urbanization (Kwesiga *et al*., 2017; Momtaz *et al*., 2013). Despite the existence of these natural water sources and sanitation programs, different methods of water treatment and purification, human health is still threatened by waterborne diseases due to drinking of water containing pathogens (Nazemi *et al*., 2018).

The effects of water microbiological and physiochemical pollution are evident in Mpondwe Lhubiriha Town Council which harbors River Lhubiriha and other water sources like bore holes, tap water, open dug wells, rainwater, and protected water springs, manifesting itself through the continuous and increasing outbreaks of water borne diseases like cholera reported in the area (Kwesiga *et al*., 2017). Potable water quality is also negatively affected by the following factors: disposal of sewage and industrial effluents, agricultural pesticides and fertilizers, and surface run-offs during heavy rains (Okot-Okumu & Otim, 2015).

According to Bwire *et al*., (2020), 7% of the Uganda population depends on surface water like lakes, rivers, wells and ponds for drinking water. Rivers, lakes, and wells (Surface water) is the most accessible however it is a natural habitat for many microorganisms which are responsible for transmission of water borne diseases such as dysentery, typhoid, and cholera.

2.2 Drinking Water Quality and Public Health

Safe portable water and good sanitation practices protect people from water transmitted diseases and enable the population to be more economically productive. Despite the abundant existence of water, the suitability of water for different uses is determined by the biological, physicochemical and radiological properties of water (Apecu *et al*., 2019). This water should be free from chemical, physical, radiological, and biological contamination (UNBS, 2014). Therefore, water quality is defined as the physical, chemical, microbiological and radiological characteristics of water (Bwire *et al.,* 2020; Omara *et al.,* 2019)**.**

The quality of drinking water is determined by the quality of water source, pollution, the level and treatment efficiency, and condition of water supply lines. Other factors which affect water quality and human health includes community sanitation practices, waste disposal methods, health education undertaken to change people's attitudes and practices related to the use of water and sanitary facilities like toilets to prevent bad practices like open defecation. Sanitation practices/waste disposal methods, water quality and health education are closely inter-related and influence each other on human health (Muyodi *et al.*, 2005) as illustrated in Figure 2 below.

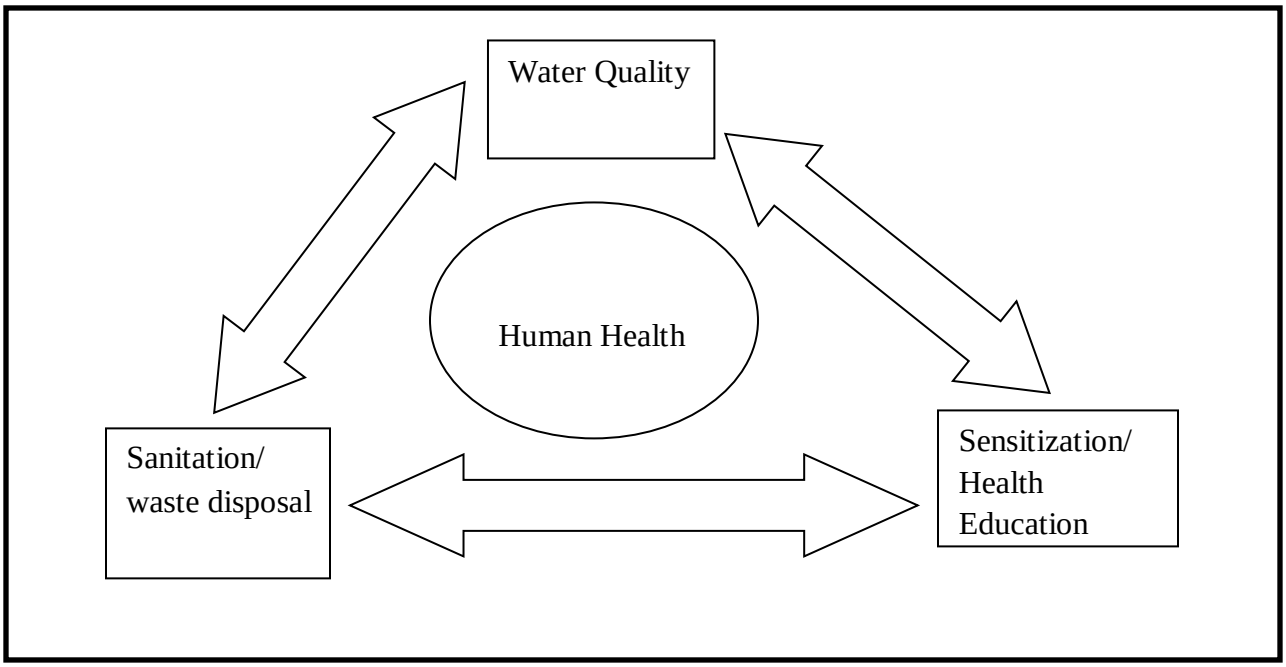

Figure 2: *Showing the relationship between water quality, sanitation, and health education (Source: Muyodi et al., 2005)*

2.2.1 Water Quality Parameters and Standard

The Uganda government has adopted and implemented, US EAS 12:2014 for potable water specification as the standard for drinking water quality and is the basis for the minimum water quality to be produced or used for domestic consumption (UNBS, 2014). The scope of US EAS 12:2014, specifies requirements and methods of sampling and testing for both treated potable water and natural potable water. The general requirement for potable water is that 'It shall be free from organisms and chemical substances that are hazardous and injurious to public health' and comply with requirements in appendix 2 (US EAS 12:2014, Potable Water Specification); (Lukubye & Andama, 2017; UNBS, 2014; Mohandesi, 2015).

Some water quality parameters include the following.

a) Physiochemical properties of water

Physiochemical properties include pH, temperature, electric conductivity (EC), turbidity, total dissolved solids, nitrates, and total hardness. The physiochemical water quality parameters standard is presented in appendix 2 adapted from UNBS Portable water analysis standard, US EAS 12:2014.

i. **pH**: pH is defined as the degree of acidity or alkalinity. It is also defined as the negative logarithm of the hydrogen ion concentration as presented by Equation 2.1 below (Uche, 2021; Bwire *et al*., 2020).

$$\boldsymbol{pH = -log_{10}[H^{+}]} \qquad 2.1$$

Most aquatic organisms live in the pH range of 6.5–8.5. Waste disposal into water sources and microbial decomposition of organic matter in the water body leads to high values of pH (Vyas *et al*., 2015). Acid rain due to the reaction of carbon dioxide accompanied by organic and inorganic solutes present in water also leads to PH variations of water which may lead to variation of other physic-chemical parameters of water. Low pH can cause the release of toxic elements or compounds into the water. Some microbiological organisms like cholera survival are in the alkaline pH range (Bwire *et al*., 2020).

ii. **Temperature**: Temperature is important in controlling the population of water flora and fauna. Water temperature varies with climatic condition changes (Vyas *et al*., 2015). Most

aquatic organisms are adapted to live in a narrow-specified temperature range and die off during drastic temperature variations i.e., when too low or high (Bwire *et al.,* 2020).

iii. **Total Suspended Solids**: These are particles of more than 2 microns in size present. High levels of total suspended solids lead to an increase of water temperatures and decreased dissolved oxygen (DO) levels in water.

iv. **Total Dissolved Solids**: These are defined as dissolved inorganic salts like sodium bicarbonates, calcium sulphate and organic matter in water. This makes Water either be categorized as fresh or salty depending on the quantity of total dissolved solids present (Uche, 2021).

v. **Electrical conductivity**: is a measure of the ability of water capability to transmit electric current (Uche, 2021; Bwire *et al*., 2020; Vyas *et al*., 2015). Electrical conductivity increases with a high temperature, high number of impurities which include dissolved substances, chemicals, and minerals present in water (Uche, 2021; Bwire *et al.,* 2020; Vyas *et al.,* 2015).

vi. **Turbidity:** is an optical measurement of water clarity. It is determined by the ability of light to pass through a water sample and is mostly caused by suspended materials such as clay, silt, organic material, plankton, and other particulate materials in water. Most of these materials come from human activities like construction, mining, and agriculture. High Turbidity levels make water visually unattractive and shield harmful microorganisms (Uche, 2021).

vii. **Colour:** Colour is one of the aesthetic and visual qualities of potable water. High Colour values in water are due to decaying organic matter suspended or dissolved organic matter.

viii. **Hardness**: Hardness in water determines soap's ability to lather in water. It also causes problems of ‘scaling’ in hot water pipes and kettles used for boiling water. There are two types of hardness which includes temporary and permanent hardness. Temporary hardness can be removed by boiling the water.

ix. **Nitrates**: Presence of high concentrations of Nitrates has a significant health risk more especially in infants below 6 months old. It inhibits the transfer of oxygen by reacting with

haemoglobin in the blood. It can also lead to cardiovascular disease, lung disease and other metabolic problems (Sandu *et al.*, 2017).

x. **Sulphates**: Sulphates present in natural water are due to the leaching of naturally existing salts like sodium sulphate or magnesium sulphate. The presence of sulphates in high concentrations above permissible values leads to the unpleasant taste of drinking water.

xi. **Iron**: Iron in water affects aesthetic aspect of water. This happens when soluble iron (11) ions (Fe^{2+} ions) react with air to form insoluble Iron (111) ions (Fe^{3+} ions) which precipitates out of solution to give water a turbid appearance as per Equation 2.2 below. These ions can also cause black or brown stains on laundry and plumbing fixtures. These ions can also cause black or brown stains on laundry and plumbing fixtures.

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3 \qquad 2.2$$

xii. **Alkalinity:** Alkalinity is the ability of water to resist pH variations.

xiii. **Dissolved Oxygen**: DO is the required oxygen for organisms in water to survive. Low dissolved oxygen in water is due to decomposition of organic materials and sewage in water (Vyas *et al*., 2015; Bwire *et al*., 2020).

xiv. **Acidity**: Acidity of water is its quantitative capacity to react with a strong base to a designated pH. Acidity is a measure of an aggregate property of water and can be interpreted in terms of specific substances only when the chemical composition of the sample is known (Vyas *et al*., 2015).

xv. **COD**: COD is defined as a measure of the oxygen equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant. COD is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies. The COD test of natural water yields the total quantity of oxygen that is required for oxidation of a waste to carbon dioxide and water.

2.3 Water Pollution

Water pollution is the contamination of water sources by substances which render water unfit for drinking, domestic use, and other activities due to changes in the physical, chemical or biological properties of water. The major causes of water pollution include high human population growth,

industrial and agricultural activities (Owa, 2014). Some of the sources of water pollution include Domestic waste, industrial effluents, insecticides, pesticides and fertilizers from agricultural activities and detergents from cleaning. These are either from direct (point source) like factories or indirect sources (non-point source) like agricultural wastes. A dispersed (or nonpoint) source is a very broad unconfined area from which a variety of pollutants enter the water body, such as the surface runoff from an agricultural area. Point sources of water pollution are easier to control than dispersed sources because the contaminated water has been collected and conveyed to one single point where it can be treated. Pollution from dispersed sources is difficult to control, and, despite much progress in the building of modern sewage-treatment plants, dispersed sources continue to cause a large fraction of water pollution problems (Owa, 2014; Lin *et al*., 2022).

Water sources contains natural inorganic contaminants like mercury, fluoride, lead, copper, chromium, cyanide and water hardness contaminants which originate from the geological strata through which the water flows and anthropogenic activities-based contaminants like microorganisms and chemicals (Fawell & Nieuwenhuijsen,2003; Sharma & Bhattacharya, 2017). Other water contaminants include Organic contaminants (like domestic waste, pesticides, and industrial wastes), Biological contaminants and Radiological contaminants (Sharma & Bhattacharya, 2017).

a) Domestic sewage

Domestic sewage is the major source of disease-causing pathogens (disease-causing microorganisms) and organic. Domestic sewage contains human body wastes (faeces and urine), wastewater from personal washing, laundry, food preparation and the cleaning of homestead utensils (Mara, 2013; Xie *et al*., 2022; Romdhana *et al*., 2019). The microorganisms present in domestic wastes decompose organic materials present in Water. This leads to depletion of the dissolved oxygen content of water and thus affects aquatic organisms to survive (Mara, 2013).

Domestic sewage is also a major source of plant nutrients, mainly nitrates and phosphates. Excess nitrates and phosphates in water promote the growth of algae. When the algae die, oxygen dissolved in the water reduces due to oxygen use by microorganisms to decompose algae. Anaerobic organisms then breakdown the organic wastes, releasing poisonous gases like methane and hydrogen sulphide, which are harmful to the aerobic organisms (Mara, 2013).

b) Solid waste pollution

Improper disposal of solid waste is the major source of water pollution. Solid waste which affects water quality includes garbage, plastics, rubbish, electronic waste, trash, and construction and demolition waste. Many solid wastes, such as plastics and electronic waste break down and leach harmful chemicals into the water, making them a source of toxic or hazardous waste. Solid waste pollution leads to damage of aquatic ecosystems and can harm wildlife directly (Xie *et al*., 2022; Ribeiro *et al*., 2022; Leal Filho *et al.*, 2022).

c) Sediment

Sediment (e.g., silt) resulting from soil erosion or construction activity can be carried into water bodies by surface runoff. Suspended sediment interferes with the penetration of sunlight and upsets the ecological balance of a body of water. When it settles out of suspension it can smother bottom-dwelling organisms (Davies-Colley *et al*., 2015).

d) Thermal pollution

Another source of water pollution is the discharge of hot water to water sources. This increases water temperature and lowers the metabolic rate of organisms. This then reduces oxygen levels due to plants and algal growth (Owa, 2014).

e) Agricultural sources (Excess fertilizer, herbicides, and pesticides)

Excess fertilizer, herbicides and pesticides is one of the non-point sources of water pollution washed by rain into surface water sources. Excess fertilizers may reach the ground water by leaching and getting in surface waters through surface run and drainage. Excess phosphorus in fertilizer leads to Eutrophication in water sources. Pesticides include insecticides, fungicides, herbicides, rodenticides, and soil fumigant and contain a wide range of chemicals such as chlorinated hydrocarbons, organophosphates, metallic salts, carbonates etc. Many of these pesticides are non-degradable and their residues have long life in the environment (Owa, 2014).

f) Industrial wastes

Industries discharge effluents which contain several inorganic and organic pollutants, which may prove highly toxic to living beings (Iloms *et al*., 2020).

2.3.1 Water Pollution Prevention

According to (Owa, 2014), the following should be done to prevent or reduce effects of Water pollution Prevention,

- Promotion of water conservation methods to prevent water wastage and save water for future use.
- Sewage water and industrial effluents should be treated before discharge to water sources.
- Cooling of hot water before release to water bodies.
- Prevention of cleaning in rivers, streams, and water storage tanks.
- Prohibition of open defecation.
- Excessive use of fertilizers and pesticides around water bodies should be prohibited.

2.4 Water Microbiological Contamination

The microbial contaminants of water include pathogens like bacteria, viruses, and parasites like microscopic protozoa and worms. These living organisms can be spread by human and animal wastes knowingly or unknowingly (Sharma & Bhattacharya, 2017). Untreated municipal waste discharge to water sources is one of major source of biological agents and affects water quality more especially in developing countries like Uganda (Daud *et al*., 2017). Bacterial contamination of drinking water is a major cause of water-borne diseases in rural areas of most developing countries like Uganda where water sources are communally shared and exposed to multiple faecal-oral transmission pathways in their neighborhood boundaries (Gwimbi *et al.,* 2019). Biological contamination of some drinking water sources also results from the influx of runoff from agricultural land after manure applications, breakdown of septic systems, and direct deposition from human beings, animals, and wastewater discharge. Thus, use of biologically contaminated water for drinking, irrigation and recreation poses health risks to people (Saturday *et al*., 2021).

2.4.1 Water Micro-organisms

The ability of drinking water to transport biological pathogens to human beings leading to sickness is well documented in most countries. Most of these biological microorganisms causes water borne diseases due to Faecal contamination of water sources (Forstinus *et al.,* 2016). Some of the microbes which lead to water contamination include Total Coliforms, E. coli, Salmonella spp., Enterococcus spp. and Clostridium perfringens spores (Edberg *et al*., 2000; Rodrigues, 2017).

a) Total Coliforms

Coliform bacteria belong to Enterobacteriaceae family. They are rod-shaped, non-spore forming, Gram-negative, aerobic or facultative anaerobic bacteria (Rodrigues, 2017) and capable of fermenting lactose to produce acid and gas at a temperature of 37 ±1 °C within 48hrs. They harbor

in the environment and faecal matter of warm-blooded animals and humans. The presence of coliforms in water is an indicator for presence of disease-causing microorganisms in water which leads to a decrease in water quality (Bai *et al.*, 2022).

b) ***Escherichia coli***

Escherichia coli (*E. coli*) is part of the Enterobacteriaceae family and harbors in the intestines of warm-blooded animals. It has a rod-shape, non-spore forming, Gram negative, facultative, has a diameter of approximately 0.5 µm and a length of 1.0 to 3.0 µm (Nurliyana *et al*., 2018; Lim *et al*. 2010) and a thermo tolerant coliform with the ability of fermenting lactose to produce acid and gas at a temperature of 44 ±0.5 °C (Bai *et al.*, 2022). They harbor large intestines in humans and are associated with several different diarrheal illnesses. The route of ingestion by human beings is through faecal-oral route. The incubation period for most *E. coli* strains is 10 hours to 14hrs depending on environmental conditions like temperature (Makvana & Krilov, 2015). *E. coli* presence is associated with fecal contamination (Bai *et al.*, 2022).

c) Salmonella Species

It's also part of Enterobacteriaceae family with diameters around 0.7 to 1.5µm, lengths from 2 to 5 µm and flagella that move in all directions, rod shaped, Gram negative facultative anaerobe, predominantly motile and non-spore forming bacterium (Momtaz *et al*., 2013; Eng *et al*., 2015).

d) Faecal Enterococcus

Faecal Enterococci are Gram-positive cocci, possess spherical cells, non-motile, and able to ferment carbohydrates to produce lactic acid. The optimum growth temperature is about 37°C (Sinton *et al*., 1993). This type of bacteria persists longer in the environment compared to other types of bacteria like *E. coli* and total coliforms (Bai *et al.*, 2022).

e) **Factors affecting microbiological growth in water.**

Total coliforms, *E. coli*, Enterococcus and Salmonella spp. reproduce by binary fission (Micha & Corradini, 2011) and the Physio-chemical factors which determine the growth of these microbes include temperature, presence of nutrients, water suspended solids and pH (Messner *et al*., 2006). The growth of micro-organisms normally occurs in the five stages as shown by Figure 3 (Micha & Corradini, 2011).

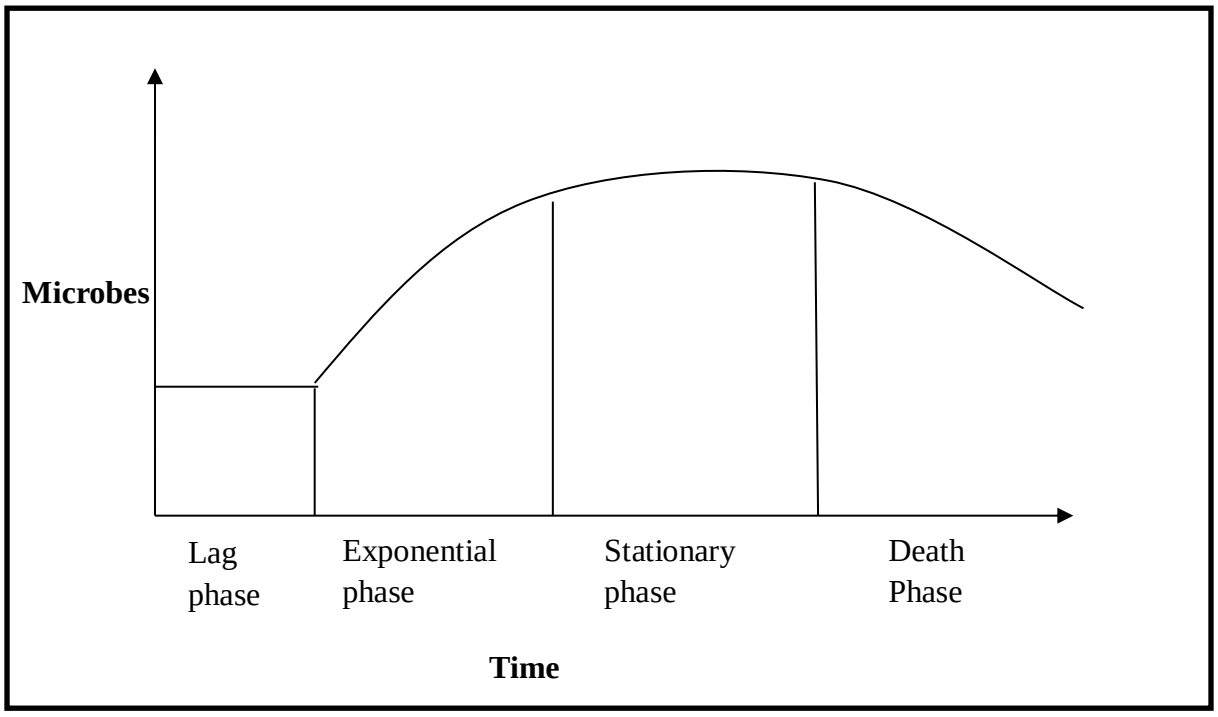

Figure 3: Growth curve of water microbes (source: Micha & Corradini, 2011).

During lag phase, the cells of microorganisms may grow but not usually in number; the log phase (exponential phase) is a period characterized by cell doubling and new microorganisms appearing per unit time proportional to current population; Stationary phase results from a situation in which growth rate and death rate are equal due to growth limiting factors such as depletion of essential nutrients and at death phase, microorganisms die. This could be caused by lack of nutrients, environmental temperature above or below the tolerance band for the species, or other distressing conditions (Micha & Corradini, 2011).

2.5 Sanitation

According to the report published by (Fuller *et al*., 2022), poor water sanitation and lack of safe drinking water take a greater human death toll than war, terrorism and weapons of mass destruction combined. This has been brought by; insufficient financial budget to water sector; Lack of safe water supply and lack of effective sanitation services and poor hygiene (Fonyuy, 2014). The post-2015 Sustainable Development Goals for sanitation call for universal access to adequate and equitable sanitation and an end to open defecation by 2030 (Okullo *et al*., 2017). Several scholars advocate for use of sanitary inspection as a vital tool in identifying causes of water contamination,

risk of future contamination and overall assessment of operation and maintenance of water sources (Lukubye & Andama, 2017; Daniel *et al*. 2020; Haruna *et al*., 2005).

Water quality and sanitation improvements, in line with good hygiene behavior change can possess significant impacts on human health through reduction of water transmitted diseases which can reduce morbidity and mortality rates and improved standards of living as illustrated by figure 4 below.

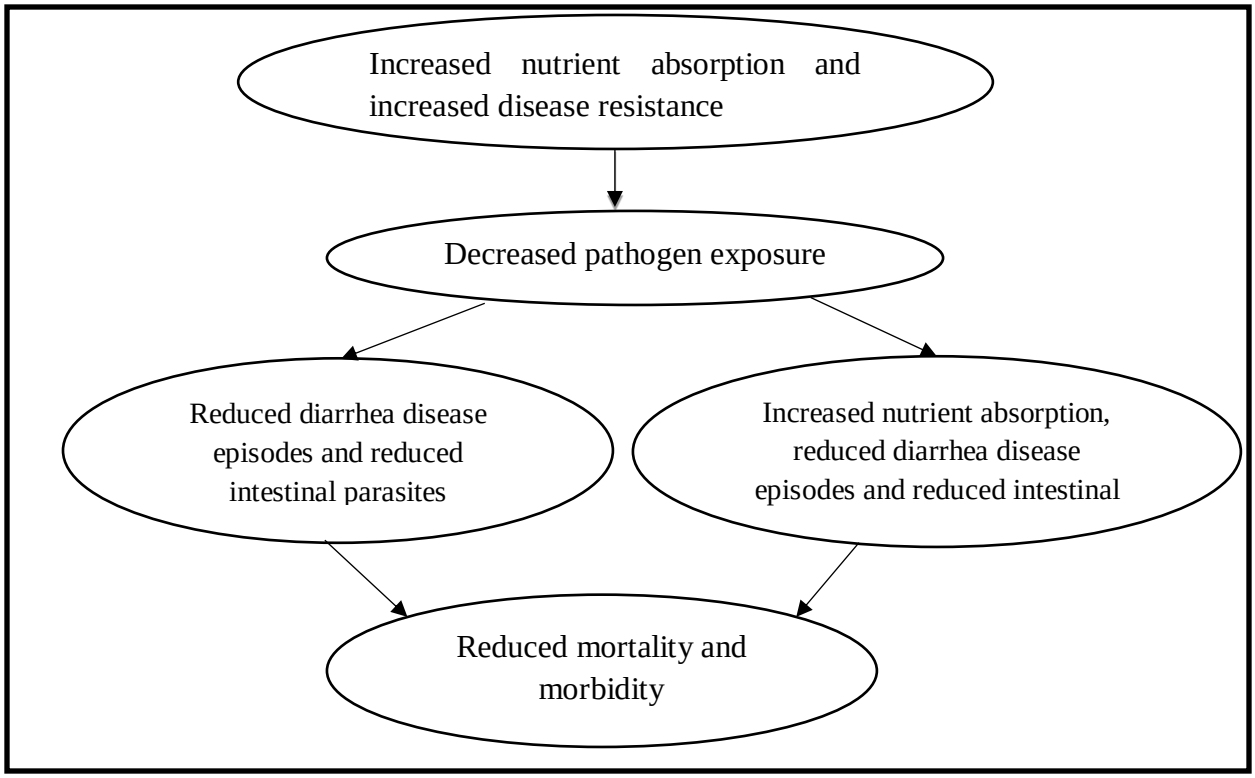

Figure 4: *Relationship between water quality, sanitation, and hygiene*

2.6 Water Transmitted Diseases

Despite numerous efforts by Government and Non-Governmental Organizations to provide safe water, the role of water as a vehicle for the transmission of waterborne diseases presented in table 1 remains a fact of major public health and environmental concern (Forstinus *et al.,* 2016). According to Elliott, (2014); the release of untreated waste to water sources provides the ideal breeding sites for disease spreading insects like houseflies and mosquitoes which acts as vectors for diseases through water, food prepared by contaminated water, directly to food or host mouth as presented in Figure 5. Also, poor environmental practice which encourages the breeding of

insects and other forms of vectors within residential areas contribute to the increasing spread of waterborne diseases (Forstinus *et al.,* 2016; Gwimbi *et al.,* 2019).

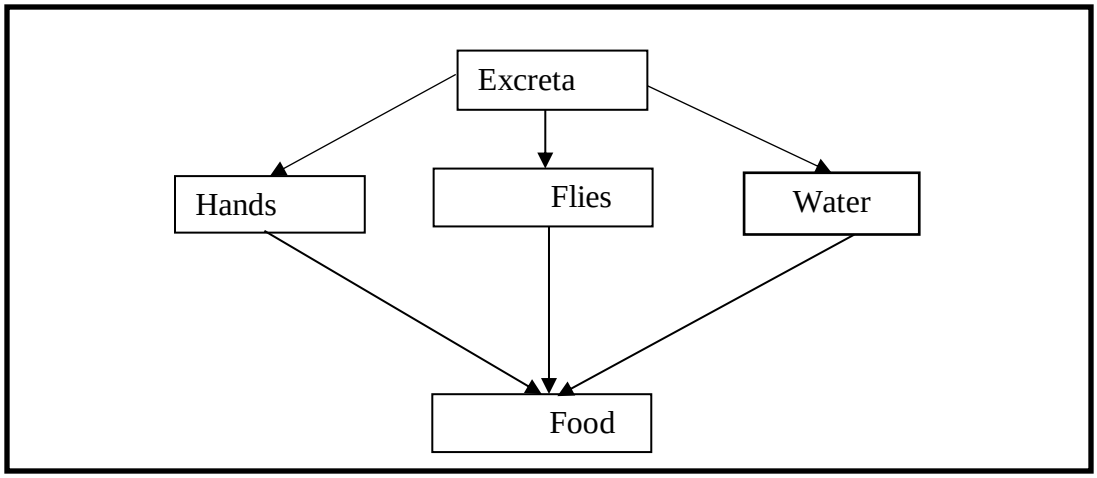

Figure 5: *Inter linkage of untreated wastes (excreta) and water borne diseases transmission to human beings adapted from (Elliott, 2014).*

Table 1: Water borne diseases (Source: Forstinus *et al*., 2016).

Disease	**Microbe type cause**
Cholera	Vibrio cholera
Giardiasis	Giardia intestinalis
Typhoid (fever)	Salmonella typhi
Hepatitis A and E	Hepatitis A and E viruses
Bacillary dysentery	Shigella dysenteriae

2.7 Water Microbiological Quality Analysis Methods

Microbial methods for quality analysis of drinking water sources are lacking in most settlements of rural and semi-urban. Additionally, microbial water quality analysis standard methods used as per WHO standards and National water quality standards in even developed countries may be extremely difficult to use in these types of settlements to ensure drinking water safety *(*Apecu *et al.,* 2019).

Total Coliforms, *E. coli*, Enterococcus and Salmonella spp. analysis in water is commonly carried out by multiple fermentation tube or most probable number method where measured quantities of

a water sample are put in test-tubes consisting of a culture medium and then incubated at a standard temperature and time frame (Ell-amin *et al*., 2012). The second method is called "Membrane filtration" method where a measured quantity of water sample is passed through a fine filter that retains bacteria. The filter is then put on culture medium and incubated at a particular standard temperature (USEPA, 2006). Other methods which are used include defined substrate, hydrogen sulphide, micro arrays, Multiplex PCR (mPCR) and Real-Time Reverse Transcription (Forstinus *et al*., 2016).

2.8 Determining the Physio-chemical characteristics of drinking water.

Testing water quality assures water quality to achieve Millennium Development Goals (MDG) 2015 of access to safe water. Water testing helps in drinking water quality parameters verification, disease outbreaks investigation and effective decision-making for policy makers (Bain *et al*., 2012). Water quality therefore has an impact on human health (Muyodi *et al*., 2005).

Van Butsel, *et al*., (2017) in their study on ecological water quality assessment of the Mpanga catchment, Western Uganda used the Belgian standard procedures (WAC/I/A/003 and WAC/I/A/010) for sample collection, preservation, and analysis.

Lukubye & Andama, (2017) assessed the Physio-chemical quality of selected drinking water sources (springs, boreholes, shallow wells, and rainfall) in Mbarara municipality with respect to World Health Organization (WHO) drinking water guidelines and other guidelines considering the increased anthropogenic activities in the municipality. Samples were analyzed for Physio-chemical parameters: Temperature, pH, Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), Electrical Conductivity (EC) and Total hardness using American Public Health Association (APHA) standard methods.

Gebresilasie, Berhe, Tesfay, & Gebre, (2021) assessed the levels of some physicochemical parameters and heavy metals in hand-dug well water sources of Kafta Humera Woreda. The concentrations of most physicochemical parameters of the hand-dug well water samples of Kafta Humera Woreda were within the permissible limit of World Health Organization and Ethiopian Standard Agency guideline for drinking water.

Ojok, Wasswa, Nakiguli, & Ntambi, (2019) studied the spatial variation in physio-chemical surface water quality in river Rwizi, Western Uganda. Laboratory analysis was conducted on water samples from five sites along the river section using standard methods for: pH, EC, TSS (Total

suspended solids), TDS, turbidity, temperature, total hardness, alkalinity, salinity, color, SO_4^{2-}, BOD, COD, DO, Ca, Mg, Fe and Mn using the respective equipment standard test methods.

Madilonga, Edokpayi, Volenzo, Durowoju, & Odiyo, (2021) temporarily assesses the water quality characteristics of Mutangwi River. Physio-chemical parameters (pH, temperature, total dissolved solids (TDS), salinity, electrical conductivity (EC), and turbidity) were determined in situ using an Extech multimeter and turbidity meter. The concentration of the selected metals (Mg, Cr, Fe, Cd, Mn, Pb, Ca, and Na) were analyzed using an Atomic Absorption Spectrophotometer. Membrane filtration method was used to analyze microbiological parameters (*Escherichia coli* and Enterococci). The physio-chemical water quality parameters as well as basic anions (fluoride, phosphate, sulphate, nitrate, and chloride) determined complied with the regulatory guideline of the World Health Organization (WHO) and the South Africa National Standards (SANS).

According to Okey-Wokeh, Obunwo, & Wokeh, (2021), Water Quality Index (WQI) is employed to aggregate different parameters into single numerical value to determine the suitability of water quality for human consumption.

Rahman, Jahanara, & Nahar (2021) assessed the physio-chemical properties of water and their seasonal variation in an urban river in Bangladesh. Water samples were collected in four distinct seasons to evaluate temperature, pH, dissolved oxygen concentration, five-day biochemical oxygen demand, chemical oxygen demand, electrical conductivity, chloride ion, concentration, total alkalinity, turbidity, total dissolved solids concentration, total suspended solids (TSS) concentration, and total hardness using standard methods (APHA, 2005).

Gebresilasie *et al.,* (2021) conducted a study on the assessment of some physicochemical parameters and heavy metals in hand-dug well water samples of Kafta Humera Woreda, Tigray, Ethiopia. Generally, the concentrations of most physicochemical parameters of the hand-dug well water samples of Kafta Humera Woreda were within the permissible limit of World Health Organization and Ethiopian Standard Agency guideline for drinking water.

Various methods for determining nitrates in water include spectrometric, fluorometric, luminescent, electrophoretic, electrochemical and chromatographic methods (Sandu *et al.*, 2017).

2.9 Water Quality Index

WQI is used to measure large number of water quality parameters and summarizes them to form a single quality value (index) in percentage which gives the General quality health status of water at a given location in an easy-to-understand way for easy decision making (Fashina, 2021; Tyagi *et al*., 2013). Some of WQI used includes Canadian Council Water Quality (CCME WQI) and Weighed Arithmetic Water quality index method (WQI).

a) Canadian council Water Quality (CCME WQI)

The CCME WQI determination is based on the following factors which includes Scope (F1), Frequency-F2 and Amplitude-F3 where Scope (F1) represents the ratio of failed parameters to total number of parameters measured in percentage, Frequency (F2) represents the percentage of specific tests that do not comply with the guidelines and Amplitude (F3) represents the amount by which failed test values do not comply with their guidelines. All these factors are determined and fed in CCME WQI equation 3.9 as elaborated in the methodology. Once the CCME WQI value has been calculated, water quality is classified accordingly (Al., 2017).

b) Weighed arithmetic Water quality index method.

WQI calculation follows the following steps; quality parameter selection, sub-indices generation, establishment of parameter weights, and final index aggregation as addressed in Figure 6 (Akhtar *et al.* 2021).

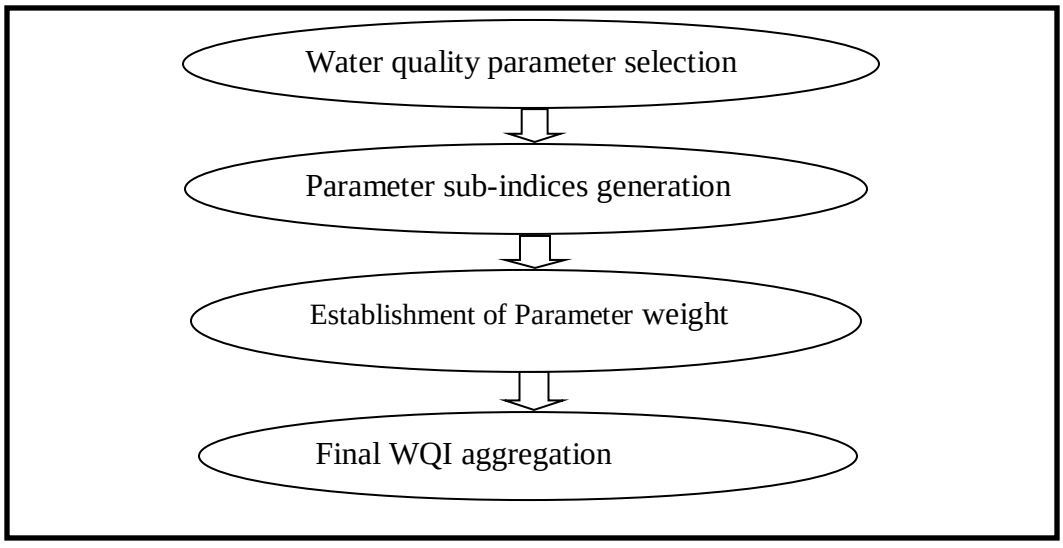

Figure 6:*WQI calculation flow (Akhtar et al., 2021)*

WQI Equation

$$WQI = \frac{\sum Q_n * W_n}{\sum W_n} \quad 2.3$$

The quality rating scale $(\mathbf{Q_i})$ for each parameter is calculated by using Equation 2.4:

$$\mathbf{Q_i} = \mathbf{100}\left[\left(\frac{V_i - V_o}{S_i - V_o}\right)\right] \quad 2.4$$

Where, is estimated concentration of with parameter in the analysed water, is the ideal value of this parameter in pure water (except pH =7.0 and DO = 14.6 mg/l), is recommended standard value of ith parameter.

The unit weight (W_i) for each water quality parameter is calculated by using the following formula:

$$\mathbf{W_i} = \frac{\mathbf{K}}{\mathbf{S_i}} \quad 2.5$$

Where, K = proportionality constant and can also be calculated by using the following equation:

$$\boldsymbol{K} = \frac{\mathbf{1}}{\sum(\mathbf{1}/\boldsymbol{S_i})} \quad 2.6$$

Other Water quality indexes which have been developed include the Nation Sanitation Foundation Water Quality Index (NSFWQI), Oregon Water Quality Index (OWQI), and the Weighted Arithmetic Water Quality Index (WAWQI). The difference between the above indexes is the statistical integration and interpretation of parameter values (Addisie, 2022).

2.10 Community hygiene and household drinking water handling practices

The presence of poorly designed pit latrines, poor hygiene practices, poor sewage systems, poor wastewater management, poor solid waste management as well as poor water collection and storage methods, may lead to contamination of water with pathogenic bacteria. Therefore, access to a safe water source alone does not ensure consistent quality of portable water. Furthermore, a better water source does not lead to full health benefits in the absence of improved water storage and sanitation, therefore good hygiene practices and handling practices are very critical in water quality management (Momtaz *et al*., 2013). Community hygiene and household drinking water handling is commonly determined by use of designed questionnaire and cross-sectional sanitary assessment (Haruna *et al*., 2005).

2.11 Pathogens removal (water treatment) methods from Drinking Water

Besides the protection of water sources, water treatment is very important towards removing contaminants from drinking water sources and systems. Water treatment steps which involve pre-treatment by coagulation, flocculation, sedimentation, and filtration stages are required to remove particles from the water source. Water is further taken through post treatment stages of disinfection to reduce disease causing pathogens like bacteria by chlorination or any other type of disinfection (Bai *et al.*, 2022).

The following methods are commonly used for removal of pathogenic bacteria, disinfection by use of Chlorine and ferrate (VI), Ozonation, water filtration, boiling, distillation, reverse osmosis, use of fiber filters, ceramic filters, UV irradiation softeners, activated alumina and use of sediment filter (Chandra, 2017).

a) Water disinfection by boiling

Boiling is the oldest and most common method of household water treatment (HWT) recommended by WHO's International Network on HWT and Safe Storage if done correctly to ensure pathogen free drinking water among at-risk populations. Intake of un-boiled water can lead to water transmitted diseases such as cholera, dysentery, and typhoid (Juran & MacDonald, 2014; Onyutha *et al.*, 2022).

b) Disinfection by use of Chlorine

Chlorination refers to addition of a measured amount of chlorine to water to kill disease causing pathogens like bacteria and viruses. Chlorine inactivates microorganisms by damaging their cell membrane. Once the cell membrane is weakened, the chlorine can enter the cell and disrupts two survival processes of cell respiration and DNA activity. The killing effect of chlorine depends on the pH of the water, temperature, chlorine level and contact time.

Chlorine reaction in water

When Chlorine gas (Cl_2) is added to water, it hydrolyses to form Chlorine Hypochlorous gas acid (HOCl) as per reaction equation 2.7 to 2.8. The formed hypochlorous acid is a weak acid and dissociates in water to release free Hydrogen ions (H^+) as per reaction equations below and this degree of ionization depends on the pH and temperature of the water (Bowman & Mealy, 2007).

$$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^- \qquad 2.7$$

$$HOCl \leftrightarrow H^+ + OCl^- \quad (2.8)$$

The generated H^+ ions in both equations lower water pH. The generation of free H+ ions help to lower water pH and most microorganisms rarely survive at low pH values (Sharma & Bhattacharya, 2017).

2.12 Summary of related Literature and Research Gaps

Momtaz et al., (2013) found out that safe water supply to a community is not a guarantee for water safety since contamination also occurs during collection, transport, and domestic storage. Momtaz *et al*., (2013) also noticed that tap water supply system/network also experiences leakages leaving water pipes exposed to microbial contamination due to poor sewage system and solid waste disposal. Therefore, this calls for proper water treatment methods before use for human consumption as identified by Chandra Bhomick (2017). From the literature in Uganda, most researchers have focused on monitoring river and tap water quality; however, there is limited information on protected wells and bore holes.

Despite of sanitary inspection application as a vital tool in identifying causes of water contamination, risk of future contamination and overall assessment of operation and maintenance of water sources (Lukubye & Andama, 2017; Daniel *et al*., 2020; Kelly *et al*., 2021 ; Haruna *et al*., 2005) and conceptual sanitary inspection and water quality, the obtained sanitary risk score is not a comprehensive representation of system risk at a given point in time but is a simplified output of a tool designed to identify observable risk factors and guide corrective action.

CHAPTER 3: METHODOLOGY

3.0 Study Area Description

3.1 Location, Geographical Setting, and Altitude

The study was conducted in Mpondwe Lhubiriha town Council located in Kasese District; Western Uganda as shown in Figure 7. It is located at the boarder of Uganda and Democratic Republic of Congo, approximately 432km (268mi) from Kampala City by road. The geographical coordinates of the town are 0° 02' 24.00"N, 29° 43' 30.00"E (Latitude: 0.0400; Longitude: 29.7250). This Town Council sits at an average elevation of 1,220 meters (about 4002.62 ft) above mean sea level.

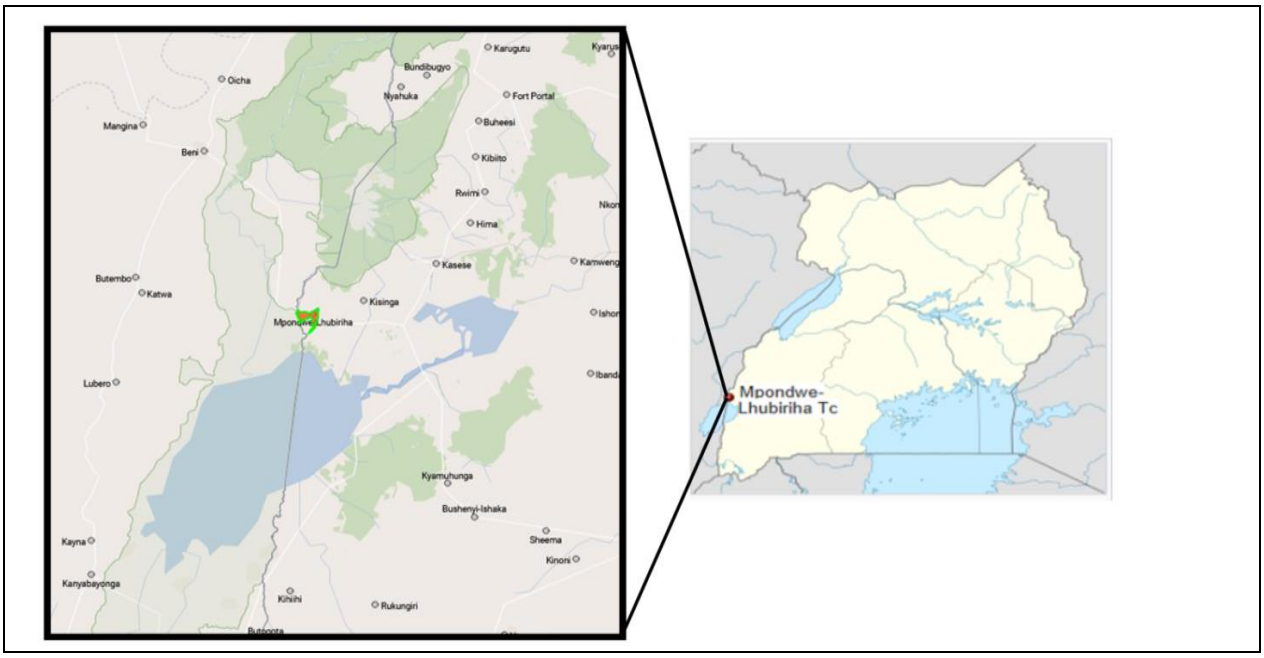

Figure 7: *Map showing location of Mpondwe Lhubiriha town council (Source: Kasese District local Government).*

The area is endowed with different water sources such as rivers, protected springs, boreholes, and streams. The rivers include R. Lhubiriha, R. Mpondwe and R. Kyanzi. It has a mountainous terrain, located on the ranges of Mountain Rwenzori. The main sources of water in the area include rivers, boreholes, protected wells and springs as well as piped tap water (Parks, 2015).

This research was carried out on key portable water collection points of river water (surface water), borehole water, tap water, protected springs and household water storage facilities of Mpondwe Lhubiriha Town Council.

According to Uganda Bureau of statistics, this area has a population of 51,351 people which includes 24,444 males and 26,907 females (UBOS, 2014); experiences two rainfall seasons of March, May, and August-November of around 800 mm (about 2.62 ft) to 1600mm (about 5.25 ft) which supports Crop growth and temperature range from 23^0C to 30.2^0C (Bahati, 2005). Due to this rainfall pattern, the research was carried out from march-may (rain season) and June-July (dry season).

3.2 Research Design

This research employed descriptive and experimental research design. Descriptive research design was used to examine community hygiene, household water handling practices and the risk of water contamination. Experimental research design was applied to determine microbial parameters (Total Coliforms, *E. coli*, Salmonella spp. and Enterococcus ssp.) and physio-chemical parameters which includes pH, temperature, electrical conductivity, total dissolved solids (TDS), turbidity, total hardness, Dissolved oxygen, and nitrates.

3.3 Method of Sample Collection, Sample Size, Storage and Analysis

Simple random sampling was employed in this research. The identified sampling points were mapped by use of Arc GIS basing on qualitative data. Recording of sampling points coordinates was done by use of Global Positioning System (GPS).

3.3.1 Size of Sample and Collection Method

3.3.1.1 Size of Sample

To determine community hygiene and household portable water handling practices. A sample of 200 people were interviewed by use of questionnaires indicated in appendix 1 section 1 and 2 adapted from Equation 3.1 (Fonyuy, 2014)

$$\boldsymbol{N = \frac{(z)^2 \times p(1-p)}{(e)^2}} \qquad 3.1$$

Where, N = required sample size,

N=196 samples/correspondents.

z = 0.95 (confidence interval at z = 1.96),

Population of households= 0.15,

e = 0.05 (random error, type 1 value of 0.05)

$$N = \frac{(1.96)^2 \times 0.15(1-0.15)}{(0.05)^2}$$

N=196 correspondents

Sixteen water sources were randomly selected for sanitary inspection and analysis for physiochemical and microbial properties of water. 16 households were also randomly selected for sanitary inspection, household water physiochemical and microbial analysis.

3.3.1. 2 Sample Collection

Water sampling points were selected randomly from different sections of the town council and labeled in terms of letter codes as indicated in appendix 4.

Introductory letter from Kampala International University was issued to the local authorities to get permission to carry out cross section examination, sanitary inspection and collect water samples from the water sources and household storage facilities for physiochemical and microbial analysis from water sources. Water samples were collected during rainy season (march-may) and dry season (June-August) between 7:00 AM - 01:00 PM. Water samples collection bottles were first sterilized in the autoclave at the temperature of 150-160^{0}C. Water samples were hand-collected in water sample bottles which were put in the ice box and delivered to the laboratory at temperature of < 4 ℃ (UNBS, 2014) for physio-chemical and microbial parameters analysis.

Figure 8: *Sample collection from R. Lhubiriha and Kanyabyondo spring*

3.4 Data Sources and Methods of Collection

To gather qualitative information from the community, data collection methods consisted of informant interviews, questionnaires, sanitary inspections, local leader's consultations, review of existing water quality and health information, and participatory observation. This method allowed for free exchange of information with the participants and local leaders. This helped in easy determination of the sampling points.

Portable water quality National standard data was obtained from UNBS and WHO 2017 guidelines (UNBS, 2014). The Quantitative data obtained from water quality analysis results was statistically analyzed by Pearson's correlation and water quality index approach (WQI). The paper map of the Town Council was obtained from Kasese District Natural resources department.

3.5 Data Processing

3.5.1 Characterization of utilized drinking water sources, community hygiene, Water handling practices and risk of contamination in Mpondwe Lhubiriha Town Council.

A list of structured interviewer-administered questionnaires was designed as indicated in the appendix 1 section 1 and 2 where a sample of 196 adults of at least 18 years old and with capacity to manage a family were interviewed. However, 220 structured interviewer-administered questionnaires were distributed to cater for any questionnaires with incomplete information. These questionnaires were used to enable acquisition of respondent general information, community hygiene practices, water treatment methods, household drinking water handling ability and knowledge, water handling practices of all selected water users during water collection, transport, and home water storage adapted from Murduca (2018).

A cross-sectional sanitary assessment was done as indicated in appendix 1, section 3 in each of the selected water sources and household to identify the risks of water contamination by completing standardized number of questions answered with either a yes or no answer for required risks of different water sources (Okullo *et al*., 2017). A score of one point was awarded for each "yes" answer (risk observed) and zero point for each "no" answer (no risk observed). By summing all "yes" scores, a final risk score was obtained which is equivalent to total sanitary risk score which was graded as zero (0%), low (1% to 30%), moderate (31% to 50%), high (51% to 80%), and very high (81% to 100%) (Haruna *et al*., 2005).

3.5.2 Determining the Total coliforms, *E. coli*, Salmonella spp. and Enterococcus levels in water samples from selected water sources and household water storage equipment.

Water samples from selected water sources and household water storage facilities, were analyzed for concentration of Total Coliforms, *E. coli*, Salmonella spp. and Enterococcus during wet season (January 2022-March 2022) and dry season (May 2022 to August 2022) by Multiple fermentation tube technique as described in UNBS Portable water quality analysis guidelines, US EAS 12:2014 (UNBS, 2014). Safety guidelines were followed as per guidelines in material safety data sheets (MSDSs) and general laboratory rules and regulations.

a) Equipment used

Glass bottles of capacity of 200 ml, Glass lens with magnification of 2-5X, stereoscopic microscope, Pipette container, Sterile graduated cylinders (100-1000 ml) covered with aluminium foil , Sterile membrane filtration units (filter base and funnel), glass wrapped with aluminium foil, Flask, filter, forceps to handle filters without damage , Thermometer, Petri dishes, 250-2000 ml volume Flasks, Membrane, Absorbent pads, Platinum wire inoculation loops, Water bath, test tubes (20 × 150 mm, borosilicate glass), Test tubes, 10 × 75 mm, borosilicate glass (Durham tubes), Caps for 20 mm diameter test tubes, Test tubes screw-cap and Filter Papers.

Figure 9: *Equipment and reagents used.*

b) Sterilization

All the glassware used in this research was wrapped in aluminium foil and sterilized in the oven at 160°C for one hour. The plastic equipment used in this analysis was sterilized in 90% ethanol for two hours and dried in an incubator at 45°C. The surface of the working table where the practical was carried out was disinfected with 95% ethanol before start-up of the experiment. Loop wires and forceps sterilized by flaming on the Bunsen burner (Idriss & Salim, 2009).

c) Reagents

MacConkey's broth, Ethanol, Distilled water, and Phosphate- buffered dilution water.

d) Culture media preparation

50 grams of MacConkey agar powder was Weighed and put in 1 Liter of purified water and mixed thoroughly well. The pH was adjusted to 7.4 and the mixture was heated to boiling until solids dissolved in water. The mixture was then sterilized by Autoclave at 121°C for 15 minutes. The mixture was then cooled to 45-50°C and mixed well before being poured into sterile Petri plates. The mixture was allowed to solidify.

e) Water samples collection

Water samples were hand-collected in water sample bottles, put in the ice box and delivered to the laboratory at temperature of < 4 °C (UNBS, 2014) for physio-chemical and microbial parameters analysis.

f) Procedure

The test was done according to the method described by water quality analysis guidelines, US EAS 12:2014 and (Ell-amin *et al*., 2012). Three volumes of a water sample were prepared for each analysis. Serial dilution of sample in phosphate buffered dilution water was done as indicated in figure 10 and figure 11. The appropriate volumes of sample and diluted sample were pipette into the tubes of medium and mixed gently. The tubes were labeled with sample numbers. Two sets of three tubes were cultured: one incubated at 37^{o}C for the detection of total coliforms, Enterococcus and the other at 44^{o}C for detection of thermo tolerant *E. coli* and salmonella.

After 24 hours the tubes which showed growth (turbidity and gas production or color change) were regarded as positive, the number of positive tubes at each dilution was recorded. According to (Idriss & Salim, 2009; Ukpong & Udechukwu, 2015), total coliforms is confirmed by color change to red at incubation temperature of 37˚C for 24 hr, Enterococcus is detected by color change to

mucoid pink, Thermo tolerant *E. coli* is determined by color change to red at incubation temperature of 44˚C for 48 hr and salmonella spp. to Colorless at incubation temperature of 44˚C for 48 hours. Then the negative tubes were returned to the incubator and re-examined after 48 hours of incubation. The pattern of positive results was compared with Most Probable Number (MPN) as shown in Mc Crady's probability table in Appendix 4.

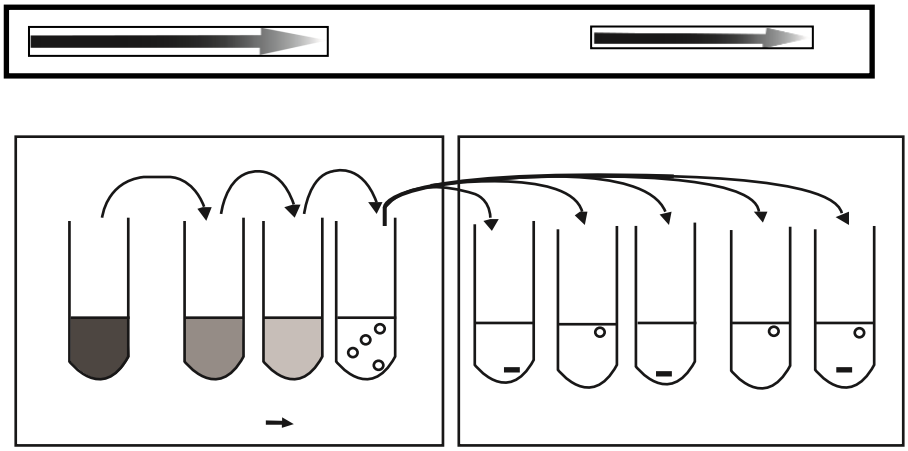

Figure 10: *Showing serial dilution of sample in phosphate buffered dilution water.*

Figure 11: *Showing serial dilute sample in phosphate buffered dilution water.*

3.5.3 Determining the physio-chemical characteristics of selected water sources and household water storage Vessels.

3.5.3.1 Onsite Physio-chemical parameters

Temperature, pH, electric conductivity, turbidity, Dissolved oxygen, and total dissolved solids were measured immediately onsite after sampling by use of a multi-meter (model HI "HANNA" instrument). The multi-meter was first calibrated as per the manufacturer's guideline before taking the measurements. The multi-meter probe was submerged in the water sample and held for some time to achieve stable readings. After reading the results, the multi-meter probe was rinsed with de-ionized water to avoid cross contamination among different water samples.

3.5.3.2 Nitrates

Analysis of nitrates was done in the laboratory by use of spectrophotometer Model DR 3900 as per user manual guidelines of the machine. HACH program was pressed on the equipment screen; **Nitrates** stored program **355 N, Nitrate HR** was selected from the main menu and pressed on. 10ml of water sample was measured and put in sample cell; the prepared sample was put into the sample holder, Contents of Nitra Ver Nitrate reagent powder pillow were added, timer icon was pressed, the cell was vigorously shaken until the timer beeped, an amber color developed after beeping for samples where nitrates were present, blank test was carried out by filling second cell with 10ml of water sample, zero icon on the screen was touched and display of 0.0 mg/l NO_3^- -N appeared till the timer beeped, the prepared sample was placed in a cell holder and read button on the screen was pressed and then results for NO_3^- in mg/l were read and recorded.

Figure 12: *Spectrophotometer Model DR 3900*

3.5.3.3 Total Hardness

Total hardness was determined by EDTA titrimetric where 100 mL of the sample (Vs) were poured into a conical flask. 2-3 drops of Solo Chrome Black T indicator were added to the sample and mixed thoroughly well and then titrated using 0.01N EDTA to a blue end point. The end point titre value of EDTA (V_t) was recorded.

Total hardness mg/l was calculated as:

$$CaCO_3 = \frac{V_t \times 1000}{V_s} \qquad 3.2$$

3.5.4 Determining Water Quality Index and relationship of water quality parameters.

3.5.4.1 Water Quality Index

The CCME WQI equation was used to determine WQI based on factors which includes; Scope (F1), Frequency-F2 and Amplitude-F3 adapted from (Al, 2017).

a) Scope (F1):

$$F1 = \frac{\text{No.of failed parameters}}{\text{Total No.of parameters}} \times 100 \qquad 3.3$$

b) Frequency (F2):

$$F1 = \frac{\text{No.of failed tests}}{\text{Total No.of tests}} \times 100 \qquad 3.4$$

c) F3 (Amplitude) represented the amount by which failed test values did not comply with their guidelines and were calculated in three steps.

Step-1: Calculation of excursion.

When the cases in which the test values were not above the set standard:

$$\text{excursion} = \frac{\text{failed test value}_j}{\text{Objective}_j} - 1 \qquad 3.5$$

For the cases in which the test values were not to drop below the set standard (guideline):

$$\text{excursion} = \frac{\text{Objective}_j}{\text{failed test value}_j} - 1 \qquad 3.6$$

Step-2: calculation of normalized sum of excursions (nse). This is the collective amount by which individual tests were out of standard and was calculated by summing the excursions of individual tests from their standards and divided by the total number of tests (both those meeting the standard and those not complying with the standard).

$$nse = \frac{\sum_{i=1}^{n} \text{excursioni}}{\text{total no.of tests}} \quad 3.7$$

F3 was then calculated by an asymptotic function that scales the normalized sum of the excursions from guidelines (nse) to yield a range between 0 and 100.

$$F3 = \frac{nse}{[0.01(\text{nse}+1)]} \quad 3.8$$

Once the factors **(F1, F2, F3)** were obtained, the WQI was then calculated from the sum of the squares of each factor as per equation 3.9 below.

$$WQI = \frac{100 - \left[\sqrt{(F1^2 + F2^2 + F3^2)}\right]}{1.732} \quad 3.9$$

Once the CCME WQI values were obtained, water quality was classified into one of the quality categories in Appendix 9.

3.5.4.2 Determining relationship of water quality parameters.

The degree of dependency of Total Coliforms, *Escherichia coli*, Salmonella spp. and Enterococcus levels with physio-chemical parameters of water, community hygiene practices and sanitary risk variables were carried out by use of Pearson's correlation coefficient (r).

3.6 Data Quality Control

Data quality assurance was done by calibrating all instruments before commencement of tests and use of test-retest method. This enabled the achievement of accurate results from the study instruments.

3.6.1 Reliability and Validity of Results

To ensure reliability and Validity of Questionnaires and cross-sectional assessment, a test-retest method was done on similar correspondents to determine consistence of results (Salkind,1997; Field, 2005; Heale & Twycross, 2015). For microbial water analysis, a widely used 3-tube MPN table was preferred which was developed to improve the precision of MPN results by evaluating the data from three consecutive dilutions (Blodgett & Moruzzi, 2006).

3.6.2 Data Analysis

Data analysis was done by using Descriptive and Bivariate statistics of SPSS 20 Program and Excel 2010.

CHAPTER 4: RESULTS

4.1 Characterization of utilized drinking water sources, community hygiene, water handling Practices and risk of contamination in Mpondwe Lhubiriha Town Council.

4.1.1 Primary water sources (utilized drinking water sources)

The majority (58.00%) of the respondents in Mpondwe Lhubiriha Town Council obtain piped tap water as their main source of water. Surface water (Rivers) and spring water are the other most common water sources within the areas being utilized by 17.00% and 16.50% of respondents respectively since they are readily available to the community. 4.00% of respondents utilize ground water (borehole water) and 3.00% of respondents use rainwater as source of drinking water. Bottled water (1.50%) is the least available source to the communities since it's typically commercial on the market.

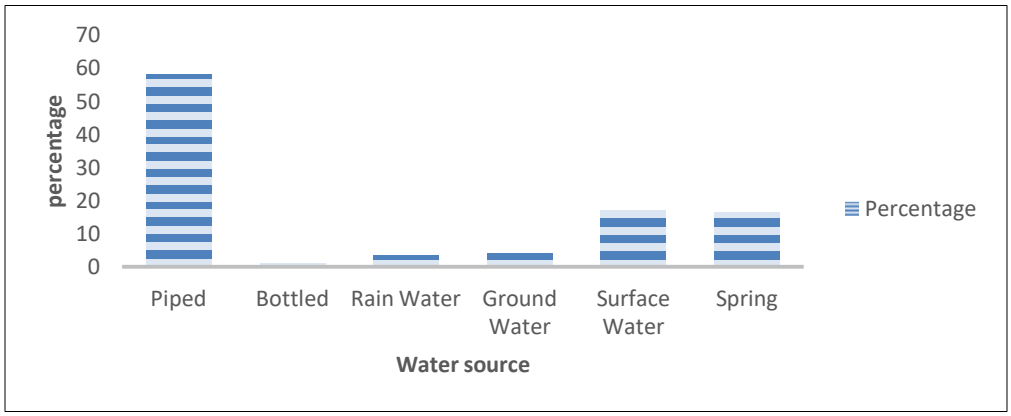

Figure 13: *Primary water sources in Mpondwe Lhubiriha Town Council.*

4.1.2 Community hygiene and water handling practices

4.1.2.1 Drinking Water collection and storage vessels

It was revealed that most (92.00%) respondents collect water in jerry cans, and these still serve as drinking water storage vessels for the majority (54.00%). Clay pots on the other hand serve as storage vessels although they are used by limited number of respondents for water collection from the different sources.

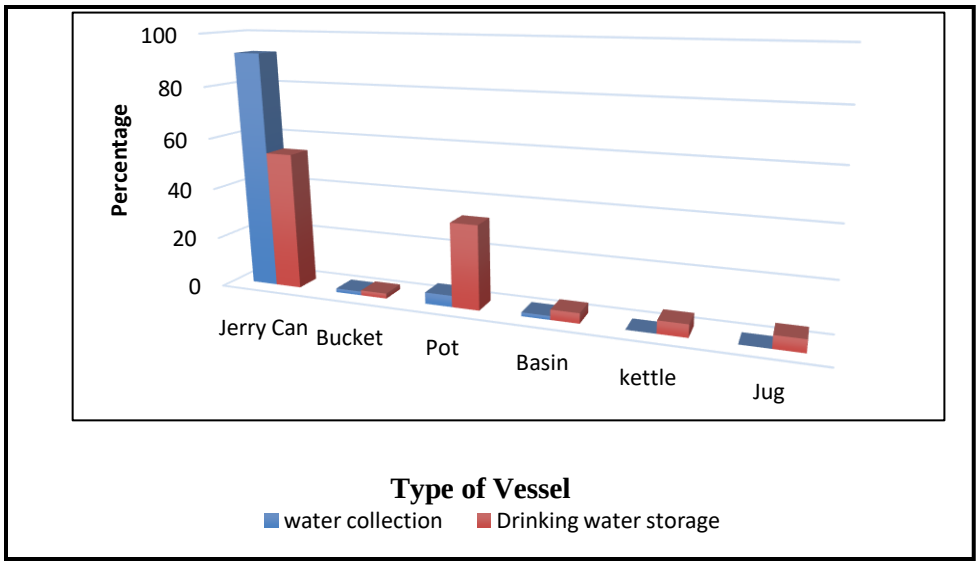

Figure 14: Water collection and storage vessels by communities in Mpondwe Lhubiriha Town Council.

4.1.2.2 Water handling practices

To better understand the drinking water storage vessel handling practices, the respondents were interviewed on the frequency of cleaning of these vessels. The study findings revealed that most (41%) of communities cleaned the drinking water vessels at unspecified time interval. It was further revealed that 23% of the respondents cleaned their drinking water storage vessels after a period of 7-14 days which leads to high risk of microbial growth in water rendering it unfit for human consumption. The details of the cleaning schedules among the respondents are further described in the Figure 15 below.

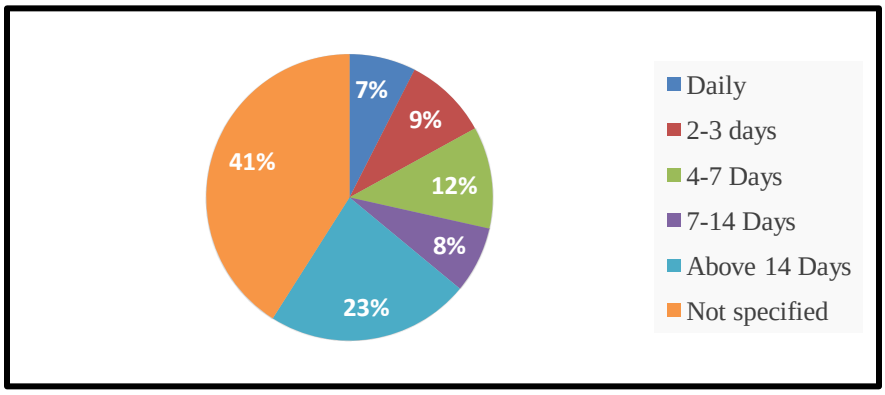

Figure 15: *Drinking water storage vessels cleaning schedule.*

The marital status of the respondents revealed a significant influence (p=0.046) on whether the respondent would cover the drinking water storage vessels. Knowledge on water borne diseases did not influence the respondents to have drinking water storage vessel covers.

Table 2: Binary Logit Regression

Explanatory variables	Intercept (B)	P-value	Exp (B)
Marital status	-0.497	**0.046***	0.609
Education	0.127	0.335	1.136
Occupation	0.040	0.682	1.040
Age	0.031	0.867	1.032
Knowledge on Water Borne Diseases	-0.183	0.664	0.832

Significance level = 0.05 (95% Confidence Interval)

It was also revealed that 8.2% of water collection vessels were observed not covered and 3.1% of water storage vessels were not properly covered. 33% of households drew water from storage vessels by dipping. Only 2.3% of households were observed to practice household water treatment methods by boiling and the rest perceived water to be naturally safe.

4.1.2 Risk of water contamination

According to the results obtained as indicated in Figure 16 and Figure 17; river water was at very high risk (100%) of physiochemical and microbial contamination, two water springs S1 and S7 were also observed at very high risk (90%) to contamination. Tap water was observed at low risk of contamination (10% to 20%). Sanitary inspection points were chosen randomly from homes of 196 respondents interviewed for water handling practices. Household H10 had very highest risk percentage of 90% and household H8 had lowest risk of contamination of 35%.

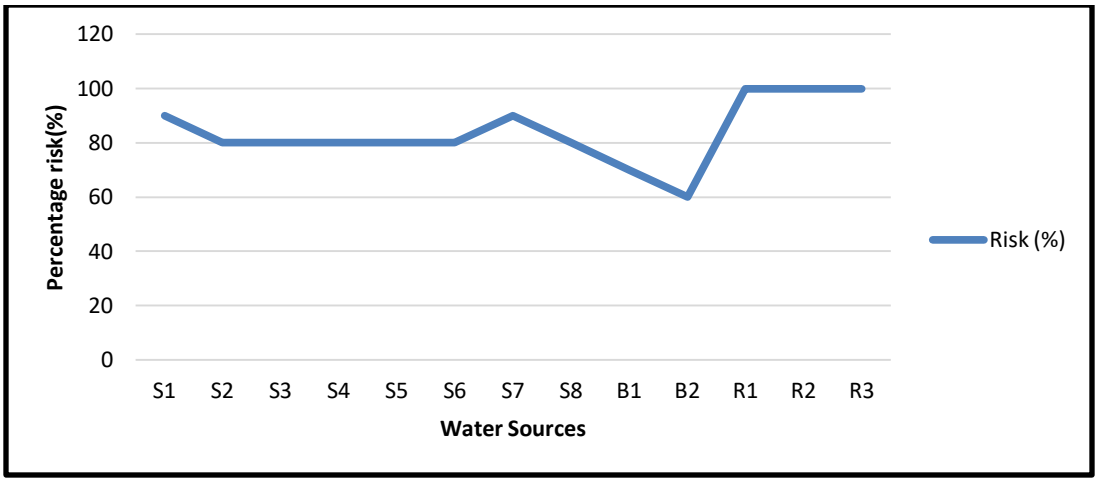

Figure 16: *Percentage risk of contamination of different water sources*

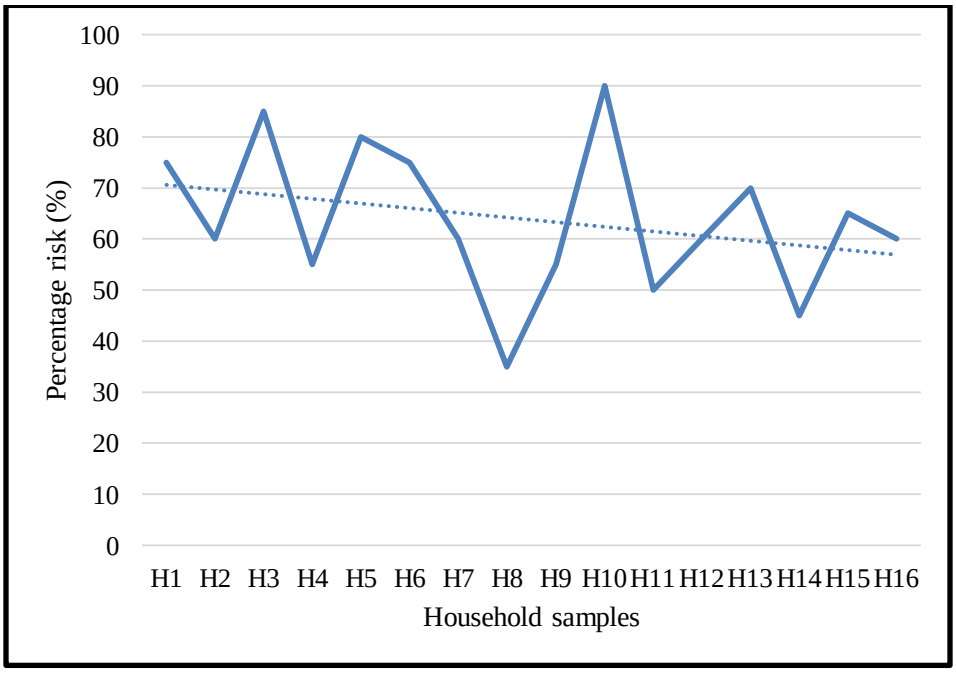

Figure 17: *Percentage risk of contamination of different households*

4.2 Determination of Total Coliforms, *E. coli*, Salmonella spp. and Enterococcus bacteria levels in the water samples from selected water sources and household water storage vessels.

4.2.1 Protected springs microbial analysis results

As per results presented in Figure 18, Kyogha and Kituti B registered the highest number of Total coliforms during wet and dry season of 64 MPN/100 mL and 38 MPN/100 mL respectively. Total coliform in Nyakimasa B spring levels were within permissible limits of WHO during wet season. Total coliform in Kigando spring presence was also within permissible limits of WHO during dry season. Kituti B registered the highest level of *E. coli* during the wet and dry season. *E. coli* levels were within the tolerance limit for water samples from Nyakimasa B and Kighando spring during the wet season. *E. coli* levels were within tolerance limit for water samples from Nyakimasa A, Nyakimasa B, and Kighando spring during dry season. Generally, there were more Total Coliforms and *E. coli* levels in water samples during wet season compared to dry season in water springs. Salmonella spp. and Enterococcus levels were within tolerance limit during wet and dry season.

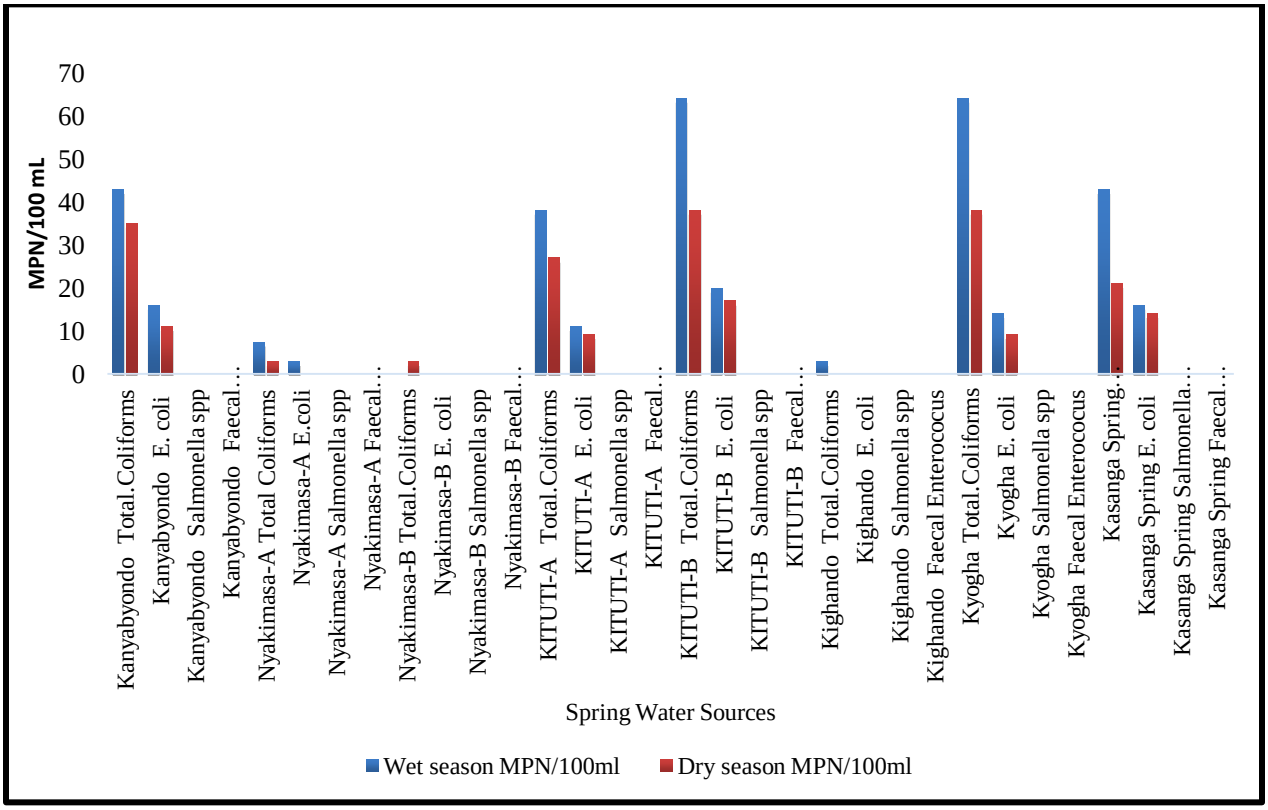

Figure 18: *Spring water microbial analysis results.*

4.2.2 Borehole water microbial analysis results

As per results in Figure 19, during wet season, Rusese borehole water sample registered the highest total coliforms levels of 20 MPN/100 mL, and Nyakahya borehole water sample registered the lowest total coliforms levels of 3 MPN/100 mL. Rusese borehole registered thermo tolerant *E. coli* levels of 11 MPN/100 mL and thermo tolerant *E. coli* levels was within set standard in Nyakahya borehole water sample during wet season. Total Coliform concentration of 9 MPN/100 mL was registered in Rusese borehole water sample during dry season and no Total Coliforms observed in Nyakahya water sample during dry season. All water samples result for *E. coli* levels were within WHO and UNBS permissible limits during dry season. Salmonella spp. and Enterococcus was not detected in all borehole water samples during wet and dry season.

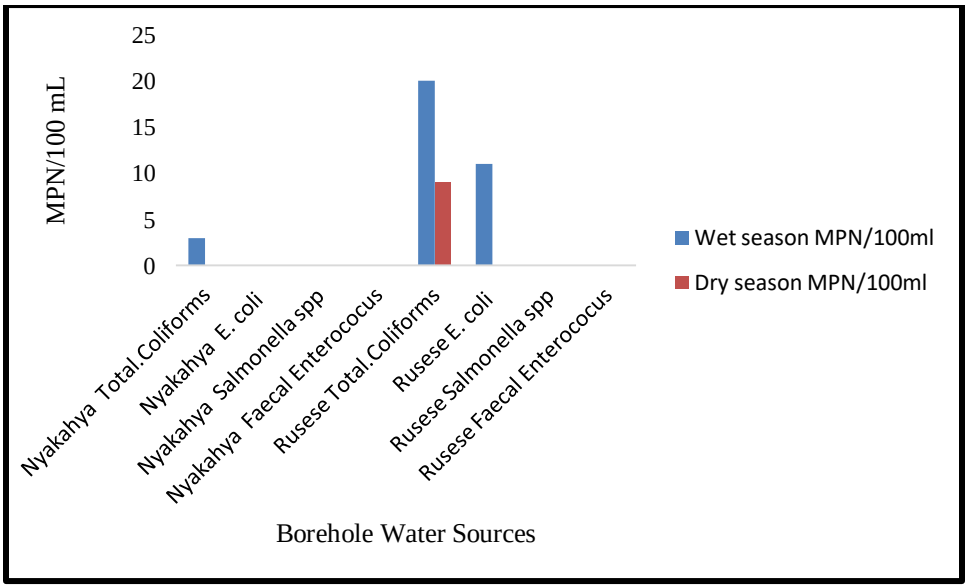

Figure 19: *Bore hole (underground) water microbial analysis results.*

4.2.3 River water microbial analysis results

The upstream of Rivers Lhubiriha and Kyanzi had the highest number of total Coliforms of 75 MPN/100 mL and River Mpondwe had the lowest value of 64 MPN/100 mL during wet season. River Lhubiriha upstream sample registered the highest number of total coliforms of 36 MPN/100 mL, and River Kyanzi upstream sample had the lowest value of 27 MPN/100 mL during dry season. River Lhubiriha registered the highest *E. coli* levels of 25 MPN/100 mL, and River Nyanzi registered the lowest *E. coli* levels of 15 MPN/100 mL during the wet season. River Lhubiriha registered the highest *E. coli* levels of 14 MPN/100 mL, and River Nyanzi registered the lowest *E. coli* levels of 9 MPN/100 mL during the dry season.

The total coliform levels at the downstream of all the rivers were in the range of 1100 to >1100 MPN/100 mL in all water samples during wet and dry season. *E. coli* was in range of 1100->1100 MPN/100 mL during wet season, highest in River Lhubiriha at >1100 MPN/100 mL. During the dry season *E. coli* levels present in the downstream water samples were in the range of 460-1100 MPN/100 mL. There were no salmonella ssp. and Enterococcus levels registered in all water samples during dry and wet season.

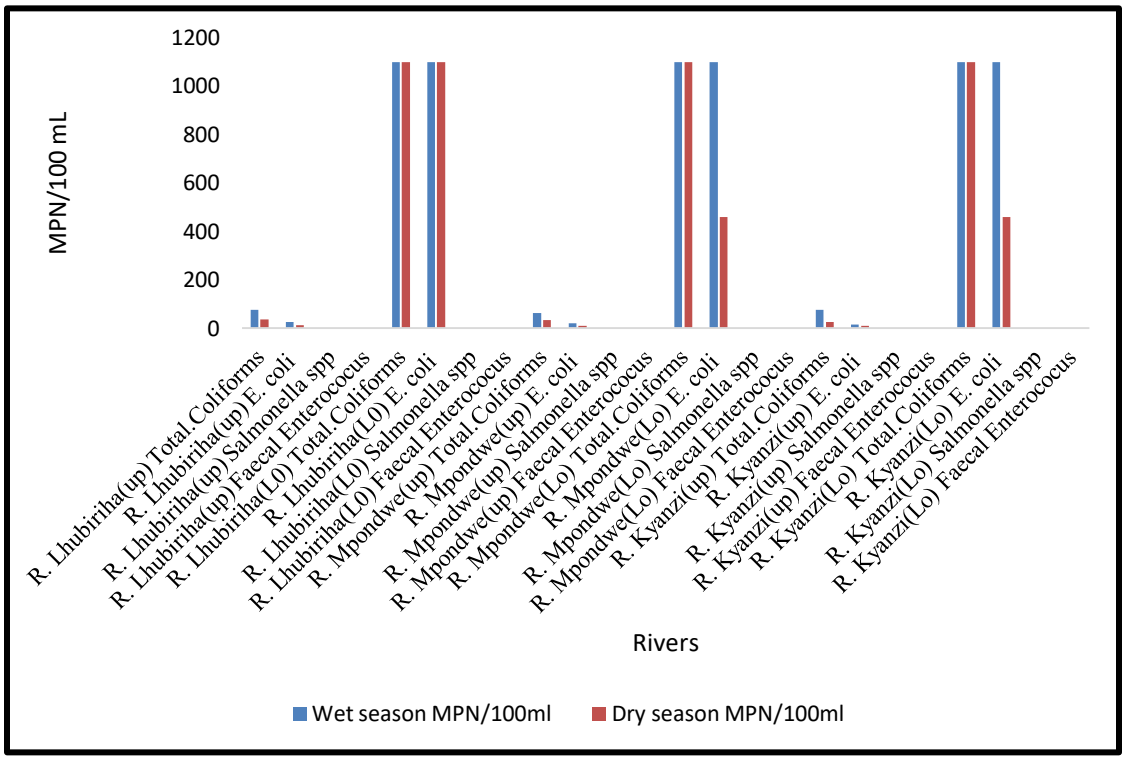

Figure 20: *River (surface) water microbial analysis results*

4.2.4 Tap water microbial analysis results

Figure 21 presents microbial analysis of tap water samples. A water sample from Kyabolokya had total coliform count of 3 MPN/100 mL during wet season and the rest of other water samples total coliform levels were within standard of UNBS and WHO during wet and dry season. *E. coli,* salmonella ssp. and Enterococcus were within tolerance limit of UNBS and WHO in all water samples during dry and wet seasons.

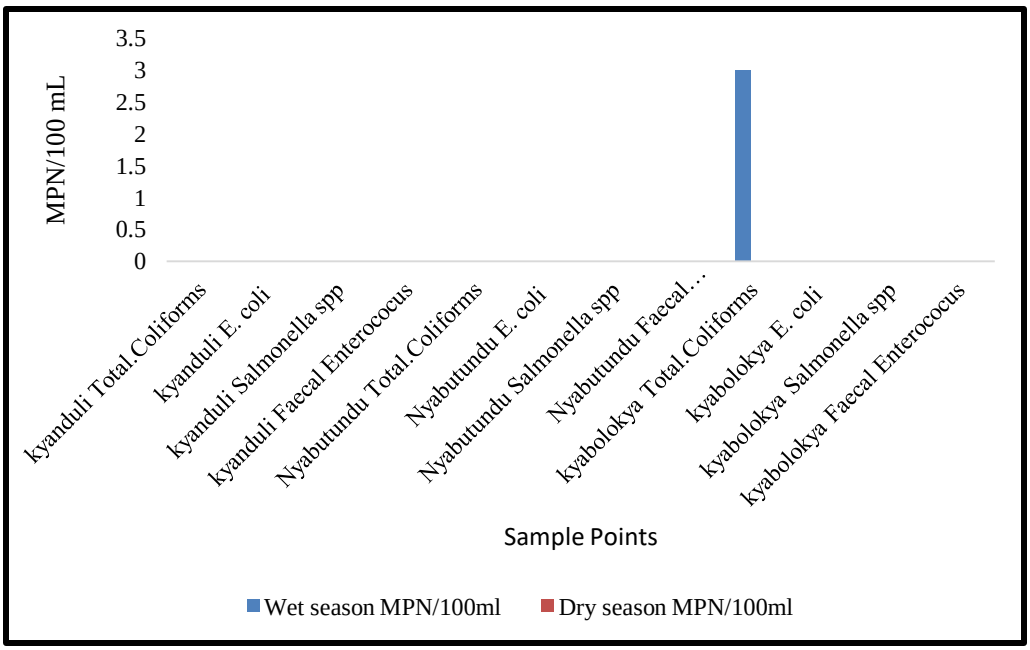

Figure 21: *Tap water microbial analysis results.*

4.2.5 Household water microbial analysis results

According to the results in figure 22, Total coliform levels were in the range of 0-75 MPN/100 mL and 0-43 MPN/100 mL during wet and dry season respectively. A household in Kalitusi, H10 using tap water as source of water near River Kyanzi had the highest value of 75 MPN/100 mL of total coliform during wet season. A household in Kyogha using spring water as source of water had the highest value of 43 MPN/100 mL of Total coliforms during dry season. *E. coli* presence was in the range of 0-20 MPN/100 mL during wet season and 0-15 MPN/100 mL during dry season. A household in Kalitusi using tap water as source of water near River Kyanzi had the highest value of 20 MPN/100 mL of *E. coli* during wet season and a household in Kasanga using spring water as source of water for drinking had the highest value of 15 MPN/100 mL of Total coliforms during dry season. No Salmonella spp. and Enterococcus were registered in all household water samples.

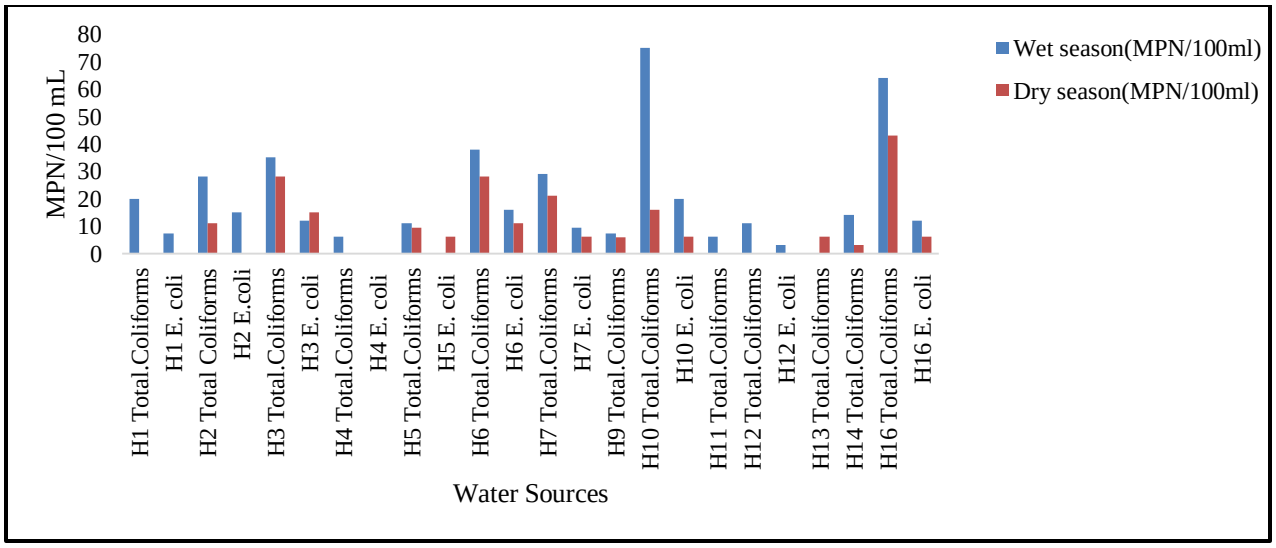

Figure 22: ***Household water (water storage vessels) microbial analysis results***

Figure 23: ***Positive and negative samples for total coliforms / E. coli presence in test tubes***

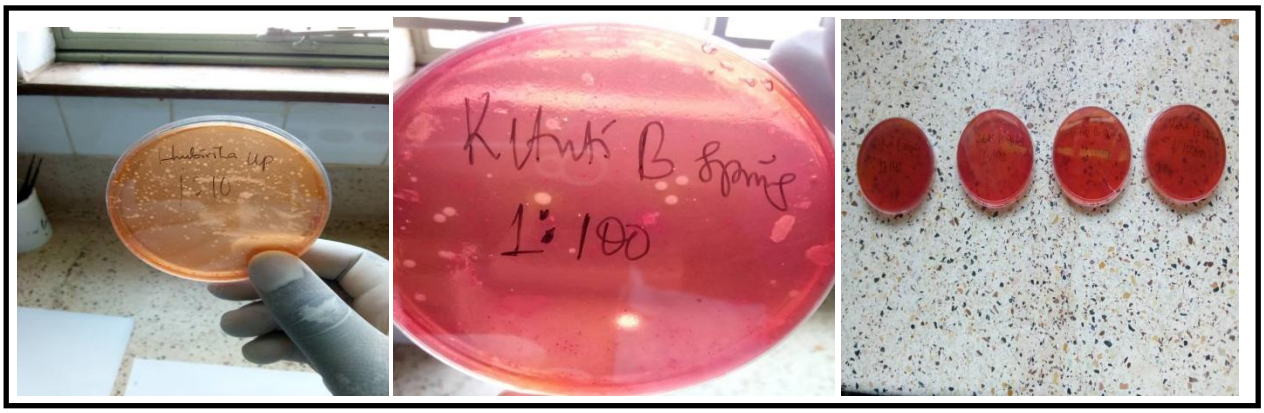

Figure 24: *Positive and negative samples for total coliforms / E. coli presence on glass lens*

4.2.6 Selected water sources & household water samples average microbial analysis results

According to the results in appendix 8 section 5, Figure 25 and Figure 26, River water samples had the highest average Total coliform levels of 585.67 MPN/100 mL and 566.33 MPN/100 mL, *E. coli* levels of 342.30 MPN/100 mL and 342.30 MPN/100 mL during wet and dry seasons. Tap water had the lowest T.C levels of 1 MPN/100 mL during the wet season, no T.C observed during the dry season and *E. coli* was not detected during the dry and wet season. Spring water had average T.C levels of 32.80 MPN/100 mL and 20.62 MPN/100 mL during wet and dry seasons, Average *E. coli* levels of 10 MPN/100 mL and 7.92 MPN/100 mL were also detected in spring water during wet and dry seasons. Borehole water had average T.C levels of 11.50 MPN/100 mL and 4.50 MPN/100 mL during wet and dry seasons, Average *E. coli* levels of 5.50 MPN/100ml were also detected in spring water during wet season and no *E. coli* was detected during dry season. Household water samples had average T.C levels of 21.53 MPN/ 100 mL and 10.72 MPN/100 mL during wet and dry seasons, Average *E. coli* levels of 5.92 MPN/100 mL and 3.50 MPN/100 mL were also detected in household water samples during wet and dry season. No Salmonella spp. and Enterococcus bacteria were registered in all water samples.

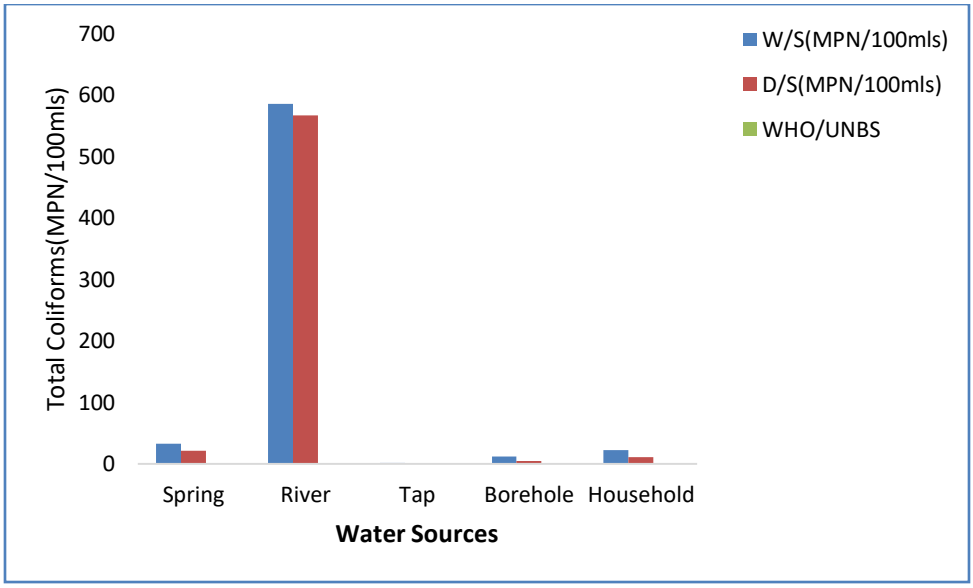

Figure 25: *showing average total coliforms levels in selected water sources and household water samples.*

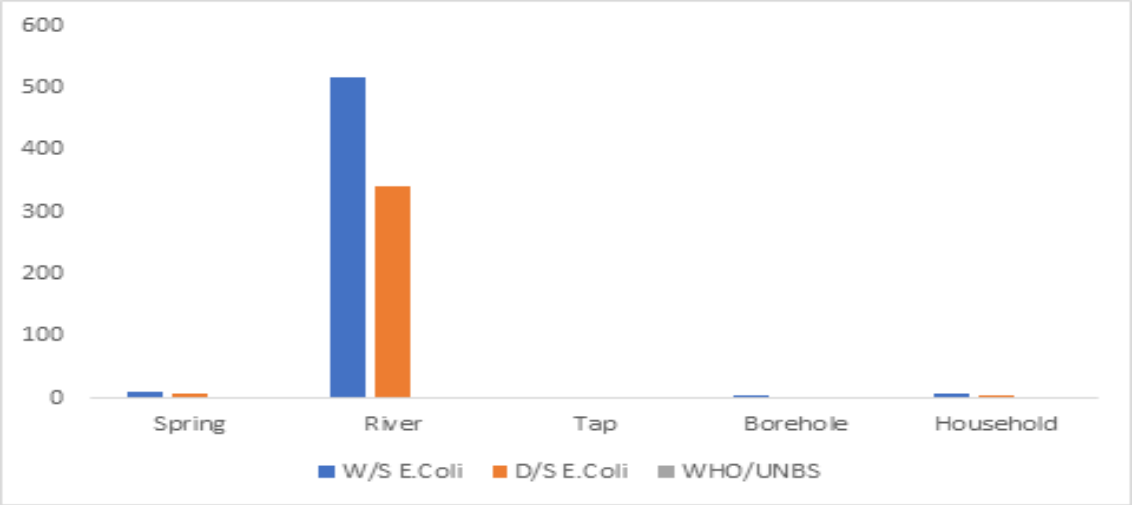

Figure 26: *showing average E. coli levels in selected water sources and household water samples.*

4.3 Determination of the physio-chemical characteristics of utilized drinking water sources and household water storage vessels in Mpondwe Lhubiriha Town Council.

4.3.1 Protected springs water physiochemical results.

Sample S7 nitrates content were above permissible values of WHO during wet and dry season. Three samples S3, S5 and S6 turbidity values were above maximum limit of 5 NTU during wet season and two samples S3 and S6 turbidity values were also registered higher than maximum limit. Average physiochemical values during wet and dry season of water samples are indicated in appendix 9 section 1.

4.3.2 Borehole water physiochemical parameters

All the physicochemical parameters result for both dry and wet season were within recommended limits of WHO and UNBS standards of drinking water. Average physiochemical values during wet and dry season of water samples are indicated in appendix 9 section 2.

4.3.3 River water physiochemical parameters

As per results obtained in appendix 9 section 3; all river water samples registered high values of turbidity above set national standard. Sample R21 (River Mpondwe-lower stream) and R31 (River Kyanzi-lower stream) Dissolved Oxygen (DO) were below set standard of >6.5 mg/l during wet and dry seasons. All water samples registered high values of nitrate content above tolerance limit during wet season.

4.3.4 Tap water physiochemical parameters

All the tap water samples physiochemical parameters results obtained conform to UNBS and WHO standards-2014.The average physiochemical parameters obtained are indicated in appendix 9 section 4.

4 3.5 Household water physiochemical analysis results

Three samples H2 (Kighando-2), H6 (Nyakimasa) and H10 (Kalitusi) turbidity values were above maximum limit of 5 NTU during wet season and two samples H8 (Mpondwe) and H10 (Kalitusi) turbidity values were also registered higher than maximum limit.

The nitrates contents during wet season of samples H2 (Kighando-2), H10 (kalitusi) and H16 (kyogha) values were above maximum limit of 50 mg/l. Sample H8 (Mpondwe) and H16 (Kyogha) nitrates values were also above permissible limit of 50 mg/l. Average physiochemical values during wet and dry season of water samples are indicated in appendix 9 section 5.

4.3.6 Variation of physiochemical parameters of selected water sources & household water samples

As per results indicated in appendix 9 section 6 and Figures 27(a), 27(b), 27(c), 27(d), 27(e), the average physicochemical parameters result of pH, E.C, TDS, temperature, and total hardness of selected water sources & household water samples obtained during wet and dry season were within permissible limits as recommended by WHO and UNBS standards. Dissolved oxygen variations were observed below national standards in river water samples. Variations in turbidity and nitrates above national standard were also observed in river water samples during wet and dry season. Average turbidity values of spring water were also slightly above national standard.

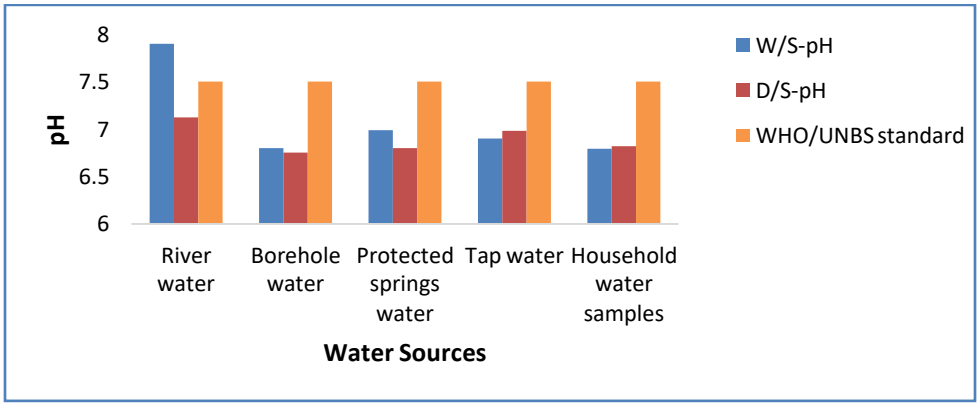

Figure 27(a): ***Average pH of drinking water sources & household samples***

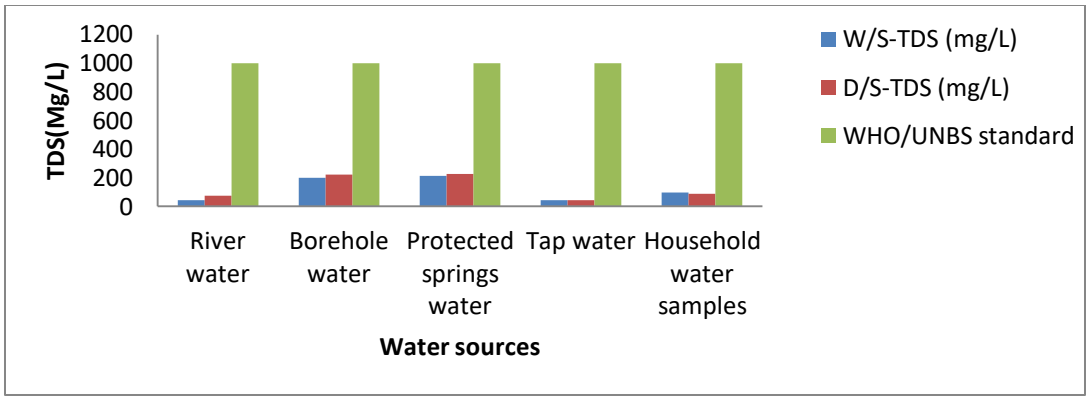

Figure 28(b): ***Average TDS of drinking water sources & household samples***

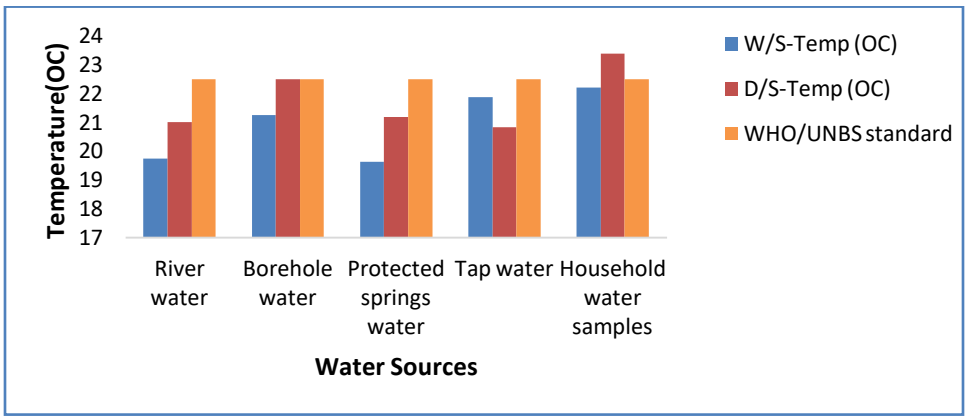

Figure 29(c): ***Average temperature of drinking water sources & household samples***

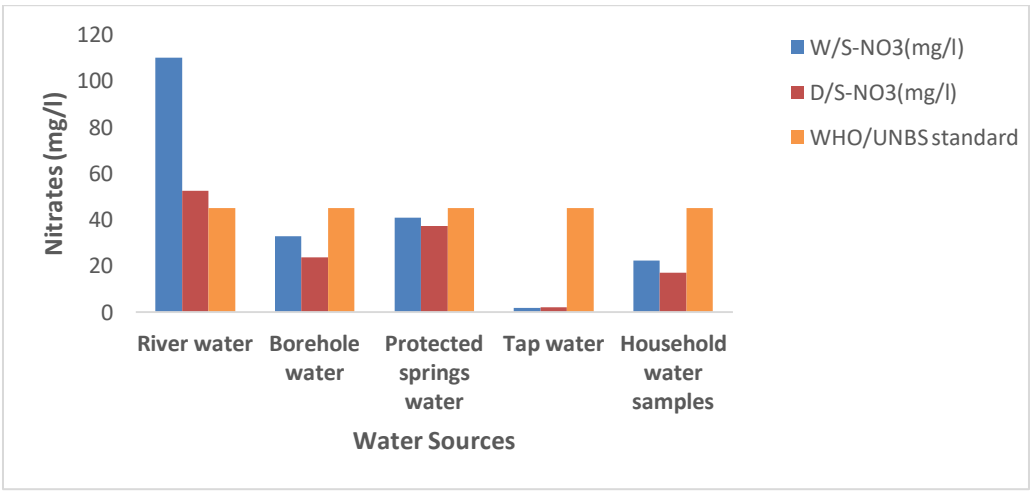

Figure 30(d): ***Average Nitrates in drinking water sources & household samples***

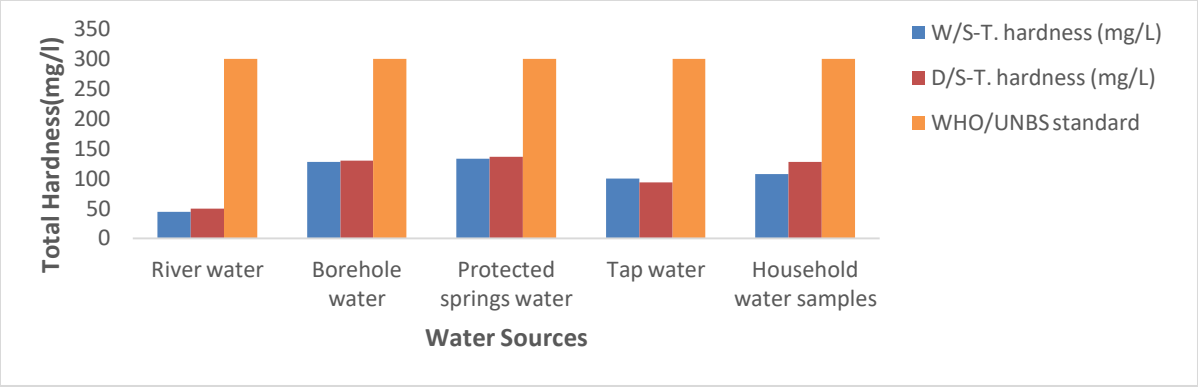

Figure 31(e): ***Average Total hardness of drinking water sources & household samples***

4.4 Determination of water quality index and relationship of quality parameters

4.4.1 Water Sources Quality Index (WQI)

Water quality index results for water sources were tap water =93.70-100.00%, borehole=76.60-90.70%, spring=69.10-90.70%, river water=38.08-57.85%. As per the results, WQI during Dry season was higher than results registered during wet season.

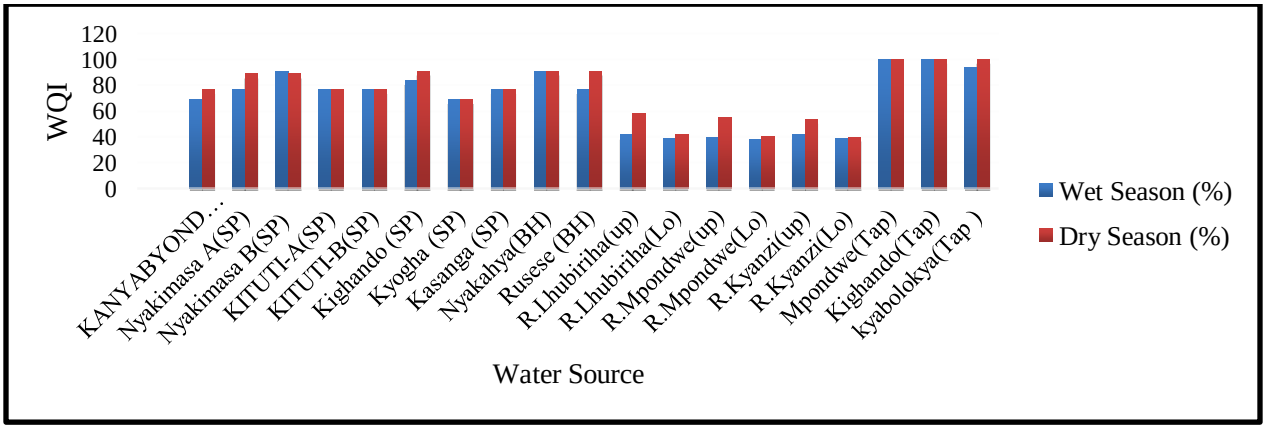

Figure 32: *showing Water Quality Index (WQI) of different water sources.*

4.4.2 Determining relationship of water quality parameters by Spearman's Correlation

Spearman's Correlation was carried out to establish whether there is a relationship between the microbial parameters (Total Coliforms and *E. Coli*) and the physiochemical parameters (pH, E.C, TDS, Temp, Turbidity, DO, NO_3 and Total Hardness) of the water samples collected as shown in appendix 10.

CHAPTER FIVE: DISCUSSION OF RESULTS, CONCLUSION AND RECOMMENDATIONS

5.1 DISCUSSION OF RESULTS.

5.1.1 Examination of utilized drinking water sources, community hygiene, water handling Practices and risk of contamination in Mpondwe Lhubiriha Town Council.

Majority (58.00%) of the respondents in Mpondwe Lhubiriha Town Council obtain piped tap water as their main source of water, this is because tap water is always ensured to be potable, and this high percentage greatly indicates high reliability and quality service provided by NWSC since the customer satisfaction index was 77.00% in 2019/2020 (Howard *et al.*, 2002). However, 58.00% is lower than 76.70% piped water usage in Kampala as per research done by Ssemugabo *et al.*, (2019). This is because NWSC water is for sale, leaving poor communities to look for alternative sources which are readily available, and community owned from spring water (16.50%) and river water (17.00%) (Howard *et al*., 2002). Furthermore, similar results were obtained by Ssemugabo *et al*., (2019) where 23.30% respondents in Kampala City used spring water as primary water source and according to Howard *et al.*, (2002) 5.10% respondents used surface water. High surface water usage in this area is because this is the area's traditional source of water. Rainwater was at 3.50% since it is seasonal and requires bulk collection/storage vessels like tanks. Similarly, according to Howard *et al.*, (2002) 0.80% respondents were using rainwater. Bottled water has become one of drinking water sources in Uganda; however as per this research bottled water (1.50%) is the least available source since it's typically commercial on the market. On average, a 500 mL or 650 mL bottled water costs between Uganda Shillings 500 and 1,000 (or 0.135 US$ and 0.263 US$).

The study findings revealed that most (92.00%) respondents collect water in jerry cans, and these still serve as the drinking water storage vessels for the majority (54.00%). This might lead to cross contamination of drinking water. It was also revealed that most (41.00%) of communities cleaned the drinking water vessels at unspecified time interval and 23.00% of the respondents cleaned their drinking water storage vessels after a period of 7-14 days; this creates an ideal time frame for bacteria to reproduce and contaminate water (Elliott, 2014).

According to Gärtner *et al.*, (2021) drinking water is frequently re-contaminated during transport and storage when water is poured into contaminated jerry cans. Clay pots are traditionally used for

water storage and keep water clean (Kumar & Garg, 2020). However, they can be contaminated if not covered well. To maintain clean and safe drinking water, these vessels should be covered with lids Gärtner *et al*., (2021) and cleaned at specified cleaning schedule. However, this study revealed that 8.20% of water collection vessels were found uncovered at time of water transportation and 3.10% of household water storage vessels were not covered. 35.00% of households drew water from storage vessels by dipping; this leads to high possibility of water contamination. Only 2.30% of households were observed to practice household water treatment methods by boiling and rest perceived water to be naturally safe. According to Luvhimbi *et al.*, 2022) some studies have registered contamination of drinking water with total coliforms and *E. coli* from water source to the point of use in the households due to use of dirty collection and storage vessels. Other factors which affect water quality include the type of water storage vessel, water storage time frame; inadequate water handling knowledge and poor sanitation and hygiene practices has all been linked with levels of water contamination in households. Therefore, water collection and storage containers should be cleaned at least once a week, covered and the cover should only be removed when pouring water from the container (Howard, 2002).

Figure 33: *Uncovered water collection jerry cans identified at Kasanga spring.*

Figure 34: *Poor hygiene practices observed at Kituti B spring.*

According to results of water sources sanitary inspection, river water was at a very high risk (100.00%) of physiochemical and microbial contamination, this clearly indicates river water is more vulnerable to contamination due to human activities and surface run off (Bwire *et al*., 2020). The risk factor was at 80.00%-90.00% making them prone to contamination. Tap water was observed at low risk of contamination (10.00% to 20.00%) this could be attributed to maintenance schedules of water sources by NWSC. The household's risk factor was between 35.00%-90.00%. High risk factor in households was attributed to poor sanitation, a requirement which is a threat to water quality.

5.1.2 Determination of Total Coliforms, *E. coli*, Salmonella spp. and Enterococcus bacteria levels in Water samples from protected springs, bore holes, rivers, and piped tap Water from NWSC water grid and household water storage vessels.

5.1.2.1 Protected springs water

The study findings revealed that Kyogha spring registered T.C above WHO standard this could be due to urban settlement and presence of toilets below required distance which can lead to sub-surface filtration of fecal matter into the water source leading to high total coliform and *E. coli* levels. Kituti B spring also registered high T.C levels this could be to location in a valley, Study findings revealed that when it rains, this place floods and increases rate of sub-surface infiltration of sewage leading to high total coliforms and *E. coli* levels (Omara *et al.*, 2019). Similar observations have been identified for spring water sources in Katwe and Kisenyi Parishes (Haruna *et al*., 2005) Thus, Kyogha and Kituti B water spring is not safe for drinking. Total coliform in Nyakimasa B spring levels were within permissible limits of WHO during wet season. Total coliform levels of Kigando spring were also within permissible limits of WHO during dry season. *E. coli* levels were within the tolerance limit for water samples from Nyakimasa B and Kighando spring during wet season. *E. coli* levels were within tolerance limit for water samples from Nyakimasa A, Nyakimasa B, and Kighando spring during dry season. This clearly indicates that these water sources are safe for use.

5.1.2.2 Borehole water

Although different studies indicate that boreholes have a better water quality because they are sunk deeper into the ground and often have greater protection against contamination (Howard, 2002), this study findings revealed that total coliforms contamination was detected in Rusese borehole and Nyakahya borehole water samples. It was further revealed that Rusese borehole tested positive for thermo tolerant *E. coli* presence of 11 MPN/100 mL during wet season and no thermo tolerant *E. coli* presence detected in Nyakahya borehole. This contamination could be due to the presence of pit latrines within the vicinity and lack of fence allowing easy accessibility to animals (Omara *et al*., 2019; Agensi *et al*., 2019; Howard, 2002) posing a high risk of water contamination as per sanitary risk factor of 60.00%-70.00% obtained during risk assessment. Similar results were obtained in Mbarara Nyamitanga secondary school Borehole with high mean total coliform counts

above permissible limit. All water samples result for *E. coli* were within WHO and UNBS permissible limits during dry season indicating safety of water during this period.

Figure 35: *Unfenced borehole of Rusese ward and Nyakahya*

5.1.2.3: River water

According to Nabeela *et al.*, (2014) and Agensi *et al.*, (2019), microorganisms mostly occur in surface water sources like rivers and wells and quality is always poor throughout the year but worst during the transition from dry to wet seasons. In most cases, surface water sources are contaminated by waste, sewage, and bacteria along the water flow paths. This study findings revealed that Total coliforms and *E. coli* concentration levels were above UNBS and WHO standards in all river water samples. It was found out that all these three rivers are in the valley allowing easy flow of surface run off into these water sources. River Mpondwe is in the heart of Mpondwe Town with an abattoir in the midstream where animals were observed to share some water with humans contaminating the water with urine and animal feces which is a source of bacteria. Settlements on riverbanks of Lhubiriha and Mpondwe were also observed making heavy rain falls to easily drain animal wastes, human wastes, and other wastes into the water body during wet season. It should also be noted that River Lhubiriha is located around the border of Uganda and DRC, agricultural activities observed, and open washing/ bathing observed in this water source. Open defecation was also identified around River Kyanzi which is more likely to end up into the river after surface run off and through other agents like humans. High rate of contamination of these water sources is linked with risk factor of 100.00% obtained in appendix 6.

Figure 36: ***Washing activities and bathing in River Lhubiriha on Uganda and DRC side.***

Figure 37: ***Open defecation and sand mining observed around River Kyanzi***

Figure 38: *Open washing in R. Mpondwe*

5.1.2.4 Tap water

Tap water is regarded safe for drinking due to effective disinfection by chlorine in the distribution system (Addisie, 2022). However, total coliform contamination was detected in water sample taken from Kyabolokya during wet season. Similar results have been reported for tap water contamination by (Addisie, 2022) where different studies indicated contamination of tap water with total coliforms, this could be due to leakages on distribution pipes (Onyutta *et al.*, 2022). The rest of the water samples' total coliform count was within the standard of UNBS and WHO. There was no presence of *E. coli*, salmonella ssp. and Enterococcus detected in all tap water samples during dry and wet season. This could be due to effective treatment of water by NWSC. This study revealed that the low contamination of tap water is linked to the achieved result of low contamination risk factor of 10.00-20.00% indicated in appendix 6.

5.1.2.5 Household water microbial analysis

During wet season, majority of household tested for presence of Total Coliform and *E. coli*, the study findings revealed that 8 households were using tap water as primary water source for drinking, out of these 2 households reported to have boiled drinking water and rest perceived tap water to be already safe. From analysis results obtained 5 samples tested positive for presence of Total Coliforms including one sample which had been boiled and 3 samples tested positive for *E. coli*. On the other hand, during dry season 9 households were using tap water for drinking, however only one claims to have boiled this water and 4 samples tested positive for presence of Total coliforms and 1 sample tested positive for presence of *E. coli*. All water samples from spring

water tested positive for total coliforms and *E. coli* during dry and wet season and the respondents from these households did not boil this water for drinking. The study findings revealed that contamination of these water sources is due to cross contamination since most of the people in this community use more than one water source and at same time it was revealed that most (92%) respondents collect water in jerry cans, and these still serve as the drinking water storage vessels for majority (54%). Some of the water storage vessels were not adequately covered and others were not covered at all, for example H5 and H10. Contamination of drinking water was also linked to poor sanitation facilities and practices in these households for example household H10, despite of using tap water which is perceived to be safe, Total Coliforms and *E. coli* was still above tolerance limit. A similar study was carried out by (Kwesiga *et al.,* 2017) where samples collected from the public water taps in the communities and water samples from household had total coliforms above tolerance limit. According to (Luvhimbi *et al.,* 2022), Previous studies in developing countries have identified a progressive contamination of drinking water samples with *E. coli* and total coliforms from source to the point of use in the households, especially because of using dirty containers for collection and storage processes. Also, the type of container used to store drinking water, the number of days of water storage; inadequate knowledge and a lack of personal and domestic hygiene have all been linked with levels of water contamination in households.

5.1.2.6 Comparison of selected water sources & household water samples microbial results

Generally, River water samples registered high total coliforms and *E. coli* count during wet and dry season due to high vulnerability to contamination from human activities like sewage disposal and inflow of wastes through surface runoff. This is in relation to the achieved high-risk factor result of 100.00%. Total coliforms and *E. coli* levels in spring water samples were high during wet season compared to dry season; this could be due to sub-surface infiltration from heavy rains experienced around this period (Omara *et al.,* 2019; Agensi *et al*., 2019). Although Borehole water is considered safe, total coliforms were above required standard during wet and dry season and *E. coli* levels were above standard during wet season, this is related to high risk factor of contamination of 60.00%, An average total coliform of 1 MPN/100 mL could be due to breakdowns and leakages on water distribution systems, Average total coliforms and *E. coli* levels were above national standard for house hold samples, this could be due to cross contamination, poor water handling practices as well as factors from already achieved household sanitary risk

factor of 39.00-90.00%. All water samples salmonella spp. and Streptococcus faecalis levels were within UNBS and WHO standard.

5.1.3 Determining the Physio-chemical characteristics of utilized water sources and household water storage vessels.

5.1.3.1 Protected springs water physiochemical results

As per the physicochemical parameters results, pH, E.C, TDS, Temperature, total hardness, and dissolved oxygen during wet and dry season were within permissible limits as recommended by WHO and UNBS standards. Nitrates content was above permissible values of WHO during wet and dry season for only one sample (Kyogha spring), the study findings revealed that presence of nitrates in spring water could be attributed to fecal contamination derived from poor domestic sewage disposal, poor sanitation and leaching of nitrates from nearby pit latrines since this place is in the town Centre (Haruna *et al*., 2005). High levels of nitrates cause diseases like cancer and lung diseases (Sandu *et al*., 2017; Addisie, 2022). Nitrate contamination of spring water from domestic sewage has been observed elsewhere in Uganda for example nitrate levels of water from protected springs in Katwe and Kisenyi parishes, Kampala city, Uganda was found above acceptable limits of UNBS and WHO in 70.00% of water samples analyzed by (Haruna *et al*., 2005). High turbidity values of samples S3, S5 and S6 could be attributed to surface run off, increased agricultural activities in these areas. High Turbidity levels make water visually unattractive and shield harmful microorganisms, thus affecting water treatment effectiveness (Uche, 2021).

5.1.3.2 Borehole water physiochemical parameters

All the physicochemical parameters result of borehole water samples for both dry and wet season were within recommended limits of WHO and UNBS standards of drinking water. This makes this water more aesthetically acceptable for drinking and domestic use. This study agrees with similar studies done in Soroti District, Uganda by (Howard, 2002) which states that borehole water have the best quality. However, there is research revealed a slight variation in physiochemical properties average values of borehole water sources between dry and wet season, this could be attributed to dilution of water table from heavy precipitations during wet season.

5.1.3.3 River water physiochemical parameters

As per results obtained, all river water samples registered high values of turbidity above set national standard which could be attributed to surface run off, poor solid waste management, increased agricultural activities around the riverbank, sedimentation, washing, sand mining and bathing in the water sources. According to (Uche, 2021) surface water sources have higher turbidity compared to groundwater sources. Related study was done by (Bwire *et al*., 2020) where all the river water samples including a sample from R. Lhubiriha turbidity values were higher than set national standard.

DO is required by water micro-organisms to live. DO for sample R21 (R. Mpondwe-lower stream) and R31 (R. Kyanzi-lower stream) was below set standard of >5 mg/l during wet and dry seasons. Low dissolved oxygen in these samples could be attributed to decomposition of organic materials from animal wastes around the abattoir near R. Mpondwe, human wastes from open defecation, open discharge of domestic sewage in water and agricultural materials washed into the rivers (Vyas *et al.,* 2015; Bwire *et al*., 2020). Similar results were obtained by (Bwire *et al.,* 2020), from R. Lubigi where DO was below the set limit and this was attributed to the decomposition of organic matter. High nitrate levels were also observed, this could be attributed to poor domestic sewage disposal, poor solid waste management, agricultural runoff, and animal wastes. The presence of nitrates can indicate the possibility of sewage, municipal solid wastes and fertilizers inputs (Nehme *et al.*, 2014).

5.1.3.4 Tap water physiochemical parameters

All the tap water samples physiochemical parameters results obtained conform to UNBS and WHO standards thus tap water is regarded safe for drinking and domestic use purposes. This could be due to effective treatment by NWSC water treatment plant (Addisie, 2022).

5.1.3.5 Household water physiochemical analysis results

As per the physicochemical parameters results, pH, E.C, TDS, Temperature, total hardness, and dissolved oxygen during wet and dry season were within permissible limits as recommended by WHO and UNBS standards. Three samples H2 (Kighando-2), H6 (Nyakimasa) and H10 (Kalitusi) turbidity values were above maximum limit of 5 NTU during wet season and two samples H8 (Mpondwe) and H10 (Kalitusi) turbidity values were also registered higher than maximum limit. The study findings revealed that according to the correspondent from this household, Sample H2

(Kighando-2) was obtained from River Kyanzi, which she collected from this river before 5:30 am in the morning and was perceived to be safe for drinking without any treatment method like boiling, however according to (Bwire *et al*., 2020) river water is susceptible to contamination by human activities like agriculture and surface run off. High turbidity value and nitrate content could be attributed to these factors, therefore requires treatment before consumption. Sample H6 turbidity value was slightly higher than set standard; this corresponds to turbidity value obtained at the water source of Nyakimasa-B. H8 and H10 are samples from tap water whose source physiochemical properties were within set standard, this variation in turbidity from national standard and respective conforming results of water source could be attributed to cross contamination, since the correspondents in this area were using jerry cans for both water collection and storage. H16 (kyogha) higher nitrates values were corresponding to water source value. Household drinking water temperatures were higher than respective water sources temperature; this gives an ideal condition for water microbial growth.

5.1.3.6 Comparison of physiochemical parameters of selected water sources and household water samples

PH, E.C, TDS, temperature, and total hardness values conform to WHO and UNBS standards. Study findings revealed variations in Dissolved oxygen and nitrates content which could be due to organic wastes discharge to water sources, poor hygiene practices and are a requirement for water microbes to survive thus affecting drinking water quality. Turbidity variations make water undesirable, and this could be attributed to anthropogenic activities along water resources and poor community hygiene practices.

5.1.4 Drinking Water Sources Quality Index (WQI) and relationship of quality parameters

5.1.4.1 Water Sources Quality Index (WQI)

Study findings revealed that River water registered the lowest WQI, thus classified as poor and signifies high vulnerability to contamination. Tap water registered highest WQI and classified as excellent quality with virtual absence of major risks, borehole water is classified as good quality with minor degree of threat; spring water is classified as fair where the water source is occasionally threatened.

5.1.4.2 Relationship of quality parameters by spearman's correlation

For spring water sources, *E. coli* has a strong positive correlation with Nitrate presence in the water samples (r=0.412, p=0.008). Total Coliforms exhibited a non-significant relationship with all the test parameters (physiochemical).

For river water sources, pH (r=0.621, p=0.000), Temperature (r=0.429, p=0.006), Turbidity (r=0.745, p=0.000) and Nitrates (r=0.557, p=0.000) had a strong positive correlation with total coliforms in the water while total coliforms had a significant negative correlation with Dissolved Oxygen (r=-0.842, p=0.000). *E. coli* exhibited a significant positive correlation with pH (r=0.680, p=0.000), Temperature (r=0.353, p=0.026), Turbidity (r=0.725, p=0.000) and Nitrates (r=0.659, p=0.000). It however exhibited a significant negative correlation with Dissolved Oxygen (r=-0.712, p=0.000).

For household water sources, total coliforms exhibited a strong positive correlation with Nitrates (r=0.659, p=0.000). *E. coli* availability in the water samples had a strong positive correlation with Nitrates (r=0.658, sign=0.000), moderate positive correlation (r=0.415, p= 0.018) and moderate negative correlation with Dissolved Oxygen (r=-387, p=0.029).

5.2 CONCLUSION

This study was conducted to determine the effect of community hygiene and water handling practices on drinking water quality in Mpondwe Lhubiriha Town Council, Kasese District, Western Uganda. Characterization of Community hygiene, water handling practices and risk of contamination was determined by Qualitative methods, Microbial parameters (Total Coliforms, *E. coli*, Salmonella spp. and Enterococcus) and Physio-chemical parameters (PH, temperature, electrical conductivity, TDS, turbidity, total hardness, Dissolved oxygen, and nitrates were determined using UNBS Portable water quality standard and APHA standards respectively and relationship of water quality parameters were determined by Water Quality Index (WQI) and Spearman's correlation.

The study findings revealed that community hygiene and water handling practices had a direct effect on water quality where Variations of water source and household water samples microbial and physiochemical quality parameters were observed due to lack of .specific cleaning schedule for water collection and storage vessels, Drinking water collection and storage vessels were not covered, some respondents were using same vessels for water collection and storage, some households were withdrawing water from storage vessels by dipping and majority of respondents do not practice household water treatment methods. Due to high charges on piped tap water, most respondents opted for alternative sources from protected springs, boreholes and river water which possess a high risk of contamination as per results obtained from sanitary risk assessment and WQI. Microbial and physiochemical parameters of water detoriated during wet season compared to dry season, this is in line with low WQI achieved during wet season compared to WQI achieved during dry season. Drinking water in this area is not safe for Drinking. Therefore, Mpondwe Lhubiriha Town Council should promote good community hygiene, water handling practices and appropriate household water treatment practices to prevent Drinking water microbial and physiochemical Quality variations from the set UNBS and WHO standard.

5.3.0 RECOMMENDATIONS

- Health Education and public awareness is required on good water handling practices, sanitation, personal hygiene, proper pit latrines use and water treatment methods at home like boiling or chlorination or use of drugs like water guard and aqua safe which will help in reducing waterborne diseases. Further, local government should allocate funds for periodic testing of these water sources in the local communities to monitor and check their bacteriological and physiochemical quality.
- Preventive maintenance of water distribution systems is required to avoid leakages on the distribution lines which can lead to intrusion of pathogens in piped tap water. Fences should be constructed around the boreholes and springs to keep away animals which directly contaminate water by defecating at the collection points. Proper solid waste, sewage collection and treatment methods are required in this Town Council to reduce water contamination.
- The Government should provide inter boundary water resource management system between Uganda and DRC to prevent inter border contamination of water resources. More so, this research has provided the foundation of knowledge for proper water handling practices and treatment methods of Households.

5.3.1 Further Studies

Further research should be carried out, especially on metal contamination of the community water sources within the area.

5.3.2 Challenges/ Limitations

During household water samples collection, some correspondents were not willing to give out water samples and execution of sanitary inspections of their households, this affected data collection sample space.

Bacteriological water analysis was expensive and analysis cost was above the prepared budget, this affected analysis of more samples.

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APPENDICES

Appendix 1: Questionnaire

Section 1: Demography

This will enable acquisition of respondent general information and household drinking water handling ability and knowledge adapted from Murduca (2018).

Note: Each respondent will be an adult of at least 18yrs old and with the capacity to manage a family.

1.1 What is your name? .....

1.2 How old are you? .....

A.	10	to	20	years	old
B.	20	to	30	years	old
C.	30	to	40	years	old
D.	40	to	50	years	old

E. Above 50years

1.3 What gender do you identify as? .....

A. Male

B. Female

1.4 What is your current marital status? .....

a. Single
b. married
c. Divorced
d. Widow or widower
e. Others ……

1.5 How many children do you have? ……

a) zero
b) 1
c) 2
d) 3
e) 4

f) 5

g) 6 or more

1.6 What is your place of residence……?

1.7 What is your education level?

A. Did not attend school.
B. Primary level
C. Ordinary level
D. Advanced level
E. Certificate level
F. Diploma
G. Bachelor's degree level
H. Master's degree level
I. PhD

1.8 What is your job occupation? ……...

a) Teacher
b) Peasant
c) Medical worker
d) Engineer
e) Businessman
f) Driver
g) Others specify? …….

1.9 Are you aware of water borne diseases? ……

a) Yes
b) No

1.10 Do you possess a toilet in your home? …….

a) Yes
b) No

1.11 Do you have animals in your household? ……

a) No
b) Yes

Section 2: Water handling practices

This will show the practices of all water users during water collection, transport, and home storage adapted from (Murduca, 2018).

2.1 What is your primary drinking water source?

a) Piped Water
b) Bottled Water
c) Rainwater
d) Groundwater
e) Surface Water
f) Spring
g) Other (please specify) _____

2.2 What is your secondary drinking water source?

a) Piped Water
b) Bottled Water
c) Rainwater
d) Groundwater
e) Surface Water
f) Spring
g) Other (please specify) _____

2.3 What is the type of vessel used for collecting water?

a) Jerry can
b) Bucket
c) Pot
d) Basin
e) Source pan
f) Others (be specific) …….

2.4 What is the cleaning schedule of the type of vessel used for water collection?

a) Daily
b) 2-3 Days
c) 4-7days
d) 7-14 days
e) Above 14days
f) Cleaning schedule not specified.

2.5 Is the type of vessel used for water collection having a cover?

a) Yes
b) No

2.6 How are the vessels used for drinking water collection handled and stored when not in use?

…….

2.7 Do you treat your water before drinking?

a) Yes
b) No

2.8 If you treat your water, how do you treat it?

a) Chlorine
b) Distillation
c) Boiling
d) Filtering
e) Settling
f) Solar Disinfection
g) Coagulation Flocculation
h) Other (Please Specify) _____

2.9 If you do not treat your water, why do you not treat it (check all that apply)?

a) Too expensive
b) Takes too much time.
c) Ineffective
d) The water is already clean.
e) Water loses taste after treatment.
f) Other (please specify) _____

2.10 If you boil your water, for what duration of time do you boil your water per day? ___ Minutes.

2.11 If you boil your water, what kind of fuel do you use to boil your water?

a) Charcoal
b) Solar
c) Main Electricity
d) Gas
e) Firewood
f) Biogas
g) Other (please specify…….

2.12 If you boil your water, how much fuel do you use to boil your water?

a) _____ (units)
b) _____ (kg)
c) _____ (pcs)
d) Others (specify) _____

2.13 What kind of vessel do you use for drinking water storage?

a) Pot
b) Source pan
c) Basin
d) Bucket
e) Kettle
f) Jug
g) Others specify……

2.14 Is the type of vessel used for drinking water storage covered?

a) Yes
b) No

2.15 How are the vessels used for drinking water storage handled and stored when not in use?

…….

2.16How often do you clean the type of vessel used for drinking water storage?

a) Daily
b) 2-3 Days
c) 4-7days
d) 7-14 days

e) Above 14days

f) Cleaning schedule not specified.

2.17 For how long is your drinking water stored? _____ days.

2.18 How many liters of water is each person drinking per day? _____ Liters

Section 3: Sanitary Inspection

Sanitary assessment will be carried out in each of the selected water sources to identify the risks for contamination with faecal bacteria organisms by use of risk factors below adapted from (Okullo et al., 2017).

SANITARY INSPECTION RISK ASSESSMENT CHECK LIST

A. Introduction

I am Mumbere Wilfred (BSc. Industrial Chemistry, MUK), currently pursuing a MSc. Environmental Management of Kampala International University and carrying out my research field work, Effect of community hygiene and water handling practices on quality of drinking water in Mpondwe Lhubiriha, Western Uganda. This risk assessment is being carried out to identify potential risks and cause of portable water contamination.

B. General information

Date…….

Water source……

Parish…….

Village…….

Area location coordinates…….

C. Community Local Authority Representative

Name……

Signature…….

Leadership title…….

Phone contact……

NIN……

D. Specific diagnostic information for assessment risk

	Risk Parameter to check	YES /NO
1.	Is the Spring source unprotected by masonry or concrete wall?	
2.	Is the Masonry protecting spring faulty?	
3.	Is the Backfill area eroded?	
4.	Does the spring lack Spilt water floods collection area?	
5.	Is the perimeter fence absent?	
6.	Can animals have access to within 10 m radius of spring source?	
7.	Is there any pit-latrine uphill and/or within 30 m of spring?	
8.	Does Surface water collect upstream of spring?	
9.	Is the Diversion ditch above spring absent/non-functional?	
10.	Are there other pollution sources uphill of spring e.g., solid waste dumps, faeces, stagnant water, and drainage channels?	

E. RESULTS AND RECOMMENDATIONS

No. of YES……

Percentage Risk……

Recommendation on remedial action…….....

F. Name and Signature of sanitarian……

Thank you so much.

Appendix 2: Water Quality Standard

Section 1: Physical parameters standard for drinking water.

S./N	Parameter	Treated potable water limits	Untreated potable water limits
i)	Color (TCU max)	15	50
ii)	Turbidity (NTU max)	5	25
iii)	Ph	6.5-8.5	5.5-9.5
iv)	Conductivity (µS\cm) max	1500	2500
v)	Suspended matter	Not detectable	Not detectable

Source: UNBS, 2014

Section 2: Chemical Quality limits for drinking water

S. No.	Parameter	Treated potable water Limit (mg/L max.)	Untreated potable water Limit (mg/L max.)
i)	Total dissolved solids	1000	1500
ii)	Total hardness, as $CaCO_3$	300	600
iii)	Aluminium, (Al)	0.2	0.2
iv)	Chloride, (Cl)	250	250
v)	Total iron, (Fe)	0.3	0.3
vi)	Sodium, (Na)	200	200
vii)	Sulphate, (SO_4)	400	400
viii)	Zinc, (Zn)	5	5
ix)	Magnesium, (Mg)	100	100
x)	Calcium, as (Ca)	150	150
xi)	Potassium, (K)	50	50

Source: UNBS, 2014

Section 3: Tolerance limits for inorganic substances in natural and treated potable water.

SI. No.	Substance	Treated potable water limit of concentration mg/L, max.	Natural potable water
i)	Arsenic, (As)	0.01	0.01
ii)	Cadmium, (Cd)	0.003	0.003
iii)	Lead, (Pb)	0.01	0.01
iv)	Copper, (Cu)	1.000	1.000
v)	Mercury, (Hg)	0.001	0.001
vi)	Manganese, (Mn)	0.1	0.1
vii)	Selenium, (Se)	0.01	0.01
viii)	Ammonia, (NH_3)	0.5	0.5
ix)	Chromium total, (Cr)	0.05	0.05
x)	Nickel, (Ni)	0.02	0.02
xi)	Cyanide, (CN)	0.01	0.01
xii)	Barium, (Ba)	0.7	0.7
xiii)	Nitrate, (NO_3)	45	45
xiv)	Boron, (Boric acid)	2.4	2.4
xv)	Fluoride, (F)	1.5	1.5
xvi)	Bromate, (BrO_3)	0.01	0.01
xvii)	Nitrite, (NO_2-N)	0.9	0.9
xviii)	Molybdenum, (Mo)	0.07	0.07

Source: UNBS, 2014.

Section 4: Limits for radioactive materials in treated and untreated potable water

SI. NO.	Radioactive material	Limits in Bq/L
i)	Gross alpha activity	0.5
ii)	Gross beta activity	1

Source: UNBS, 2014.

Section 5: Portable Water microbial quality standard (UNBS, 2014)

S/No.	**Type of microorganism**	**Portable water microbiological limit**	**Standard**
1	E. coli in 100ml	Absent	ISO 9308-1
2	Salmonella in 100ml	Absent	ISO 6785
3	Total coliforms in 100ml	Absent	ISO 4832
4	Staphylococcus aureus in 100ml	Absent	ISO 6888-1
5	Enterococcus in 100ml	Absent	ISO 7899-2
6	Shigella in 100ml	Absent	ISO 21567
7	Total viable counts at 37^0C	50 Max	ISO 6222
8	Total viable counts at 22^0C	100 Max	ISO 6222

Source: UNBS, 2014.

Appendix 3: Water sampling points

Spring water		**Bore hole water**		**River water**		**Tap water**		**Household water**	
Area name	Sample code	Area name	Sample code	Area name	Sample code	Area name	Sample code	Area name	Sample code
Kanyabyondo spring	S1	Nyakahya	B1	Lhubiriha(upstream)	R01	kyandduli	T1	kigando 1	H01
Nyakimasa Spring-A	S2	Rusese	B2	River Lhubiriha (Lower stream)	R11	Nyabutundu	T1	kigando 1	H02
Nyakimasa Spring –B	S3			River Mpondwe(upstream)	R02	kyabolokya	T3	Kasanga	H03
Kituti-A	S4			River Mpondwe (lower stream)	R12	kalitusi	T4	Nyakahya	H04
Kituti-B	S5			River Kyanzi(upstream),	R03			Rusese	H05
Kyogha Spring	S6			R13=River Kyanzi (lower stream).	R13			Nyakimasa	H06
Kasanga Spring	S7							Kituti	H07
Kigando spring	S8							Mpondwe	H08

								Nyabugando	H09
								Kalitusi	H10
								Kyabolokya	H11
								Nyambuka	H12
								Kyandului	H13
								Kaserengethe	H14
								Nyabutundu	H15
								Kyogha	H16

Appendix 4: Mc Crady's probability Most Probable Number (MPN)

TABLE: MPN table for a three-replicate design from FDA's Bacterial Analysis Manual.									
Positive Tubes					Positive Tubes				
0.1	0.01	0.001	MPN	95% Confidence Range	0.1	0.01	0.001	MPN	95% Confidence Range
0	0	0	<3.0	0-9.5	2	2	0	21	4.5-42
0	0	1	3	0.15-9.6	2	2	1	28	8.7-94
0	1	0	3	0.15-11	2	2	2	35	8.7-94
0	1	1	6.1	1.2-1.8	2	3	0	29	8.7-94
0	2	0	6.2	1.2-1.8	2	3	1	36	8.7-94
0	3	0	9.4	3.6-3.8	3	0	0	23	4.6-94
1	0	0	3.6	0.17-1.8	3	0	1	38	8.7-110
1	0	1	7.2	1.3-1.8	3	0	2	64	17-180
1	0	2	11	3.6-38	3	1	0	43	9-180
1	1	0	7.4	1.3-20	3	1	1	75	17-200
1	1	1	11	3.6-38	3	1	2	120	37-420
1	2	0	11	3.6-42	3	1	3	160	40-420
1	2	1	15	4.5-42	3	2	0	93	18-420
1	3	0	16	4.5-42	3	2	1	150	37-420
2	0	0	9.2	1.4-38	3	2	2	210	40-430
2	0	1	14	3.6-42	3	2	3	290	90-1000
2	0	2	20	4.5-42	3	3	0	240	42-1000
2	1	0	15	3.7-42	3	3	1	460	90-2000
2	1	1	20	4.5-42	3	3	2	1100	180-4100
2	1	2	27	8.7-94	3	3	3	>1100	420-4000

Appendix 5: classification of WQI results.

Sno.	WQI (%)	Classification	Remarks
1	95-100	Excellent	Water quality is protected with a virtual absence of risks
2	80-94	Good	Water quality is protected with only a minor degree of threat.
3	65-79	Fair	Water quality is usually protected but occasionally threatened or impaired.
4	45-64	Marginal	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
5	0-44	Poor	water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Appendix 6: percentage risk of contamination of different water sources.

Code	Contamination Risk Score (No. of YES)	Percentage Risk
	Spring water sources	
S1	2, 3, 4, 5, 6, 7, 8, 9, 10	90
S2	2, 3, 4, 5, 6, 8, 9, 10	80
S3	2, 3, 4, 5, 6, 7, 8,10	80
S4	2, 3, 4, 5, 6, 8, 9, 10	80
S5	2, 3, 4, 5, 6, 7, 8, 10	80
S6	2, 3, 4, 5, 7, 8, 9, 10	80
S7	2, 3, 4, 5, 6, 7, 8, 9, 10	90
S8	2, 3, 4, 5, 7, 8, 9, 10	80
	Borehole water sources	
B1	3, 4, 6, 7, 8, 9, 10	70
B2	3, 4, 6, 7, 8, 10	60
	River water sources	
R1	1,2,3, 4, 5,6, 7, 8, 9, 10	100
R2	1,2,3, 4, 5,6, 7, 8, 9, 10	100
R3	1,2,3, 4, 5,6, 7, 8, 9, 10	100
	Tap water.	
T1	5, 9	20

T2	5,9	20
T3	5	10

Appendix 7: percentage risk of water contamination of different households.

code	Contamination risk score (No. of YES)	Percentage (YES/20) risk
H1	1,2,3,4,5,6,7,8,9,10,12,13,16,19,20	75
H2	1,3,4,5,7,8,10,12,13,17,19,20	60
H3	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,17,20	85
H4	1, 3,4,5,7,8,9,10,11,12,20	55
H5	1,3,4,5,6,7,8,9,10,11,12,13,14,15,17,20	80
H6	1,2,3,4,5,6,7,8,9,10,12,13,16,19,20	75
H7	1,3,4,5,8,10,11,12,13,14,16,19	60
H8	1, 3,5,7,8,11,12	35
H9	1,3,5,7,8,10,12,13,17,19,20	55
H10	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 20	90
H11	1,3,5,7,8,10,12,13,17,19	50
H12	1, 2,3,4,5,7,8,9,10,11,12,20	60
H13	1,3,4,5,6,7,8,9,10,12,13,16,19,20	70
H14	1,3,5,7,10,12,13,17,19	45
H15	1,3,4,5,6,8,11,12,13,14,16,19	65
H16	1,3,4,5,7,8,10,12,13,17,19,20	60

Appendix 8: Water microbial analysis results

Section 1: Microbial analysis results of protected springs

Sample Number	Sampling point/Details	Bacteria	Wet season MPN/100 mL	Dry season MPN/100 mL
S1	*Kanyabyondo spring*	Total. Coliforms	43	35
		E. coli	16	11
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
S2	Nyakimasa Spring-A	*Total* Coliforms	7.4	3
		E. coli	3	0
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
S3	Nyakimasa Spring –B	Total Coliforms	0	3
		E. coli	0	0
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
S4	KITUTI-A Spring	Total. Coliforms	38	27
		E. coli	11	9.2
		Salmonella spp.		0
		Streptococcus faecalis	0	0
S5	KITUTI-B spring	Total. Coliforms	64	38
		E. coli	20	17
		Salmonella spp.		0

		Streptococcus faecalis	0	0
S6	Kighando Spring	Total. Coliforms	3	0
		E. coli	0	0
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
S7	Kyogha Spring	Total. Coliforms	64	38
		E. coli	14	9.2
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
S8	Kasanga Spring	Total. Coliforms	43	21
		E. coli	16	14
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0

Section 2: Microbial analysis results of Borehole water

Sample Number	**Sampling point/Details**	**Bacteria**	**Wet season MPN/100 mL**	**Dry season MPN/100 mL**
B1	*Nyakahya Borehole*	Total. Coliforms	3	0
		E. coli	0	0
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
B2	*Rusese Borehole*	Total. Coliforms	20	9

		E. coli	11	0
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0

Section 3: Microbial analysis results of River water

Sample Number	Sampling point/Details	Bacteria	Wet season MPN/100 mL	Dry season MPN/100 mL
R01	*River Lhubiriha(upstream)*	Total. Coliforms	75	36
		E. coli	25	14
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
R11	*River Lhubiriha (Lower stream)*	Total. Coliforms	>1100	>1100
		E. coli	>1100	1100
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
R02	*River Mpondwe(upstream)*	Total. Coliforms	64	35
		E. coli	22	11
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
R12	*River Mpondwe (lower stream)*	Total. Coliforms	>1100	>1100
		E. coli	1100	460
		Salmonella spp.	0	0

		Streptococcus faecalis	0	0
R03	*River Kyanzi(upstream)*	Total. Coliforms	75	27
		E. coli	15	9
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
R13	*River Kyanzi (lower stream)*	Total. Coliforms	>1100	1100
		E. coli	1100	460
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0

Section 4: Microbial analysis results of Tap water

Sample Number	**Sampling point/Details**	**Bacteria**	**Wet season MPN/100 mL**	**Dry season MPN/100 mL**
T1	Tap water-kyanduli	Total. Coliforms	0	0
		E. coli	0	0
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
T2	Tap water-Nyabutundu	Total. Coliforms	0	0
		E. coli	0	0
		Salmonella spp.	0	0
		Streptococcus faecalis	0	0
T3	Tap water-kyabolokya	Total. Coliforms	3	0

			E. coli	0	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0

Section 4: Microbial analysis results of household water samples

Sampling point		**Water source**	**Bacteria**	**Wet season**	**Dry season**
H1	*Kighando 1*			MPN/ml	MPN/ml
		Tap water	Total. Coliforms	20	0
			E. coli	7.4	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H2	*Kighando 2*	*Tap water*	*Total* Coliforms	28	11
			E. coli	15	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H3	*Kasanga*	*spring*	Total. Coliforms	35	28
			E. coli	12	15
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H4	*Nyakahya*	*Borehole*	Total. Coliforms	6.1	0
			E. coli	0	0

			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H5	*Rusese*	*borehole*	Total. Coliforms	11	9.4
			E. coli	0	6.1
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H6	*Nyakimasa*	*spring*	Total. Coliforms	38	28
			E. coli	16	11
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H7	*Kituti*	*spring*	Total. Coliforms	29	21
			E. coli	9.4	6.2
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H9	*Nyabugando*	*Rainwater*	Total. Coliforms	7.4	6
			E. coli	0	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H10	*Kalitusi*	*Tap water*	Total. Coliforms	75	16

			E. coli	20	6.1
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H11	*Kyabolokya*	*Tap water*	Total. Coliforms	6.1	0
			E. coli	0	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H12	*Nyambuka*	*Tap water*	Total. Coliforms	11	0
			E. coli	3	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H13	*Kyanduli*	*Tap water*	Total. Coliforms	0	6.2
			E. coli	0	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H14	*Kaserengethe*	*Tap water*	Total. Coliforms	14	3
			E. coli	0	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H15	*Nyabutundu*	*Tap water*	Total. Coliforms	0	0

			E. coli	0	0
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
H16	*Kyogha*	*spring*	Total. Coliforms	64	43
			E. coli	12	6.1
			Salmonella spp.	0	0
			Streptococcus faecalis	0	0
UNBS/WHO-2014				0	0

Section 5: Average Microbial analysis results of selected* water sources and *household water samples.

Water source	T.C		*E. Coli*		Salmonella spp.		Streptococcus faecalis	
	wet season	**Dry season**	**wet season**	**Dry season**	**wet season**	**Dry season**	**wet season**	**dry season**
Spring	32.8	20.62	10	7.92	0	0	0	0
River	585.67	566.33	**560**	**342.3**	0	0	0	0
Tap	1	0	0	0	0	0	0	0
Borehole	11.5	4.5	5.5	0	0	0	0	0
Household	21.53	10.72	5.92	3.15	0	0	0	0
Average	**130.5**	**120.434**	**116.284**	**70.674**	**0**	**0**	**0**	**0**
WHO/UNBS-2014	**0**	**0**		**0**	**0**	**0**	**0**	**0**

Appendix 9: Water physiochemical analysis results

Section 1: Spring water samples physiochemical parameters

Source	pH		E.C (µS/cm)		TDS (mg/L)		Temp (°C)		Turb (NTU)		DO (mg/l)		NO_3^- (m
	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S
Kanyabyondo	7.10	6.90	613.0	624.0	303.3	312.0	21.0	22.5	5	5	9.8	7.6	49.00
Nyakimasa-A	7.20	6.80	389.0	451.0	191.0	226.0	19.0	19.5	5	5	8.6	9.1	29.12
Nyakimasa – B	6.90	6.90	501.0	510.0	252.0	255.0	19.0	20	**6***	**6***	9	8.2	30.50
Kituti-A	7.00	6.70	340.0	321.0	170.0	161.0	20.0	21	5	5	8.4	8.2	37.86
Kituti-B	6.90	6.80	337.0	342.0	166.9	171.0	19.0	21	**6***	5	8.0	8.3	42.55
Kighando	6.80	6.70	390.0	400.0	196.5	200.0	19.0	22	**6***	**6***	11.0	9.2	33.30
Kyogha	7.10	6.80	487.00	590.0	244.0	295.0	20.0	22.5	5	5	8.5	7.9	**59.01***
Kasanga	6.90	6.80	406.0	413.0	201.1	207.0	20	21	3	3	8.7	9.6	45.00
Average	**6.99**	**6.80**	**432.87**	**456.38**	**215.58**	**228.19**	**19.62**	**21.19**	**5.12**	**5**	**9.0**	**8.52**	**40.79**
UNBS/WHO standard-2014	6.5-8.5		1500 Max		1000 Max		20-25		5 Max		>6.5		
Std Dev.	**0.1**	**0.1**	**94.4**	**110.4**	**47.0**	**55.1**	**0.74**	**1.10**	**0.99**	**0.93**	**0.96**	**0.70**	**10.19**

Note: *W/S Wet Season Results, D/S is Dry Season results*

Section 2: Borehole water samples physiochemical parameters

Source	pH		E.C (µS/cm)		TDS (mg/L)		Temp (^OC)		Turb (NTU)		DO (mg/l)		N
	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/
Nyakahya	6.7	6.7	518	583	258.64	291.5	21.5	23	1	1	8.3	7.9	3
Rusese	6.9	6.8	286	315	143.5	157.5	21	22	2	2	7.5	7.4	3
Average	**6.8**	**6.75**	**402**	**449**	**201.07**	**224.5**	**21.25**	**22.5**	**1.5**	**1.5**	**7.9**	**7.65**	**32.**

UNBS/WHO standard-2014	6.5-8.5		1500 Max		1000 Max		20-25		5 Max		>6.5		
Std Dev.	**0.14**	**0.07**	**164.05**	**189.50**	**81.42**	**94.75**	**0.35**	**0.71**	**0.71**	**0.71**	**0.57**	**0.35**	**2**

Note: *W/S Wet Season Results, D/S is dry Season results*

Section 3: River water samples physiochemical parameters

Source	**pH**		**E.C (µS/cm)**		**TDS (mg/L)**		**Temp (^{0}C)**		**Turbidity NTU)**		**DO (mg/l)**		**N**
	W/S	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**
R. Lhubiriha (upstream)	7.2	6.9	39	55	21	27.5	18	19	195*	120	6.9	6.4	6
R. Lhubiriha (Low stream)	8.8	7.1	28	105	13.72	52.5	20	21	298*	205	5.5	5.2	1
R. Mpondwe(up)	7.2	7.3	115	187	58	93.5	19	22	240	95	6.4	5.6	8
R. Mpondwe (Low stream)	8.6	7.6	106	204	51.7	102	21.5	22	310	220	4.8	4.1	1
R. Kyanzi (upstream)	7.1	6.7	119	162	57.04	81	20	21	190	107	6.1	5.9	7
R. Kyanzi (Low stream)	8.3	7.1	108	179	57	89.5	20	21	269	250	4.7	4.4	
Average	**7.9**	**7.12**	**85.83**	**148.7**	**43.08**	**74.33**	**19.75**	**21.00**	**250.33**	**166.17**	**5.73**	**5.27**	**11**
UNBS/WHO standard-2014	6.5-8.5		1500 Max		1000 Max		20-25		5 Max		>6.5		
Std Dev.	**0.78**	**0.31**	**40.96**	**57.11**	**20.17**	**28.56**	**1.17**	**1.10**	**50.97**	**66.53**	**0.89**	**0.88**	**3**

Note: *W/S Wet Season Results, D/S is Dry Season results*

Section 4: Piped tap water samples physiochemical parameters

Sample point	pH		E.C (µS/cm)		TDS (mg/L)		Temp (^{0}C)		Turbidity (NTU)		DO (mg/l)		NO_3
	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S
Mpondwe	6.9	6.9	78	78	40.5	40.5	21	21	0.8	0.5	13.5	14.1	1.56
Kighando	6.8	7.05	96	104	41.65	45.13	21.5	21	0.5	0.6	12.91	11.3	2.04
Kighando	6.9	7	90	94	46	43.9	23.1	20.5	0.5	0.5	15.2	13.8	1.89
Average	**6.9**	**6.98**	**88**	**92**	**42.72**	**43.18**	**21.87**	**20.83**	**0.6**	**0.53**	**13.87**	**13.07**	**1.83**
UNBS/WHO standard-2014	6.5-8.5		1500 Max		1000 Max		20-25		5 Max		>6.5		
Std Dev.	**0.06**	**0.08**	**9.17**	**13.11**	**2.90**	**2.40**	**1.10**	**0.29**	**0.17**	**0.06**	**1.19**	**1.54**	**0.25**

Note: *W/S Wet Season Results, D/S is Dry Season results*

Section 5: Household water samples physiochemical parameters

Location	pH		E.C (µS/cm)		TDS (mg/L)		Temp (^{O}C)		Turbidity (NTU)		DO (mg/l)	
	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S	W/S	D/S
Kighando 1 (Tap)	6.8	6.9	73	140.4	38	75.32	24	22	0.5	0.5	12.4	13.13
Kighando 2 (River)	7.3	6.95	88.5	98.1	49	48.17	23	25	28	0.7	6.2	11.6
Kasanga (SP)	6.8	6.8	298	330	188	163.5	22	26	4	1	7.86	8.71
Nyakahya (BH)	6.6	6.4	420.3	440.9	213	201.95	22	24	0.9	0.9	8.14	7.32
Rusese (BH)	6.7	6.8	300.5	356.6	148.85	178.2	26	22	4	0.8	7.55	8.81
Nyakimasa (SP)	6.9	6.8	243.7	157.4	120	79	20.5	25	6	3	9.47	8.1
Kituti (SP)	6.7	6.5	194.4	247.6	101.1	122.9	21.5	21	5	2	7.92	7.29

Mpondwe (SP)	6.4	7.6	381.6	105.5	191	52.65	22	25	4	20	8.63	6.87
Nyabugando (Tap)	6.8	6.9	96	104.3	48.2	53.05	23	20	0.7	0.5	14.3	11.9
Kalitusi (Tap)	7.1	6.9	132	95.7	59.9	47.48	23.5	22.3	13	6	12.71	10.64
Kyabolokya (Tap)	6.8	6.9	126.1	110.9	63.21	55.03	20.5	23	1	1	12.42	13.72
Nyamambuka Tap)	6.8	6.9	87.4	117.6	43.5	59	23	24	2.5	2.5	11.74	12.4
Kyanduli (Tap)	6.9	6.7	130.9	108.4	66.5	52.93	19	26.5	0.8	2	12.1	11.78
Kasengerethe (Rain)	6.5	7	19.5	111.6	10	55	24	22.5	3	0.7	18.6	13.19
Nyabutundu (Tap)	6.9	6.8	119.3	98.1	68.95	50.16	20.5	23	0.4	0.7	13.12	12.06
Kyogha (SP)	6.7	6.3	259.5	321.7	128.76	161	21	23	1	3	7.8	8.1
Average	**6.79**	**6.82**	**185.67**	**184.05**	**96.12**	**90.96**	**22.21**	**23.39**	**4.675**	**2.83**	**10.68**	**10.35**
UNBS/WHO standard-2014		6.5-8.5	1500 Max		1000 Max			20-25	5 Max			>6.5
Std Dev.	**0.2**	**0.3**	**118.2**	**115.0**	**62.0**	**54.7**	**1.7**	**1.8**	**7.0**	**4.8**	**3.3**	**2.4**

Note: *W/S Wet Season Results, D/S is Dry Season results*

Section 6: Average physiochemical parameters of selected water sources & household water samples

	pH		**E.C (µS/cm)**		**TDS (mg/L)**		**Temp (^{O}C)**		**Turbidity NTU)**		**DO (mg/l)**		**NO_3^- (mg/l)**		**T. (mg/l**
	W/S	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**	**D/S**	**W/S**
	7.9	7.12	85.83	148.7	43.08	74.33	19.75	21.00	**250.33**	**166.17**	**5.73**	**5.27**	**110.05**	**52.50**	44.0
ter	6.8	6.75	402	449	201.07	224.5	21.25	22.5	1.5	1.5	7.9	7.65	32.715	23.73	127.6

r	6.99	6.80	432.87	456.38	215.58	228.19	19.62	21.19	**5.12**	5	9	8.52	40.79	37.28	133.0
	6.9	6.98	88	92	42.72	43.18	21.87	20.83	0.6	0.53	13.87	13.07	1.83	2.04	99.6
es	6.79	6.82	185.67	184.05	96.12	90.96	22.21	23.39	4.675	2.83	10.68	10.35	22.33	16.95	107.57
D 14	6.5-8.5		1500 Max		1000 Max		20-25		5 Max		>6.5		45 Max		3

Appendix 10: Parametric estimates of the spearman correlation

Microbial parameters		**Physiochemical Parameters**							
		pH	**E.C**	**TDS (mg/L)**	**Temp (^{O}C)**	**Turbid (NTU)**	**D.O (mg/l)**	**NO_3^- (mg/l)**	**T. hardness (mg/l)**
Spring water sources									
Total Coliforms	Pearson Correlation	-.071	-.140	-.127	.079	.046	.105	.158	-.106
	Sign. (2 tailed)	.665	.390	.434	.628	.778	.521	.330	.517
	n	40	40	40	40	40	40	40	40
E. Coli	Pearson Correlation	.052	-.223	-.161	.157	-.243	-.115	.412**	-.032
	Sign. (2 tailed)	.752	.167	.320	.332	.130	.480	.008	.843
	n	40	40	40	40	40	40	40	40
River Water Sources									
Total Coliforms	Pearson Correlation	.621**	.095	.100	.429**	.745**	-.842**	.557**	.022
	Sign. (2 tailed)	.000	.560	.537	.006	.000	.000	.000	.891
	n	40	40	40	40	40	40	40	40

E. Coli	Pearson Correlation	.680**	-.057	-.052	.353*	.725**	-.712**	.649**	-.076
	Sign. (2 tailed)	.000	.726	.751	.026	.000	.000	.000	.642
	n	40	40	40	40	40	40	40	40
Household Water sources									
Total Coliforms	Pearson Correlation	-.024	.137	.149	.048	.272	-.272	.659**	-.010
	Sign. (2 tailed)	.896	.454	.416	.792	.132	.132	.000	.955
	2	32	32	32	32	32	32	32	32
E. Coli	Pearson Correlation	.158	.150	.171	.098	.415*	-.387*	.658**	.053
	Sign. (2 tailed)	.387	.412	.349	.592	.018	.029	.000	.774
	n	32	32	32	32	32	32	32	32