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Master Dissertation

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WATER POLICY

Presented by

Claydon Mumba KANYUNGE

TITLE: INTEGRATING HOUSEHOLD WATER TREATMENT AND SAFE STORAGE PRACTICES IN ZAMBIA'S NATIONAL WATER POLICY FOR EFFECTIVE REGULATION, EVALUATION AND SUSTAINABLE WATER PROVISION

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DECLARATION

This thesis was written and submitted in accordance with the rules and regulations governing the award of Master of Science in Water Policy of the Pan African University. I declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree, except where states otherwise by reference or acknowledgement, the work presented is entirely my own.

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APPROVAL

This thesis of Claydon Mumba Kanyunge is approved as fulfilling the requirements of the Degree of Master of Science in Water Policy at the Pan African University Institute of Water and Energy Sciences, Tlemcen, Algeria.

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ABSTRACT

Providing safe water to the poor in developing countries is a challenge that has persisted through decades of international development efforts. Household Water Treatment and Safe Storage (HWTS) has been put forth as an interim solution that could reduce the burden of waterborne diseases. The study aimed to examine HWTS practices and the quality of water in households of peri-urban communities of Lusaka, Zambia. The study was conducted in three peri-urban areas in Lusaka, namely, Chaisa, Kanyama and Ngombe. These communities were selected based on the presence of Water Trusts, population size and water-borne disease outbreak statistics. Twenty-six households were selected randomly. The study revealed that 42% of participating households treated their water by chlorination, boiling and SODIS (Solar Disinfection). It further revealed that 73% of the households that treated their water noticed a reduction in the occurrence of diarrhoeal diseases that could have resulted from the consumption of contaminated water. It was observed that 50% of the households obtained their water from private boreholes, while 42% and 8% of the households collected their water from kiosks and shallow hand-dug wells respectively. Seventy-three per cent of the households stated they store their water in both buckets and jerrycans, 12% stored their water in buckets and jerrycans only while 4% of households stored water in drums. Secondary data from literature revealed that Zambia does not have any National Policy or Strategic Plan document that addresses HWTS. In addition, the study revealed that the Zambia Bureau of Standards is responsible for certifying HWTS products but does not include any details of requirements for certifying HWTS in its certification policy document. The major challenge regarding the formulation and implementation was lack of government involvement in HWTS methods and performance analysis being practiced in Zambian communities. Furthermore, the study revealed that several countries, such as Ghana and Tanzania, have formulated Strategic Plans that address HWTS, which Zambia can learn from.

Keywords: HWTS, diarrhoeal diseases, National Policy, Strategic Plans, certification

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ACRONYMS AND ABBREVIATIONS

APHA	American Public Health Association
BOD	Biological Oxygen Demand
CAWST	Centre for Affordable Water and Sanitation Technology
CDC	Centre for Disease Control
CFR	Case Fertility Rate
CFU	Coliform Forming Units
DO	Dissolved Oxygen
HWTS	Household Water Treatment and Safe Storage
ILO	International Labour Organisation
IPCS	International Programme on Chemical Safety
LWSC	Lusaka Water Supply and Sanitation Company Limited
MLGRD	Ministry of Local Government and Rural Development
MoH	Ministry of Health
MWED	Ministry of Water and Energy Development
NGO	Non-Governmental Organisation
NTU	Nephelometric Turbidity Units
POU	Point of Use
RWSS	Rural Water Supply and Sanitation
SODIS	Solar Disinfection
SPSS	Statistical Package for Social Sciences
TNTC	Too Numerous to Count
UN	United Nations
UNICEF	United Nations International Children's Emergency Fund
USEPA	United States Environmental Protection Agency
USNRC	United States National Research Council
UV	Ultraviolet
WARMA	Water Resources Management Authority
WBG	World Bank Group
WHO	World Health Organisation
WRM	Water Resources Management

WSS	Water Supply and Sanitation
ZABS	Zambian Bureau of Standards

CHAPTER 1

INTRODUCTION

1.1 Background

Household Water Treatment and Safe Storage (HWTS) is a proven intervention to improve drinking water quality and reduce diarrhoeal diseases. Achieving meaningful health gains from HWTS requires scaling-up of the intervention to those populations most at risk. Such scaling-up depends, in large part, on national enabling environments such as legal framework and policies (WHO, 2012).

In many countries, no specific legal frameworks for social (safe water) enterprises exist. In these countries, social enterprises often adopt the legal status of a (non-profit) association or a co-operative. Whether a social enterprise can operate effectively is, for instance, highly dependent on the extent to which the legal framework enables the enterprise to attract capital. Also, the lack of implementation of the laws and regulations influence the businesses environment (Chew, 2010).

Governments can also implement policies that facilitate sustainability and scale-up of safe water businesses. The presence of policies specifically tailored to household water treatment solutions (HWTS), for instance, can help maximise the impact of efforts to promote and implement different HWTS practices. The government can also implement policy measures that can effectively be enforced by the Zambia Bureau of Standards to support social entrepreneurs or foster a more general culture of social entrepreneurship (ILO, 2016).

Providing universal access to safe, pathogen-free, reliable piped water supplies into households is the ideal solution to water-borne illness. However, the high capital and maintenance costs of piped supply systems mean that universal safe piped water is likely decades away for many developing regions. Household water treatment and safe storage (HWTS) practices – like boiling, chlorination and filtration – provide an interim solution for managing water safety at home if carried out consistently and correctly (Sobsey, 2002). Some studies have shown that HWTS practices yield improvements in drinking water quality and reductions in diarrhoeal disease (Sobsey et al., 2008; Sobsey, 2002; Clasen et al.,2007; Elsanousi et al., 2009). Humans have been treating drinking water through filtration, boiling and coagulation for centuries (Sobsey, 2002). In recent years, the availability and promotion of diverse HWTS products by governments, NGOs, industry and international organisations have increased markedly. Despite the introduction of diverse products and the advocacy and implementation efforts by NGOs, boiling is the only HWTS practice to achieve scale (Clasen, 2008). Additionally, many HWTS programmes and studies have reported high initial uptake and use that declines rapidly over time (Sobsey et al., 2008; Brown et al., 2009).

Globally, HWTS efforts are promoted through the International Network on Household Water Treatment and Safe Storage (the "Network"). The Network, established in 2003 by WHO and as of 2011 co-hosted by WHO and UNICEF, includes those international, governmental and non-governmental organisations, private sector entities and academia that subscribe to the Network mission. Specifically, this is: "to contribute to a significant reduction in water-borne and water-related vector-borne diseases, especially among vulnerable populations, by promoting household water treatment and safe storage as a key component of community-targeted environmental health programmes" (WHO/UNICEF, 2011). The main areas of Network activity are reflected in four working groups: policy/advocacy, research/knowledge management, implementation/scale-up and monitoring and evaluation (WHO, 2012).

WHO's 'international scheme to evaluate household water treatment technologies' (the Scheme) offers independent and consistent testing possibilities to evaluate the performance of specific HWTS products. The efficiency of the removal of microbial pathogens is tested by applying the concept of acceptable risk to estimate the disease burden associated with the exposure to pathogens in drinking water (WHO, 2011). Organisations and businesses can get their technology tested by applying to the Scheme. Zambia is yet to include HWTS in its policies considering water treatment can be included in various sectors such as health, national development planning, environment and water sectors. Yet, none of the mentioned sectors has included any written information regarding HWTS. There has been active involvement of the private sector in HWTS provision in various communities around the country. Most notably of many interventions is a project carried out by CAWST (Centre for Affordable Water and Sanitation Technology) and Seeds of Hope Zambia between 2014 and 2016. The project involved the use of Biosand Filters in Peri-urban areas of Lusaka and Ndola. The utilisation of the Biosand filters proved to be effective in both areas. However, follow-up monitoring and evaluation and government involvement in the project was not present (Sichone and Strand, 2014).

1.2 Problem Statement

Zambia is among many states whose National Water Policy does not address HWTS and neither are there any institutions in the country that regulates or evaluates HWTS. Policies regarding HWTS are important as they focus on water quality and supply and disease prevention and control; thus, lacking such policies can put many people at risk of water-borne diseases.

Since Zambia does not have a national strategy for HWTS that bridges the many national water and health efforts, this calls for the government to consider integrating HWTS in its National Water Policy. One key challenge in realising benefits from HWTS policies is limited coverage in areas and among populations where water quality improvements would have an important impact on health. This has, therefore, resulted in poor regulation and evaluation of many HWTS by the government.

Based on identified challenges, greater support is needed to develop and implement national HWTS policies, encourage integration with other health interventions and diarrhoeal disease prevention efforts, and strengthen monitoring, evaluation and regulation. To undertake this, the National Water Policy of 2010, Ministry of Health Policy 2012, Zambia Bureau of Standards documents and other countries HWTS policies and regulations were studied to examine HWTS practices in these documents, which can be used in the formulation of policies and strategies.

1.3 Aim

The study aimed to examine HWTS practices and how Zambia can formulate national policies on HWTS regulations and evaluation which in turn can improve decision making by HWTS practitioners and provide a useful resource to those planning and implementing HWTS programmes.

1.4 Objectives

The following are the objectives which arose from the aim:

i. To analyse the water quality of household water stored in communities of Chaisa, Kanyama and Ngombe in Lusaka, Zambia;
ii. To assess and evaluate the performance of HWTS in improving the quality of water and reducing diarrhoeal disease within selected communities of Zambia;
iii. (a) To analyse the Zambian national water policy and the Zambian Bureau of standards documents with regards to HWTS;

     (b) To analyse national policies, documents and regulations from other countries with HWTS policies and how they are being implemented;
iv. To identify key challenges towards policy formulation of HWTS in Zambia; and
v. To identify the requirements for certification of HWTS technologies in Zambia.

1.5 Research Questions

To answer to the objectives, the research questions are:

i. How effective are HWTS in improving water quality and water-borne disease prevention? and
ii. How can HWTS practices be integrated into Zambia's national water policy?

1.6 Significance of the Study and Scientific Contribution

With numerous HWTS products and technologies available, Zambia should formulate HWTS policies so that consistent standards for quality and performance are established by the Zambian Bureau of Standards to protect consumers. The most common types of HWTS used in Zambian households include chlorination, solar disinfection, boiling and the use of biosand filters. In Zambia, the Zambian Bureau of Standards (ZABS) is the body responsible for standard formulation, quality control and certification of products. However, the Bureau does not address HWTS in any of its documents, and this, therefore, presents an opportunity for the Bureau to consider HWTS in this certification and quality control analysis. The Zambian Government must set standards and regulations, when implemented and enforced, can help to market and scale-up effective and sustainable HWTS products. Some of the potential benefits include increased trust of consumers and the consistent quality of the HWTS products. With the presence of policies and regulations, the Zambian Government can also provide certification of HWTS products to inform the public which specific products provide safe water and are of good quality. This can help increase confidence in products which maximises the likelihood of adoption and sustained use.

1.7 Scope of Work

The research project involved a desktop study, field and laboratory work:

i. In the desktop study, a literature review was carried out to document and understand previous studies on HWTS in Zambia and different countries. Literature review was also carried out to document policies and national strategies that have been formulated and implemented in different countries;
ii. In the field, study sites were defined and households were selected based on vulnerability to water-borne diseases, population and nature of water sources;
iii. Household water sampling was conducted for the selected sites in April and May 2020. Physical, chemical and microbiological analyses were conducted at University of Zambia Civil Engineering Department (Environmental Engineering Laboratory) and School of Mines Geochemical Laboratory; and
iv. Water samples were also collected from the kiosks, privately-owned boreholes, municipal boreholes and shallow wells. The data collected in the field was combined with the theoretical understanding of characterisation of potable water quality to interpret it.

1.8 Thesis Organisation

The thesis consists of seven chapters, which are outlined below.

Chapter 1: Background to the research, research problem, objectives, questions, hypothesis and scope of work are included in this chapter.

Chapter 2: This chapter consists literature review on types of HWTS, HWTS policies and strategies in Tanzania and Ghana, national coverage of water and sanitation in Zambia, chemical, microbiological and physical parameters and their effects on human health, WHO and ZABS guidelines for drinking water quality, and analysis of certification of HWTS products.

Chapter 3: Description of the study areas – location of Chaisa, Kanyama and Ngombe in and geology of the study areas is described in this chapter.

Chapter 4: This chapter describes data collection and analysis methods.

Chapter 5: The analyses of results appear in this chapter. This chapter also contains the discussion and interpretation of results on the quality of water from various households and sources in Chaisa, Kanyama and Ngombe.

Chapter 6: The conclusions and recommendations appear in this chapter. Following this chapter are references and appendices.

CHAPTER 2

LITERATURE REVIEW

2.1 General Remarks

This chapter presents a review of literature regarding the use of HWTS and its significance in developing countries such as Zambia. The need is to have a deeper understanding of the importance of integrating HWTS in policies so as to improve not only the quality of drinking water but also the health of individuals. This chapter highlights various types of HWTS and how they are being used to treat contaminated water. In addition, policies and strategies for countries like Ghana and Tanzania have formulated with regards to HWTS are included. This chapter also reviews the types of waterborne diseases common in Zambia then concludes on literature regarding certification of products in Zambia.

2.2 Safe Drinking Water

Safe drinking water is a human right and fundamental requirement for good health (UN, 2010). Access to safe drinking water is being monitored worldwide and data shows that over 600 million people use sources that are not yet improved (WHO & UNICEF, 2010). However, the number of people consuming safe drinking water is likely to be overestimated because water from improved sources is not necessarily safe to drink (Bain, Cronk, Wright, et al., 2014; Onda, LoBuglio, & Bartram, 2012; Sobsey, Stauber, Casanova, Brown, & Elliott, 2008).

Many sources declared as improved contain faecal contamination as shown in a review of over 319 individual studies - especially in low-income countries and rural settings (Bain, Cronk, Wright, et al., 2014). In addition, even if the water drawn at the source is of good quality, numerous sources of potential recontamination exist during transport and storage, and through consumption habits (e.g. contaminated transport or storage containers, dipping hands into stored water or sharing the same cup for scooping).

Inadequate water that is not safe to drink constitutes one of the greatest risk factors for diarrhoeal disease and accounts for around a third of approximately 842,000 diarrhoeal deaths in 2012 due to inadequate water, sanitation and hygiene practices (Prüss-Ustün et al., 2014). The consistent consumption of safe drinking water can significantly reduce the burden of diarrhoeal disease although there is some debate around the degree of effectiveness of different treatment technologies, mostly due to their incorrect or inconsistent application (Boisson et al., 2013; Clasen, 2015; Hunter, Zmirou-Navier, & Hartemann, 2009; Ojomo, Elliott, Goodyear, Forson, & Bartram, 2015; Wolf et al., 2014).

Where no adequate infrastructure exists, the individual has to evaluate his or her possibilities to create a positive, protective environment for her or himself, one's family, and community. Therefore, to have safe drinking water, Sobsey (2002) promoted Household Water Treatment and Safe Storage (HWTS) as an interim solution for managing water safety at home if carried out consistently and correctly. This represent an intermediate off-the-grid solution for such settings and can increase the quality of water at the point of use (POU) (Wolf et al., 2014).

Significant reductions of diarrhoeal prevalence can be expected from HWTS usage, and it is one of the most important means for prevention (Arnold & Colford, 2007; Cairncross et al., 2010; Clasen, Haller, Walker, Bartram & Cairncross, 2007). The health benefits from HWTS methods might even exceed those that can be expected from improvements at the source level (due to the problem of recontamination) (Sobsey et al., 2008).

Achieving health gains associated with HWT and safe storage depends on two key requirements. First, HWT technologies must be microbiologically effective; i.e. they must sufficiently reduce pathogens to protect health. Second, such technologies must reach and be consistently and correctly used by the groups most at risk for waterborne disease. This requires consideration of a number of key factors such as effective supply chains, affordability, user preferences and changing and sustaining user behaviour. When effective methods are used correctly and consistently, HWT and safe storage can reduce diarrhoeal disease by as much as 45 % as shown Figure 1.

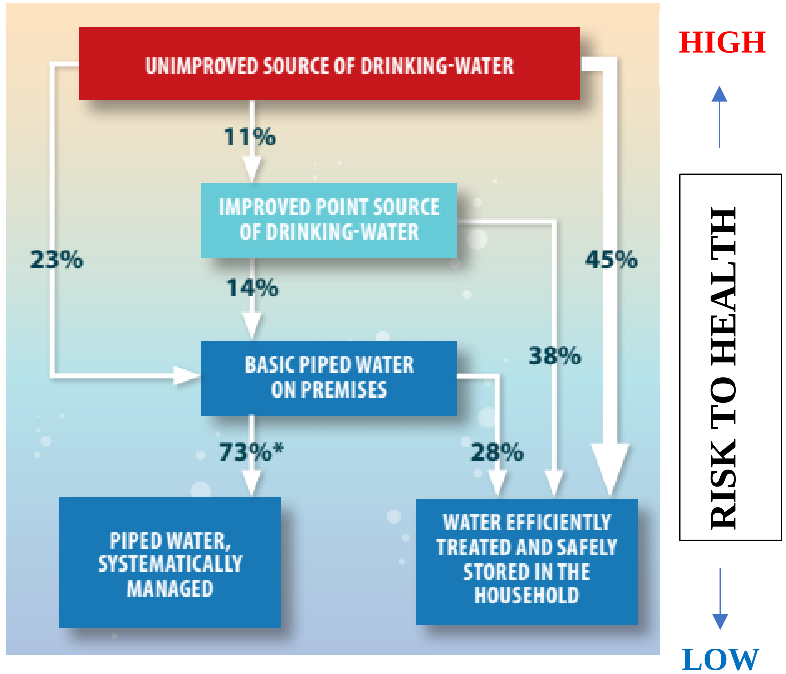


Figure 1: Estimated reductions in diarrhoeal disease from household water treatment (WHO, 2014)
* The estimates are based on limited evidence and should therefore be considered preliminary

2.3 Household Water Treatment and Safe Storage (HWTS) Methods

Several options exist for water treatment at the point of use, which is at the household level where the water is also consumed. Water designated for drinking and the preparation of food, but also for safe handwashing can be purified by boiling, disinfection, or filtration (Sobsey et al., 2008), among others.

2.3.1 Boiling

Water can be sterilised by heating it up to the boiling point for a certain amount of time before letting it cool down. This is microbiologically very effective against all kinds of water-borne pathogens (WHO, 2011). Boiling is probably the oldest and one of the most common options used for drinking water treatment around the globe (Clasen, Thao, Boisson, & Shipin, 2008; Gadgil, 1998; Ojomo et al., 2015). Although in a widespread application, boiling is very energy-intensive. Boiling all water designated for consumption within a household is oftentimes not economically feasible and can demand large shares of the available household income when large quantities of fuel have to be purchased regularly (Gilman & Skillicorn, 1985; Psutka, Peletz, Michelo, Kelly, & Clasen, 2011). Gathering enough firewood is a time-consuming and burdensome work of millions of women around the globe (Cecelski, 1987). In addition, indoor air pollution from burning biomass fuels can cause severe side effects especially on children's health such as respiratory infections and represents another problem on its own (K. Smith, 2013; E. M. Smith, Plewa, Lindell, Richardson & Mitch, 2010). Water that has been boiled is also not protected from recontamination and therefore requires rigorous safe storage practices.

2.3.2 Filtration

Filtration is the process of physical removal of dirt and pathogens through porous membranes, sand, or cloth. According to an evaluation study of different HWTS technologies, ceramic and biosand filters show reliable effectiveness in improving drinking water quality and users' health in the long-term and have the greatest potential to become widely used in developing countries (Sobsey et al., 2008).

Different types of filters can be used for water purification, starting from the of simple cloth for filtration, to ceramic or fibre membranes and biosand filters. However, the principle is always the same of physically removing dirt particles and biological components, including pathogens by passing the water through microbiologically small openings or pores. These are retained inside the filter while only the purified water exits the filter on the clean side.

Ceramic filters, for example, are produced locally in many developing countries and their microbial effectiveness varies with production methods and quality of the material (Sobsey et al., 2008). Biosand filters, in addition, contain a biologically active layer which enhances the effectiveness of deactivating specific pathogens such as bacteria.

2.3.3 Chlorination of drinking water

Disinfection of drinking water can be achieved using chemical substances. Chlorine is a widely available, easily produced and low-cost chemical that is used to render water safe for consumption. Chlorine can be purchased in different forms, such as liquids (household bleach), or solid in the form of powder or tablets designed to treat a fixed quantity of water. The usage of chlorine at POU has been widely recommended by the U.S. Centers for Disease Control (CDC) (Sobsey et al., 2008).

Chlorine is also added into piped water systems in many countries around to prevent the contamination of the transported water. Chlorination is effective against bacteria and viruses, and to a lesser extent against protozoa (Sobsey et al., 2008). Chlorine is especially effective against cholera, why it is often distributed in the emergency context during or prior to feared cholera outbreaks. It is, however, not effective against some classes of pathogens such as *Cryptosporidium* (WHO, 2011). The amount of chlorine necessary to be added also depends on the quality of the water. High turbidity of the raw water might reduce its effectiveness, needs higher dosages, and is recommended to be filtered first. A contact time of around 30 minutes is usually sufficient to \ effectively disinfect the treated water but can also depend on the quality and temperature of the water (WHO, 2011).

One of the main advantages of chlorine over other treatment technologies is that it provides lasting protection from recontamination due to the free chlorine in the water that can disinfect contaminating elements that are introduced into the water at a later point. The crucial point in using chlorine is to dose the correct amount of disinfectant to a given quantity of water. While under-dosing results in a reduced efficacy to kill microbiological pathogens, adding too much chlorine can induce a strong, sometimes bitter taste and odour to the water, which can lead to rejection by consumers (Freeman, Quick, Abbott, Ogutu & Rheingans, 2009; Luby, Mendoza, Keswick, Chiller, & Hoekstra, 2008).

There is quite a grown discussion around the toxicity of chemical disinfection by-products, which can result from adding chlorine into drinking water (Luilo & Cabaniss, 2011; K. Smith, Samet, Romieu, & Bruce, 2000; Chu et al., 2015). However, the current WHO guideline for drinking water quality rates the risk of these by-products to be largely outweighed by their benefits and therefore recommends treatment using chlorine within set dosage limits (WHO, 2011).

2.3.4 Coagulation-flocculation

Chlorination is sometimes combined with a coagulant, which chemically bonds to the disinfected material in the water leading to its sedimentation. This is one of the more expensive technologies (McGuigan et al., 2012) and usually only available where it is specifically distributed during epidemics. These materials come in the form of tablets or sachets for a fixed amount of water.

2.3.5 SODIS (Solar Disinfection)

Solar Disinfection (SODIS) is a very simple, low-tech technology that uses sunlight to disinfect water. The water is placed in clear plastic or glass bottles and exposed to the sun for several hours, during which radiation from the UV–A spectrum in combination with increased temperatures improve the microbiological quality of the water. However, the water has to be clear for the sunlight to effectively pass through, which means that turbid water needs to be filtered before it is exposed to the sunlight (Sommer et al., 1997; Wegelin & Sommer, 1998).

SODIS has been extensively studied over the last decades and has been shown to effectively reduce almost all water-borne pathogens, both under laboratory conditions and in field studies (McGuigan et al., 2012). Its impact on health and diarrhoea reduction has been subject to quite some discussion, but clinical trials show significant reductions of illness when used correctly and consistently.

Although SODIS has been the least prevalent technology among households using HWTS, it is in use in over 50 countries around the globe by an estimated 4.5 million people (McGuigan et al., 2012). Among the range of existing options, SODIS is potentially the cheapest technology needing the least resources on the consumer’s side (Clasen, Haller, et al., 2007).

2.3.6 Other HWTS technologies

There are a number of other HWTS water purification technologies (e.g. using ozone), which are less common, oftentimes requiring a higher technological standard and are thus incongruous to household settings in less developed regions. These options will, therefore, not be addressed further in this thesis. However, a few types of HWTS products currently sold on the Zambian market are shown in Appendix 1. Most of the products shown are distributed by Davis & Shirtliff who are one of the leading suppliers of water-related equipment in the Eastern and Southern African region.

2.3.7 Consumer behaviour

The success of HWTS technologies in providing safe drinking water for the prevention of disease does not solely rely on the microbiological efficacy of the treatment method to remove threats, but also on their correct, consistent and continuous usage (Clasen, 2015). A slight reduction in adherence is shown to lead to a rapid decrease in the expected health benefits from POU technologies (Brown & Clasen, 2012). Therefore, the application and consistent usage of treatment products and technologies almost exclusively rely on the consumer's behaviour.

In consequence, it is essential to understand the drivers, motivators and factors, which operate within people's mindsets that steer or determine an individuals' choices and behaviours (WBG, 2015). Consumer's behaviour can be understood from different perspectives within the social sciences such as sociology, economics, political sciences and others. When it comes to health-relevant behaviours, psychological approaches from within the class of behavioural sciences offer a number of tools and theories, as well as evidence on how the individual works and makes up his or her mind about different behavioural options (Hall, 1983).

2.4 Physicochemical Parameters

The physicochemical characteristics of water samples from selected water sources and households in Chaisa, Kanyama and Ngombe were analysed to assess the quality of waters for suitability for human consumption. The physicochemical parameters that were analysed include pH, turbidity, arsenic, fluorides, chlorides, phosphates and nitrates.

2.4.1 pH

The concentration of hydrogen ions in a solution is called pH; it is the indicator of the acidic or alkaline condition of water status and quantifies the basic or acidic nature of a solution. The pH scale ranges from one (acidic) to 14 (basic) with seven as Neutral. The standard range for any purpose such as survival of fish and its use as drinking water in-terms of pH is 6.5 to 8.5 (Alam, 2007).

The pH value depends on various phases of water treatment and water supply, such as acid-base, neutralisation, coagulation, sedimentation and corrosion control (Ranjeeta, 2011). Due to acid rain or discharges, pH changes which in turn increases the bacterial degradation, thereby depleting the Dissolved Oxygen (DO) and hence the Biological Oxygen Demand (BOD) requirement exponentially rises.

A direct relationship between human health and the pH of drinking water is impossible to ascertain, because pH is so closely associated with other aspects of water quality. Acids and alkalis are weak and usually very dilute. However, because pH can affect the degree of corrosion of metals as well as disinfection efficiency, any effect on health is likely to be indirect and due to increased ingestion of metals from plumbing and pipes or inadequate disinfection (Alam, 2007).

Exposure to extreme pH values results in irritation to the eyes, skin and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH values higher than 11. In addition, solutions of pH 10 to 12.5 have been reported to cause hair fibres to swell (Alam M., 2007). In sensitive individuals, gastrointestinal irritation may also occur. Exposure to low pH values can also result in similar effects. Below pH 4, redness and irritation of the eyes have been reported, the severity of which increases with decreasing pH. Below pH 2.5, damage to the epithelium is irreversible and extensive (WHO, Working Group, 1986). In addition, because pH can affect the degree of corrosion of metals as well as disinfection efficiency, it may have an indirect effect on health.

2.4.2 Turbidity

Turbidity, a measure of the cloudiness of water, has often been used as a proxy for microbiological contamination. Some studies have found that turbidity was correlated with microbiological contamination in source water and filtered drinking water (LeChevallier et al. 1991a, 1991b). However, turbidity is a nonspecific measure of the scattering of light by particles suspended in water and is thus influenced by various types of particulates, including silt, clay, and organic matter, that can differ in prevalence among water systems (Burlingame et al. 1998).

2.4.3 Arsenic

Arsenic is widely distributed throughout Earth's crust, most often as arsenic sulphide or as metal arsenates and arsenides. In water, it is most likely to be present as arsenate, with an oxidation state of 5, if the water is oxygenated.

Arsenic is introduced into water through the dissolution of rocks, minerals and ores, from industrial effluents, including mining wastes and via atmospheric deposition (IPCS, 1981; Nadakavukaren et al., 1984; Hindmarsh & McCurdy, 1986). In well-oxygenated surface waters, arsenic (V) is generally the most common arsenic species present (Irgolic, 1982; Cui & Liu, 1988); under reducing conditions, such as those often found in deep lake sediments or groundwater, the predominant form is arsenic (III) (Lemmo et al., 1983; Welch et al., 1988). An increase in pH may increase the concentration of dissolved arsenic in water (Slooff et al., 1990).

Except for individuals who are occupationally exposed to arsenic, the most important route of exposure is through the oral intake of food and drinking water, including beverages made from drinking water. The mean daily intake of arsenic from drinking water will generally be less than 10 μg; however, in those areas in which drinking water contains elevated concentrations of arsenic, this source will make an increasingly significant contribution to the total intake of inorganic arsenic as the concentration of arsenic in drinking water increases (Yost et al., 1998).

A number of studies have attempted to show that arsenic is an essential element, but a biological role has not been demonstrated so far (USNRC, 1999, 2001). Arsenic has not been demonstrated to be essential in humans (IPCS, 2001).

Early clinical symptoms of acute intoxication from arsenic exposure include abdominal pain, vomiting, diarrhoea, muscular pain and weakness, with flushing of the skin. These symptoms are often followed by numbness and tingling of the extremities, muscular cramping and the appearance of a papular erythematous rash (IPCS, 2001).

There have been numerous epidemiological studies that have examined the risk of various cancers associated with arsenic ingestion through drinking water. Many of these studies are ecological-type studies and many suffer from methodological flaws, particularly in the measurement of exposure. However, there is overwhelming evidence that consumption of elevated levels of arsenic through drinking water is causally related to the development of cancer at several sites, particularly skin, bladder and lung (IPCS, 2001).

2.4.4 Fluoride

Fluorine is a common element that does not occur in the elemental state in nature because of its high reactivity. It accounts for about 0.3 g/kg of the Earth's crust and exists in the form of fluorides in several minerals, of which fluorspar, cryolite and fluorapatite are the most common.

Fluoride may be an essential element for animals and humans. For humans, however, the essentiality has not been demonstrated unequivocally and no data indicating the minimum nutritional requirement are available. To produce signs of acute fluoride intoxication, minimum oral doses of at least 1 mg of fluoride per kg of body weight is required (Janssen et al., 1988).

Many epidemiological studies of possible adverse effects of the long-term ingestion of fluoride via drinking water have been carried out. These studies establish that fluoride primarily produces effects on skeletal tissues (bones and teeth). Low concentrations provide protection against dental caries, especially in children. The pre- and post-eruptive protective effects of fluoride (involving the incorporation of fluoride into the matrix of the tooth during its formation, the development of shallower tooth grooves, which are consequently less prone to decay and surface contact with enamel) increase with concentration up to about 2 mg of fluoride per litre of drinking water. The minimum concentration of fluoride in drinking water required to produce it is approximately 0.5 mg/litre.

However, fluoride can also have an adverse effect on tooth enamel and may give rise to mild dental fluorosis (prevalence: 12 to 33%) at drinking water concentrations between 0.9 and 1.2 mg/litre (Dean, 1942).

In Zambia, dental fluorosis is not very common and is generally not well documented (Shitumbanuma et al., 2006; WaterAid and British Geological Survey, 2000). However, from a study done in an area with hot springs in Choma District of the Southern Province of Zambia by Shitumbanuma et al. (2006), it was observed that there exists a high incidence of people with discoloured and mottled teeth due to drinking water with high fluoride content. Furthermore, WaterAid and British Geological Survey (2000) reported that although there is no proper documentation on levels of fluoride in Zambian groundwater, concentrations are generally expected to be increased in some areas of the East African Rift (the Zambezi and Luangwa valleys in the south-east) especially that high fluoride concentrations (above 1.5 mg/l the WHO guideline value) have been found in groundwater from the rift areas of neighbouring Tanzania and Malawi, areas of granitic geology.

2.4.5 Chloride

Chloride is a salt compound resulting from the combination of the gas chlorine and a metal. Some common chlorides include sodium chloride (NaCl) and magnesium chloride ($MgCl_2$). Chlorine alone as Cl_2 is highly toxic, and it is often used as a disinfectant. In combination with a metal such as sodium, it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plant and animal life.

Chlorides associated with sodium (sodium chloride) exert salty taste when its concentration is more than 250 mg/l. Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney disease. Sodium chloride may impart a salty taste at 250 mg/l; however, calcium or magnesium chloride are not usually detected by taste until levels of 1000 mg/l are reached. The Zambian Bureau of Standards (ZABS) require chloride levels not to exceed 250 mg/l in public drinking water supplies (ZABS, 2010).

2.4.6 Phosphate

Phosphorus is one of the essential nutrients necessary for the nutrition and growth of living organisms. Like nitrogen, it is a limiting nutrient for algal growth because it occurs in the least amount relative to the needs of plants (Chapman, 1992). In natural and wastewaters, phosphorus occurs almost solely as dissolved phosphate and it is the most significant form of phosphorus in natural water. Orthophosphate is the most thermodynamically stable form of phosphate and is the form commonly identified in laboratory analysis and also used by plants. Furthermore, polyphosphates in water are unstable and eventually convert to orthophosphate (Nolan, B., 2000).

Surface waters and groundwater become contaminated from both natural and anthropogenic sources of phosphates. Natural sources of phosphorus in both surface and groundwater include atmospheric deposition, natural decomposition of rocks and minerals, weathering of soluble inorganic materials, decaying biomass, runoff and sedimentation. Anthropogenic sources include; fertilisers, wastewater and septic system effluent, animal wastes, detergents, industrial discharge, phosphate mining, drinking water treatment, forest fires, synthetic material development surface (Manahan,1993).

The recommended value of phosphorus in drinking water, according to ZABS, is 6 mg/l (ZABS, 2010). Though in the permissible limit, it is essential for human health; however, beyond the permissible limit, it may damage the kidney and cause osteoporosis (Slatopolsky et al.,1971). In most water bodies phosphorus is recognised as the limiting nutrient. A small amount of phosphorous may enhance the growth of algae and aquatic vegetation leading to eutrophication of the aqueous system (Handa, 1990). Phosphate in water results into algal bloom formation in water bodies. Hence, eutrophication and water quality are maintained by controlling the entry of the phosphorus (Holman et al., 2008).

In order to prevent eutrophication, phosphate discharge in water bodies should be within 0.05 mg/l limit (USEPA, 1986) and to prevent algal blooms, and it should be maintained between 0.01 and 0.03 mg/l. Algal blooms ultimately produce harmful toxins. Such polluted water cannot be recommended even for irrigation.

Degradation of organic load by bacteria causes depletion of oxygen in water bodies. Fishes and other aquatic animals cannot survive and die in oxygen-deficient conditions. Therefore, the removal of phosphate from water becomes necessary.

2.4.7 Nitrate

Nitrate is used mainly in inorganic fertilisers. It is also used as an oxidising agent and in the production of explosives. Purified potassium nitrate is used for glass making. Several publications (WHO, 2006; Gustafson, 1993; Kross et al., 1993) have reported that nitrate (NO_3) is found naturally in the environment and is an important plant nutrient. It is present at varying concentrations in all plants and is part of the nitrogen cycle.

Nitrate can reach both surface and groundwater as a consequence of agricultural activity (including the excess application of inorganic nitrogenous fertilisers and manures), from wastewater disposal and from the oxidation of nitrogenous waste products in human and animal excreta, including septic tanks (Burkart and Kolpin, 1993). Surface water nitrate concentrations can change rapidly owing to surface runoff of fertiliser, uptake by phytoplankton and denitrification by bacteria, but groundwater concentrations generally show relatively slow changes (Jalali, 2005; Jalali, 2007). In some cases, groundwater may also have nitrate contamination as a consequence of leaching from natural vegetation (Burkart and Kolpin, 1993).

In most countries, nitrate levels in drinking water derived from surface water do not exceed 10 mg/l. In some areas, however, concentrations are higher as a result of runoff and the discharge of sewage effluent and certain industrial wastes. In Zambia, the permissible limit of nitrates in potable water is 10 mg/l (ZABS, 2010).

The guideline value for nitrate of 50 mg/l is based on epidemiological evidence for methaemoglobinaemia in infants, which results from short-term exposure and is protective for bottle-fed infants and, consequently, other population groups. This outcome is complicated by the presence of microbial contamination and subsequent gastrointestinal infection, which can increase the risk for this group significantly (Fewtrell, 2004).

Authorities should, therefore, be more vigilant that water to be used for bottle-fed infants is microbiologically safe when nitrate is present at concentrations near the guideline value. It is recommended that water should not be used for bottle-fed infants when nitrate levels are above 100 mg/l, but that it may be used if medical authorities are vigilant for signs of methaemoglobinaemia when the nitrate concentration is between 50 and 100 mg/l, particularly where a high rate of gastrointestinal infection is present in infants and children in a given population (Gatseva and Dimitrov, 1997).

2.4.8 Faecal Coliform Bacteria

Faecal coliform are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhoea, cramps, nausea, headaches or other symptoms (Ansa-Asare et al., 2009; Ashbolt et al., 2001). These pathogens may pose a special health risk for infants, young children and people with severely compromised immune systems (WHO, 2008).

The major health risk associated with groundwater is from the microbial pathogens derived from human and animal faeces (Lehloesa and Muyima, 2000). Pathogenic organisms found in groundwater with high counts of faecal coliforms include especially *Escherichia coli*, and other pathogenic microorganisms such as *Vibrio cholerae, Aeromonas hydrophila, Shigella dysenteria, Salmonella typhimurium, Pseudomonas spp*, *Klebsiella spp* (Momba et al., 2006) and these organisms contribute to water-borne diseases occurring in a number developing countries world over

2.5 HWTS in other countries

There are various countries around the world that are integrating HWTS in their national policies. A survey done by WHO in 2012 involved a list of selected countries that either had HWTS policies and strategies in their national policies or had policies related to HWTS (Table 1). The survey aimed at assessing national HWTS policies and to understand national evaluation and regulation of HWTS better.

Table 1: Responding countries by WHO region that participated in a global survey on HWTS (WHO, 2011)

<table>
<tr><th colspan="3">African</th><th>Americas</th><th>Eastern Mediterranean</th></tr>
<tr><td>Burkina Faso
Burundi
Congo (the)
Côte d'Ivoire
Democratic Republic of the Congo (the)
Ethiopia</td><td>Gambia (the)
Ghana
Kenya
Madagascar
Malawi
Mali
Mozambique
Nigeria
Rwanda</td><td>South Africa
Swaziland
Togo
Uganda
United Republic of Tanzania (the)
Zimbabwe</td><td>Haiti
Honduras
Uruguay</td><td>Iran (Islamic Republic of)
Jordan
Oman
Pakistan
Saudi Arabia
Somalia
Sudan (the)
Syrian Arab Republic (the)
Tunisia</td></tr>
<tr><th colspan="2">European</th><th colspan="2">South-East Asia</th><th>Western Pacific</th></tr>
<tr><td colspan="2">Andorra
Estonia
France
Hungary
Netherlands (the)
Norway</td><td colspan="2">Bangladesh
Indonesia
Nepal</td><td>Cambodia
Lao People's Democratic Republic
Philippines (the)</td></tr>
</table>

The results were summarised according to the four main sections of the survey: institutions, policies and targets, policy implementation, and regulation and evaluation. The final section of the results presented an overview of readiness to scale-up HWTS based on planned policy structures (WHO, 2012).

2.5.1 Institutions

From the survey, it was observed that 59% of the 46 responding countries, indicated that the Ministry of Health is the lead in issues relating to HWTS. In other countries, the Ministry of Water and the Ministry of Environment were lead ministries, accounting for 15% and 9%, respectively of responses (WHO, 2012).

It was also observed from the survey that collaboration on HWTS issues was nearly universal among responding countries. Nearly all, 91%, indicated that two institutions collaborate on HWTS issues, and 54% have three or more institutions working together. In a great majority of instances, this involved the Ministry of Health and the Ministry of Water. To coordinate HWTS collaboration, nearly two-thirds of responding countries (63%) had established an inter-ministerial committee. Examples of these are the National Water Forum in Bangladesh, the National Water and Sanitation Committee in the Democratic Republic of the Congo, and the National Household Water Treatment Technical Working Group in Kenya (WHO/UNICEF, 2011; WHO, 2012).

2.5.2 Policies and Targets

Countries were also asked to provide details on policies related to HWTS. Most of the policies mentioned focused on water quality and supply or disease prevention and control. Within these policies, HWTS was not necessarily mentioned, but rather the importance of safe drinking water was highlighted (WHO, 2011).

Only two of the responding countries (Ghana and Tanzania) indicated that they had a national strategy for HWTS that bridge the many national water and health efforts where HWTS was included (MoH, 2012). In addition, 72% of responding countries indicated they considered HWTS within national policy structures. Less than half, 43% (20 countries), of responding countries reported having targets relevant to HWTS. Out of the 20 targets, 15 focused on water quality or general health aspects, and only five (Ethiopia, Ghana, Haiti, Rwanda and Tanzania) countries had specific HWTS targets (WHO, 2012).

2.5.3 Policies and Strategies Introduced by Ghana and Tanzania

The National Water Policy of Ghana (2007) was developed to provide a framework for the sustainable development of Ghana's water resources. The policy includes various cross-sectoral issues related to water-use and the links to other relevant sectoral policies such as those on sanitation, agriculture, transport and energy (MWRWH, 2007). In 2014, the Government of Ghana developed the Household Water Treatment and Safe Storage Strategy. The strategy set in motion the framework and implementation guidelines for ensuring the safety of water at the point of use or consumption. It was developed against the backdrop of the low practice of household water treatment by households in many parts of the country (MLGRD, 2014).

The Government of Tanzania developed the National Water Policy in 2002 whose main objective was to develop a comprehensive framework for sustainable development and management of water resources. The policy aimed at ensuring that beneficiaries participate fully in planning, construction, operation, maintenance and management of community based domestic water supply schemes (MWLD, 2002). In 2011, the Government of Tanzania developed the Comprehensive Country Plan for Scaling Up Household Water Treatment and Safe Storage 2011-2016 strategy that was aimed at reducing waterborne diseases in households (MoH, 2012).

2.5.4 Implementation Support and Challenges

From the WHO 2012 survey, 42 (91%) responding countries indicated government support for HWTS, and the most common measure listed among the countries was advocating for the integration of HWTS into health programmes (WHO, 2011; WHO, 2012).

Other supportive government actions listed included the development of guidelines on HWTS (48%) and the creation of task forces to address HWTS (46%). A sizable proportion of countries had also reduced or eliminated tariffs on imported HWTS products (22%), often categorising HWTS as "essential medicines" in order to reduce the cost barrier of such products. A large majority, 76%, of countries identified limited monitoring of HWTS use and impact as one of the key challenges (WHO/UNICEF, 2011; WHO, 2012).

2.5.5 Regulation and Evaluation

Only 41% of responding countries regulated products according to their performance, or ability to remove chemical and microbial contaminants. A much larger proportion, 65%, of countries certified or recognise internationally certified household water treatment technologies. Out of those countries that certified HWTS technologies, 73% tested the technology in a laboratory setting (WHO, 2012).

In those countries that had a formal regulation system, the lead ministry was the Ministry of Health followed by the Bureau of standards and the Ministry of Water (48%, 13% and 13%, respectively) (WHO, 2012). Other lead regulation ministries included the Ministry of Industry and Trade (Lao People's Democratic Republic), the Administration of State Sanitary Work

(Uruguay) and the National Action Committee on Water, Sanitation and Hygiene (Zimbabwe) (WHO/UNICEF, 2011).

Of those countries that indicated laboratory testing as a requirement for national certification, indicator bacteria (faecal coliform) were the most commonly tested parameter at 59%, followed by physicochemical contaminants at 37%. Some countries (39%) also reported testing for pathogens such as bacteria, viruses or protozoa (WHO, 2012).

2.5.6 Readiness to Scale-Up based on Policy Structures

Using a simple matrix of the presence of five key policy and regulation elements, an assessment of readiness to scale-up HWTS was conducted. Specifically, countries were assessed on the existence of national policies, national HWTS targets, a committee and structure for HWTS coordination, regulations on HWTS products and certification of HWTS technologies. This provided an important snapshot of political readiness to scale-up HWTS. Countries such as Ethiopia, Ghana and Uruguay had all five elements. Other countries such as Kenya, Rwanda, Zimbabwe, Togo, Sudan and Uganda, had four elements. Nigeria, Malawi and Tanzania had three elements (WHO, 2012)

2.6 The WHO International Scheme to Evaluate HWT Technologies

The WHO has been a key supporter of HWTS for many years now. Specifically, the International Network to Promote HWTS (the Network) is at the centre of all major HWTS activities. It was established by the WHO in 2003 with the following as its mission: "To contribute to a significant reduction in water-borne and water-related vector-borne diseases, especially among vulnerable populations, by promoting household water treatment and safe storage as a key component of community-targeted environmental health programmes." In 2011, the Network established several targets, including a policy-based target intended to support HWTS scale-up and accelerate policy efforts in developing countries (WHO, 2011).

In addition to supporting policy development, the Network has also initiated research, including a global survey on HWTS policies in 2012 and a rapid market assessment of HWTS in 2015. The main intent of the rapid market assessment was to identify the HWTS products currently on the market, and it also investigated the regulatory environments in the three countries to better understand the context in which these products were being distributed and sold.

In developing the Scheme, the WHO aimed to address the need for evaluating HWTS by creating a set of criteria and testing guidelines that would allow for objective, independent and consistent testing of HWTS products. The result of the WHO's efforts was a set of performance targets and an evaluation procedure.

The microbiological performance guidelines were taken directly from a tiered system developed by Brown and Sobsey for the 2011, WHO report, with the main change being a replacement of "highly protective," "protective," and "interim" with a neutral, three-star performance classification. The performance criteria for the Scheme is given in Table 2.

Table 2: WHO recommended microbiological performance criteria for HWT technology performance classification (WHO, 2011)

Performance classification	**Bacteria** **($\log_{10}$ reduction required)**	**Viruses** **($\log_{10}$ reduction required)**	**Protozoa** **($\log_{10}$ reduction required)**	**Interpretation** **(assuming correct and consistent use)**
★ ★ ★	≥4	≥5	≥5	Comprehensive protection (very high pathogen removal)
★ ★	≥2	≥3	≥2	Comprehensive protection (high pathogen removal)
★	Meets at least 2-star (★★) criteria for two classes of pathogens			Targeted protection
----	Fails to meet WHO performance criteria			Little or no protection

The three pathogen classes (Table 2 above) occur widely in drinking water supplies impacted by animal and/or human excreta. For example, in a global study involving over 20,000 children in seven developing countries, rotavirus, *Cryptosporidium* protozoa and some toxin-producing strains of the bacterium *Escherichia coli* (*E. coli*) were among the top pathogens associated with moderate to severe diarrhoea (Kotloff et al., 2013). In addition, increased *E. coli* contamination in household water has been associated with an increase in child diarrhoea (Luby et al., 2015). Thus, in many faecally-contaminated drinking water sources, it is important that HWT technologies sufficiently reduce all three classes of pathogens.

Within each class of pathogen, there are many different organisms associated with waterborne diseases and it is neither feasible nor practical to evaluate the performance of HWT technologies against each of them. Instead, reference organisms have been selected to represent the three classes. These reference organisms are: *E. coli* (bacteria), coliphages MS2 and phiX174 (viruses) and *Cryptosporidium parvum* (protozoa).

2.7 Waterborne Diseases in Zambia

Waterborne diseases caused by bacteria that are epidemic prone in Zambia include cholera, typhoid fever and dysentery. Infections enter the body through the mouth. These diseases are contracted through contaminated food and drink, being in contact with contaminated faeces or vomitus. Common signs and symptoms of enteric diseases in Zambia include diarrhoea and vomiting (MoH, 2010).

In peri-urban communities in Lusaka, cholera cases have been associated with lack of household latrines, limited safe water sources and lack of personal hygiene practices (Sasaki et al., 2008) as well as insufficient coverage of storm-runoff drainage networks (Sasaki et al., 2009) resulting in substantial flooding. Waterborne diseases have been directly linked to the consumption of drinking water from shallow wells (Sasaki et al., 2008). Shallow wells, common to peri-urban communities, are created by digging through the top layer of substrate until groundwater is reached.

The presence of faecal coliform bacteria in drinking water of peri-urban areas such as Chaisa, Kanyama and Ngombe is due to microbiological pollution of groundwater. Groundwater quality is more at risk in large settlements such as high-density peri-urban areas because of the lack of proper sanitation facilities. In some cases, facilities are available but of poor quality (Nyambe and Maseka, 2000). In many peri-urban areas, there is a lack of a sewerage treatment plant, and therefore people depend on pit latrines. Since the majority of the residents in peri-urban areas depend on groundwater for domestic use, they are at a high risk of waterborne diseases caused by various microbial pathogens.

2.7.1 Cholera

The World Health Organization has documented the profile of cholera in Zambia from 1978 to 2010. Cholera was first reported in 1977 with major outbreaks occurring in 1990 and 1999 that lasted for 3 and 4 months, respectively. Another cholera outbreak occurred in 2004 that lasted until 2010 and spilt over to 2012, thus becoming pandemic. From 2013 to 2016, no cases of cholera were documented by WHO (2014; 2015; 2016; 2017), although an outbreak of cholera occurred in Chibombo District between 9 February and 20 March 2016 in which 23 suspected and confirmed cases were seen with no deaths at the district health facility. Eight of the 18 stool cultures were positive for *Vibrio cholerae* (Chirambo et. al, 2016).

Another outbreak occurred in Lusaka District between 5 February and 24 April 2016 in which 1079 cases and 20 deaths (case fatality rate [CFR] = 1.9%) were recorded. Yet another epidemic was recorded in Kapiri Mposhi District between 11 September and 21 October 2016 with 27 cases and 2 deaths (CFR = 7.4%). The same epidemic was documented for the period February to 31 May 2016 in which 1054 cases were reported with a CFR of 1.9%. During the same epidemic, 1139 cases and 20 deaths (CFR = 1.8%) were reported during epidemiological weeks 5 to week 24 (Chirambo et. al, 2017).

The most recent cholera outbreak in Zambia began in October 2017 and was concentrated in the peri-urban communities of Lusaka, starting in Chipata Compound and spreading to Kanyama (Sladoje, 2018). The outbreak resulted in 5,414 cases and 98 deaths of Lusaka residents between October 4, 2017 and May 12, 2018 (Sinyange et al., 2018).

2.7.2 Bacteria dysentery

There is little documentation of dysentery epidemics in Zambia. In June 1990, an outbreak of *Shigella dysenteriae* Type 1 dysentery was reported in a prison in western Zambia and by December 1991, a total of 24,774 cases had been recorded with a case fatality rate of 10.2% (van der Hoek et. Al, 1996). There are no other documented epidemics. Factors associated with dysentery included: recent contact with a person with dysentery, a family member with preceding dysentery, households sharing their latrine with other households, obtaining drinking water only by hand dipping and eating cooked relish (a cooked meat or vegetable dish) purchased from a vendor (Tuttle, 1995).

2.7.3 Typhoid fever

Few typhoid fever epidemics have been documented in Zambia. Bisseru (1984) reported an outbreak of typhoid fever in a girls' camp in Zambia. A more recent outbreak of typhoid fever was reported in 2010-2012 that affected 2,040 patients, with a fatality rate of 0.5% (Hendriksen, 2015). Piped water supply was associated with a reduction in the incidence of typhoid fever in Lusaka, Zambia. Provision of safe piped water is critical in the prevention of typhoid fever as well as curtailing the epidemic. Regular monitoring of antibiotic sensitivity patterns is vital in good management of cases. Tracking typhoid fever epidemics would provide information on its prevention and further studies should be conducted on risk factors for typhoid fever to guide targeted interventions in Zambia.

2.8 Zambia National Water Policy 2010

The Government of Zambia has a water policy which provides an overall policy framework for the country's water sector. The 2010 water policy covers several parameters including Water Supply and Sanitation (WSS), which comprises of water quality and quantity including water charges and tariffs, Water Resources Management (WRM) and Rural Water Supply and Sanitation (RWSS) (MEWD, 2010).

The policy was examined for any HWTS as given in the objectives of this study.

2.9 Certification of HWTS

The Zambia Bureau of Standards (ZABS) is the service provider for Standards Certification for industry in Zambia. Certification refers to confirmation or an attestation that products, processes or systems of an organisation meet the requirements of a standard or specification (ZABS, 2017). Certification provides assurance that products, services and processes meet national or international standards/specifications. This is done through a review, assessment or audit. The Bureau offers two types of certification schemes, namely, Product Certification and Systems Certification.

2.9.1 Product Certification

Product certification involves the issuance of a certificate or mark (or both) to demonstrate that a specific product meets a defined set of requirements such as safety, fitness for use or interchangeability characteristics for that product, usually specified in a standard. It promises guaranteed quality to the consumer and acceptable manufacturing practices to the manufacturer (ZABS, 2017).

The product certification mark is normally found on the product or its packaging and may also appear on a certificate issued by the product certification body. The mark carries a reference to the number or name of the relevant product standard against which the product has been certified (ZABS, 2017). Products such as membrane filters, SODIS polyethene bottles, coagulants, bottled chlorine and UV filters are sold without been certified in the country. Some imported products, however, are certified by the regulatory body from the country in which they are manufactured.

2.9.2 Systems Certification

A management system is a company's structure for managing its processes and activities that transform inputs of resources into a product or service which meets the company's objectives while satisfying the customers' quality requirements, complying with regulations meeting environmental and public health objectives. ZABS offers training and certification in the management systems for companies or organisations that plan to supply or manufacture products such as HWTS technologies (ZABS, 2017).

CHAPTER 3

DESCRIPTION OF THE STUDY AREA

Three peri-urban communities were selected for this study based on the presence of Water Trusts, population size, hydrogeological properties and waterborne disease outbreak statistics (Reaver et. al, 2016-in prep.). These were Chaisa, Ngombe and Kanyama.

3.1 Water Trusts in Chaisa, Kanyama and Ngombe

Water Trusts were present in all the study areas. The role of the Water Trusts is to extract ground water from aquifers via boreholes that are located throughout the communities. The extracted water is treated with chlorine for disinfection then stored in elevated storage tanks. The treated water in the tanks is then distributed via underground pipes to kiosks. Water Trusts are also responsible for all issues relating to water management and sanitation within peri-urban communities. The established Water Trusts in the study areas operate under Lusaka Water Supply and Sanitation Company Limited (LWSC) water and sanitation licence through a delegated management contract agreement.

3.2 Population size of Chaisa, Kanyama and Ngombe

In a Water Trust manager's survey conducted by Reaver et al. (2016-in prep.), it was observed that Chaisa had a population size of 42,000 while Kanyama and Ngombe had a population size 300,000 and 110,000 respectively.

3.3 Geology and Hydrogeology of Chaisa, Kanyama and Ngombe

Chaisa is located in the northern part of Lusaka, whereas Ngombe is located in the northeast part of Lusaka and Kanyama in the southwest (Figure 2). The generalised geology of Lusaka (Figure 2) indicate that Chaisa and Ngombe overlie the Chunga and Cheta formations, while Kanyama is centrally located atop the Lusaka Formation. Kanyama has been denoted extremely vulnerable to groundwater contamination (Kang'omba & Bäumle, 2013).

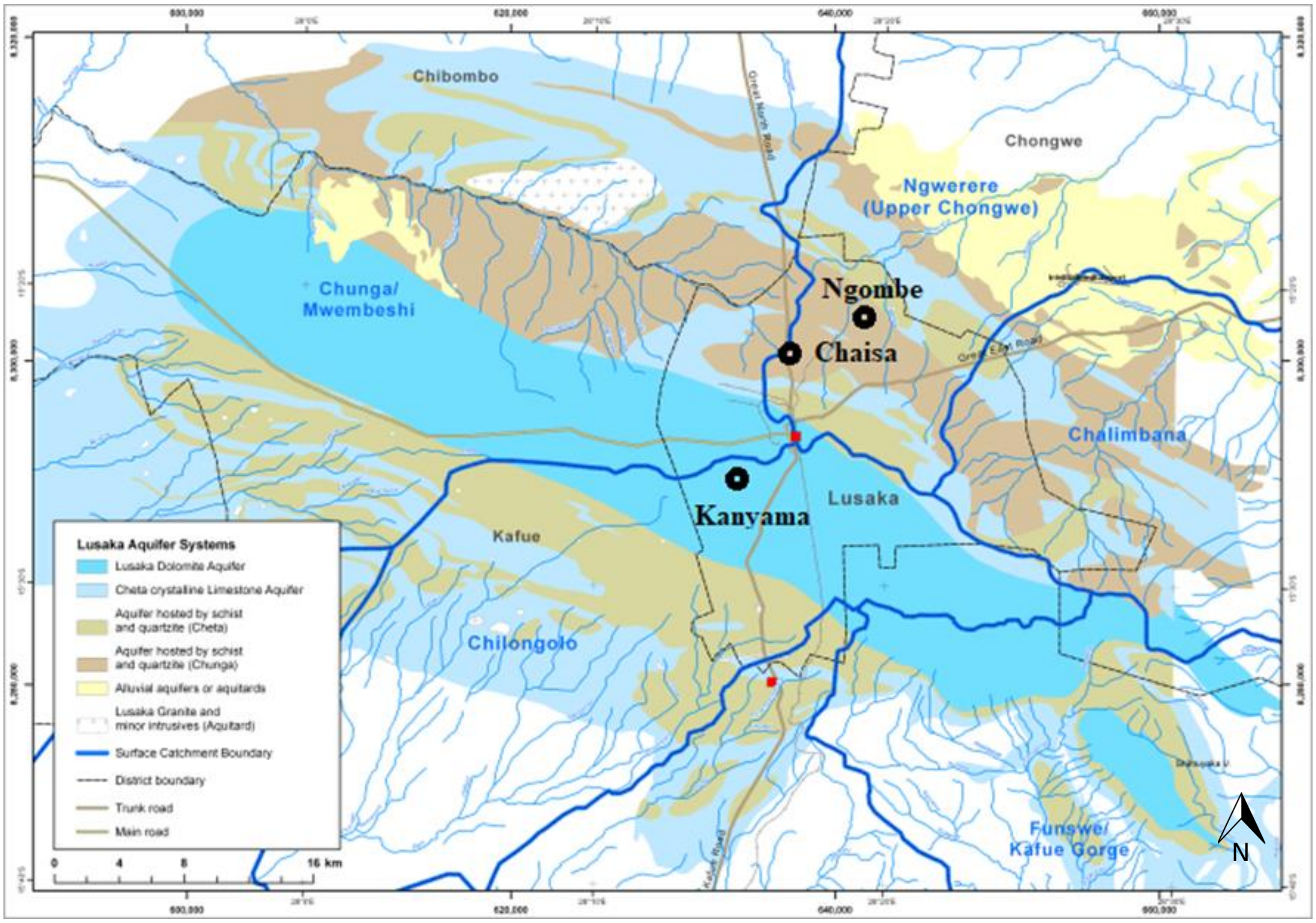


Figure 2: Generalised geology of the Lusaka area, Zambia (Bäumle and Kang'omba, 2012). The locations of Chaisa, Kanyama and Ngombe are shown

Based on the underlying geology, soil type and soil thickness, Kang'omba and Bäumle (2013) assigned groundwater contamination vulnerability classes to the study area (Figure 3). Most of the area associated with the Lusaka Formation was designated as extremely vulnerable to groundwater pollution. Most groundwater sources in these areas are at risk of microbiological contamination from pit latrines, which may be directly connected via highly conductive karst conduits. This situation can lead to bacterial and nitrate contamination and the spread of waterborne diseases.

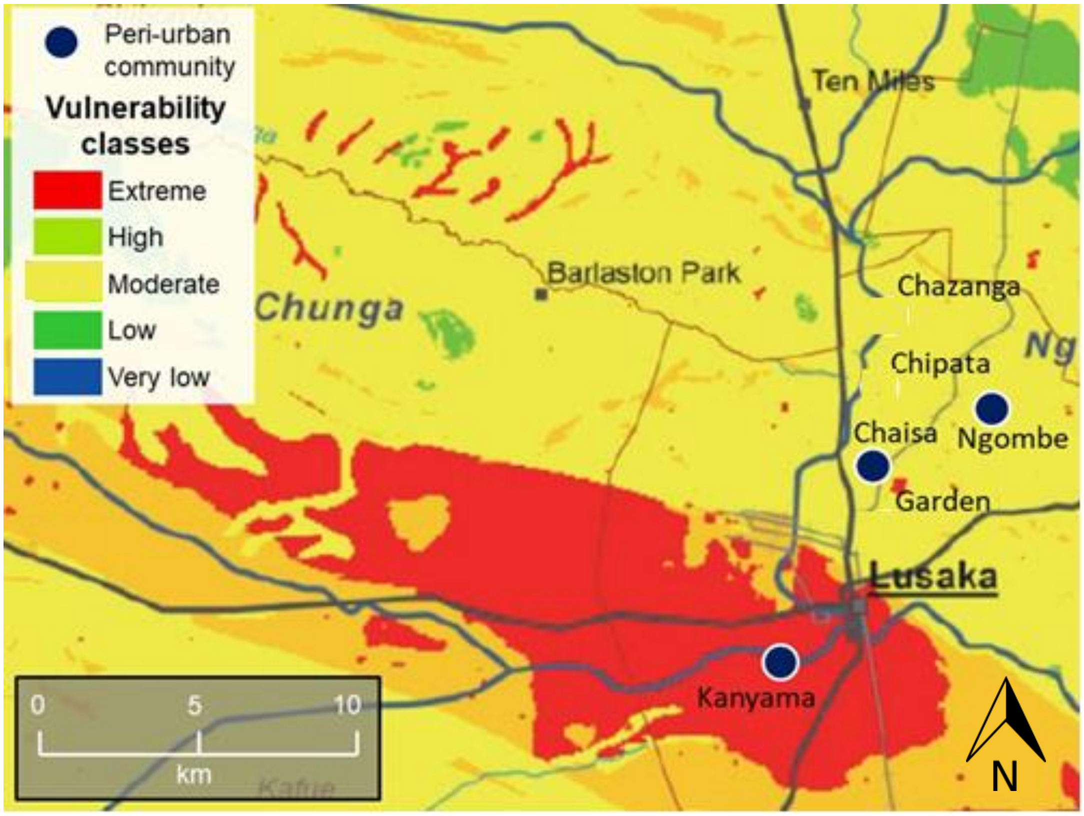


Figure 3: Groundwater vulnerability map of Lusaka, Zambia showing the vulnerability class of the three study areas (Chaisa, Kanyama and Ngombe), from Kang'omba and Bäumle (2013)

The geology, groundwater vulnerability class and aquifer classification of the study areas are presented in Table 3.

Table 3: Geology, groundwater vulnerability class and aquifer classification of Chaisa, Kanyama and Ngombe, Lusaka, Zambia, from Bäumle R. & S. Kang'omba (2009), Bäumle R. & S. Kang'omba (2012) and Kang'omba and Bäumle (2013)

Community	**Formation**	**Rock Type**	**Vulnerability Class**	**Aquifer Classification**
Chaisa	Chunga	Psammitic to pelitic schist	Moderate	Limited water resource
Kanyama	Lusaka	Crystalline dolomite & dolomitic limestone	Extreme	Highly productive
Ngombe	Chunga	Psammitic to pelitic schist	Moderate	Limited water resource

3.4 Occurrence of Waterborne Diseases

As indicated earlier, cholera epidemics in Zambia have been frequent since 1990, occurring in 1991, 1993, 1999, 2004, 2009, 2010, 2016 and 2017 with the number of deaths totalling 4,731 (Sladoje, 2018). Most cholera outbreaks in Zambia concentrate in the peri-urban communities of Lusaka, especially the most densely populated peri-urban area, Kanyama (Sladoje, 2018). Cholera and other waterborne diseases are associated with poor water and sanitation infrastructure and frequently occur in the several peri-urban townships of Lusaka, therefore the townships were selected.

CHAPTER 4

METHODOLOGY

4.1 General Remarks

This chapter presents the methods used in data collection, highlights the primary and secondary sources and types of data and outlines the data analysis that was conducted. It also outlines the limitations of the study. These include:

i. Pre-Fieldwork: This stage involved problem definition, literature review on HWTS, physical, microbiological and chemical parameters of water, WHO and ZABS standards for drinking water, searching and collection of literature on water quality from libraries and the internet;

ii. Field and Laboratory Work: This stage comprised collection of household water samples, water samples from different sources, distribution of questionnaires to households, and analyses of the physical, microbiological and chemical parameters in the laboratory; and

iii. Post-Fieldwork: This stage involved data processing, data analysis and presentation and thesis writing.

4.2 Data Collection

The study used both primary and secondary data. These were collected differently. Primary data collection was done during fieldwork, whereas secondary data was compiled from various sources of literature.

4.2.1 Primary Data

A total of 51 samples from 45 sites in Chaisa, Kanyama and Ngombe were taken during four sampling efforts on 28th April, 2020, 4th May, 2020, 5th May, 2020 and 14th May, 2020. In total, water samples were collected from 26 households, eight privately-owned boreholes, seven kiosks linked to Water Trust boreholes, two Water Trust or municipal boreholes and two shallow hand-dug wells. An additional six samples from six households (two from each community) which had the highest nitrate concentrations and faecal coliform count from the first sampling, were sampled twice while other households were only sampled once.

The sampled points were used to analyse the relationship between underground water flow and quality of water sampled in the households and from various water sources.

4.2.1.1 Sampling and Measurement

Fifteen sample bottles for each community were prepared in advance by preheating them at 102°C in the oven in order to sterilise them. For each study area, 15 sterilised sample bottles were placed in two cooler boxes (six sample bottles in one box and nine bottles in another box), which contained blocks of ice. To avoid contamination during sample collection, ethanol was used to sterilise tap outlets and cups used to collect water in households were thoroughly rinsed before water was collected. In shallow wells, samples were collected using the same equipment used by the residents to withdraw water, usually a bucket on a rope.

A sampling book was used to record particular details of the sampling. Information such as sample ID number, location, date, time and sources of water was recorded in the sampling book. Interviews concerning Household Water Treatment and Safe Storage were carried out to all participating households and their responses were summarised in a tabulated format. The questionnaire and responses used are attached in Appendix 2 and 3, respectively.

Within five hours after collection, the water samples were carried to the University of Zambia Civil Engineering Department (Environmental Engineering Laboratory) and School of Mines Geochemical Laboratory for analysis. The results from the analyses were tabulated, printed and signed.

During sampling in Chaisa, Kanyama and Ngombe, pictures of sources of water and storage containers used by different households were taken (Figures 4a and b, 5a and b, 6a and b, 7a and b, 8a and b, 9a and b, and 10a and b). The participating households were asked to bring out the containers they used for storing drinking water. Its from these storage containers water samples were collected for analysis at the laboratory.

(a) (b)

Figure 4: (a) A communal tap/kiosk and (b) a private borehole tap stationed close to a pit latrine in Chaisa, Lusaka, Zambia

(a) (b)

Figure 5: (a) A jerrycan and (b) a bucket used to store water in households in Chaisa, Lusaka, Zambia

(a) (b)

Figure 6: (a) A municipal borehole tap and (b) An elevated municipal tank in Kanyama, Lusaka, Zambia

(a) (b)

Figure 7: (a) Water sampling at a shallow well and (b) A pit latrine located close to a shallow well in Kanyama, Lusaka, Zambia

(a) (b)

Figure 8: (a) Storage containers (left: bucket, right: jerrycan) and (b) A kiosk in Kanyama, Lusaka, Zambia

The Figure 9a, 9b and 10a and 10b show the water sources and storage containers commonly used in Ngombe.

(a) (b)

Figure 9: (a) A private borehole tap and (b) A kiosk tap stand in Ngombe, Lusaka, Zambia

(a) (b)

Figure 10: (a) Buckets and (b) a jerrycan used to store water in households in Ngombe, Lusaka, Zambia

4.2.1.2 Microbiological Parameters

Faecal coliform is the only biological parameter that was analysed. The numbers of faecal coliforms were determined using the membrane filtration technique. A measured volume of water was filtered through a membrane.

Bacteria, if present, was retained on the membrane and incubated for 24 hours at 44^{o}C. To ensure sterile conditions, petri dishes, medium and forceps were all autoclaved. After each sample preparation, the filtration unit was also flame-sterilised using 70% methanol. Great care was taken during transportation and also in the laboratory to avoid contamination of the water samples.

4.2.1.3 Physical and Chemical Parameters

Physical parameters that were analysed include pH and turbidity. The chemical parameters analysed included: arsenic, chlorides, fluorides, nitrates and phosphates.

The collected water samples were taken using a pipette from the middle of the beaker for analysis of physical parameters (pH and turbidity). The turbidity for each of the water samples collected from households and various water sources were measured using a turbidity meter (Oakton T-100). The pH was measured using a pH meter (pH Model 3310).

The chemical parameter tests were carried out in conformity with standard methods for the Examination of Water and Wastewater adapted from the American Public Health Association (APHA), 1998.

Nitrate (NO_3^-) was analysed using the calorimetric method. Fluoride (F^-) was analysed using the electrometric method, while chloride (Cl^-) was analysed by systronics spectrophotometer. Phosphate (PO_4^{3-}) was analysed using the vanadomolydophoric acid method. Arsenic (As^{3-}) was analysed using the spectrometric method.

4.2.1.4 Household Survey

Twenty-six questionnaires were distributed to the all the participating households. The purpose of using a questionnaire was to investigate HWTS within the communities and if they experience any illnesses as a result of consuming their stored household water.

The data was entered using Statistical Package for Social Sciences (SPSS) version 26 programme and Excel 2016 was used to create bar graphs and pie charts from the recorded data.

4.2.1.5 Sampling points in Chaisa

Ten water samples were collected from ten households in Chaisa (Table 4, Figure 11). Furthermore, five water samples of the water sources were collected from three kiosks and two privately-owned boreholes (Table 4, Figure 12). In Chaisa, Kanyama and Ngombe, coordinates of the sampling points were recorded using Google Earth's GPS system through photographs that were taken at each of the sampling points. In addition, a transect SW to NE is indicated on the maps based on the groundwater flow direction of Bäumle and Kang'omba's (2012) which is used for result interpretation in Chapter 5 (Figures 11 and 12). To observe any physico-chemical or microbiological parameter variation, the results are presented in form of bar and line graphs.

Table 4: Locations and descriptions of various water sources and households in Chaisa, Lusaka, Zambia

Sample ID	**Source**	**Location**	**Description**
JM	Privately-owned borehole	15°23'00.8"S 28°17'00.2"E	Opposite Mansa Road
MN	Privately-owned borehole	15°23'02.1"S 28°16'54.4"E	Junction between Imwiko and Chipanda Road
TS	Kiosk	15°22'57.69"S 28°17'6.93"E	Near Mint Square Pub and Grill
1B	Kiosk	15°23'00.3"S 28°16'57.7"E	Chipanda Road
2C	Kiosk	15°23'0.34"S 28°17'2.32"E	Off Chipanda Road
NG 4	Household	15°23'03.0"S 28°17'00.4"E	Along Chipanda Road
CH3	Household	15°23'01.6"S 28°17'00.2"E	Chipanda Road
CH1	Household	15°22'59.4"S 28°16'51.5"E	Devine Mercy (Chaisa) Catholic Church
CH2	Household	15°23'0.96"S 28°17'0.35"E	Opposite Devine Mercy Church
CH5	Household	15°23'1.18"S 28°16'54.21"E	Junction between Imwiko and Chipanda Road
CH6	Household	15°22'56.28"S 28°17'0.74"E	Bimbe Road Near Mint Square Pub and Grill
CH7	Household	15°22'58.18"S 28°16'59.26"E	Near Mint Square Pub and Grill
CH8	Household	15°22'53.94"S 28°17'5.20"E	Chaisa Legacy Academy
CH9	Household	15°23'0.25"S 28°17'5.58"E	Off Chipanda Road
CH10	Household	15°22'59.91"S 28°17'8.14"E	Off Chipanda Road

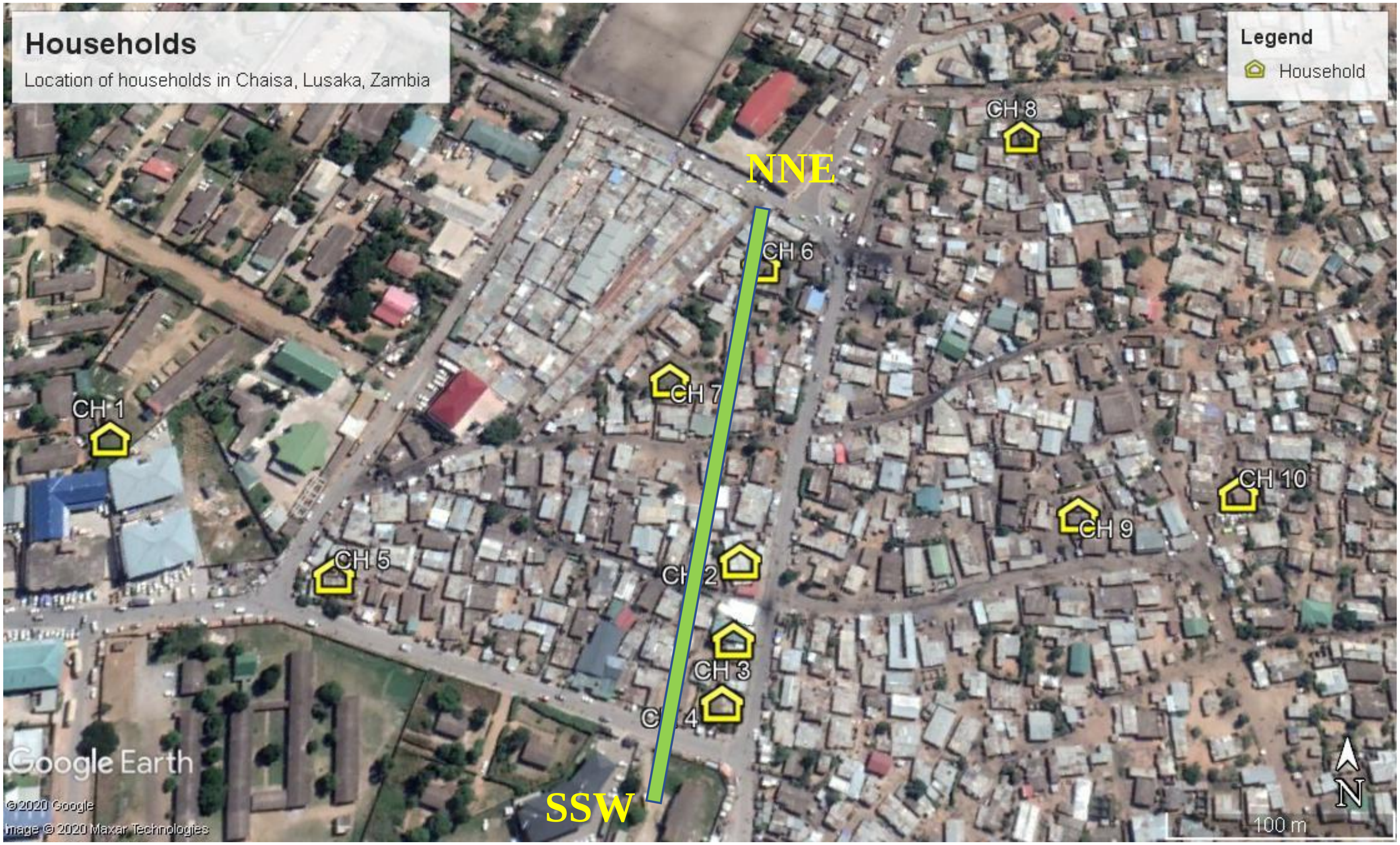


Figure 11: Transect from south-southwest (SSW) to north-northeast (NNE) passing through household sampling points (CH 4, CH 3, CH 2, CH 7 and CH 6) in Chaisa, Lusaka, Zambia. Based on Bäumle and Kang'omba, (2012), groundwater flow direction is also from SSW to NNE

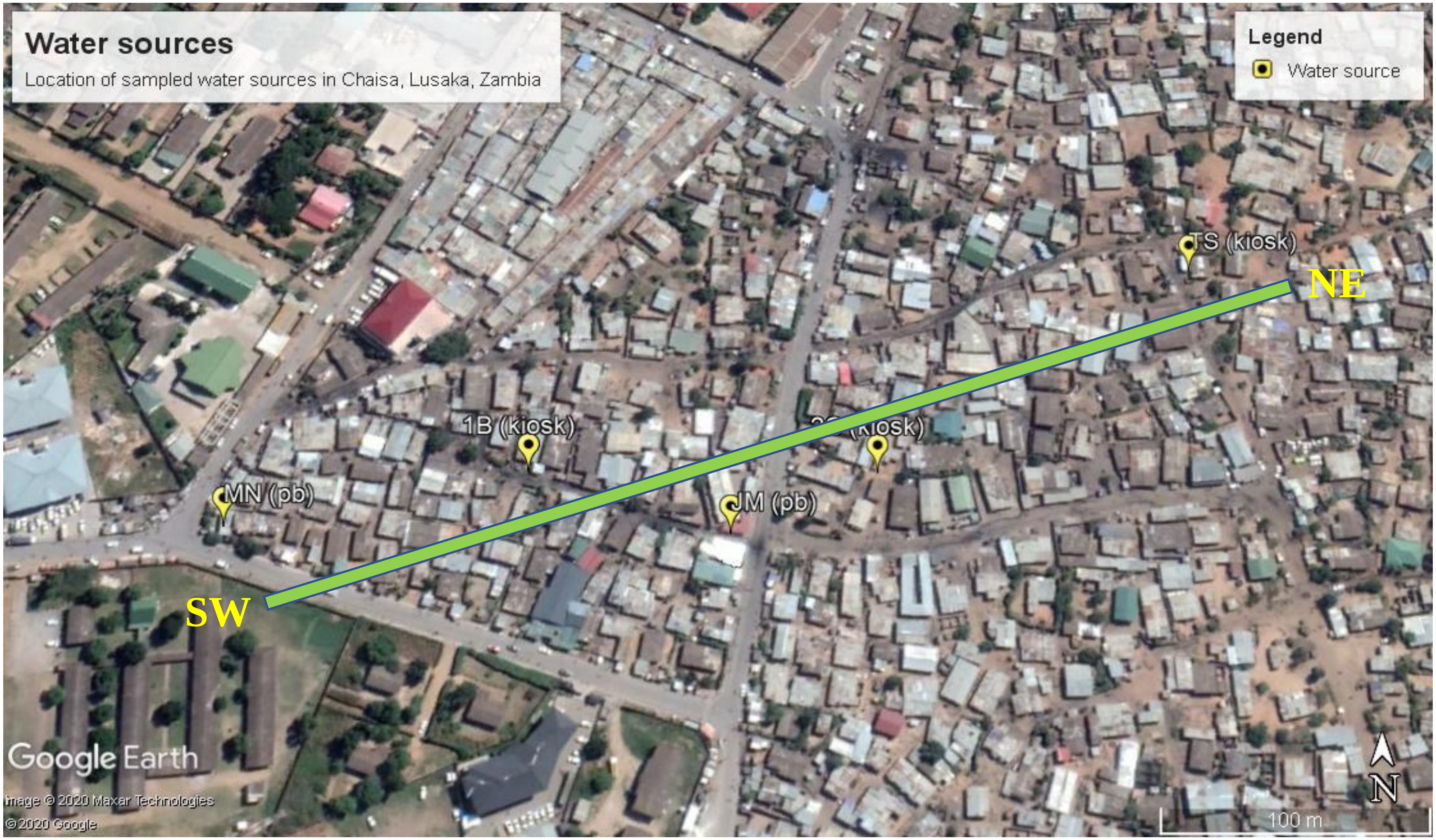


Figure 12: Transect from southwest (SW) to northeast (NE) passing through water sources (MN – private borehole, 1B - kiosk, JM – private borehole, 2C – kiosk and TS - kiosk 7) in Chaisa, Lusaka, Zambia. Based on Bäumle and Kang'omba, (2012), groundwater flow direction is also from SW to NE

4.2.1.6 Sampling points in Kanyama

Kanyama was the largest and most densely populated area among the three studied areas, therefore, a larger area was covered when collecting water samples from both households and water sources but same number of samples to Chaisa.

Eight water samples were collected from eight households in Kanyama (Table 5, Figure 13). In addition, seven water samples of water sources were collected from two municipal boreholes, two privately-owned boreholes, two shallow hand-dug wells and only one kiosk (Table 5, Figure 13). A transect NE to SW is indicated for households (Figures 13 and 14) based on the groundwater flow direction used by Bäumle and Kang'omba (2012).

Table 5: Locations and descriptions of various water sources and households in Kanyama, Lusaka, Zambia

Sample ID	Source	Location	Description
KYC	kiosk	15°26'03.7"S 28°15'03.3"E	Kingdom Hall of Jehovah's Witnesses (Kanyama East)
KYF	Shallow well	15°26'01.6"S 28°15'03.0"E	Opposite Kingdom Hall of Jehovah's Witnesses (Kanyama East)
KYG	Shallow well	15°26'05.1"S 28°15'02.8"E	Opposite ABC Printers
KYB	Municipal borehole	15°26'28.0"S 28°14'59.1"E	By Kanyama Water Trust
KYA	Municipal borehole	15°26'29.3"S 28°14'58.4"E	By Kanyama Water Trust
KYD	Privately-owned borehole	15°26'19.94"S 28°14'56.80"E	Hilltop Grocery
KYE	Privately-owned borehole	15°26'01.5"S 28°15'01.6"E	Muntanda Bantu Road
KYH 1	Household	15°26'3.46"S 28°14'59.38"E	Along Muntanda Bantu Road (Pen Store)
KYH 2	Household	15°26'2.69"S 28°14'57.68"E	Damac Academy

KYH 3	Household	15°26'3.82"S 28°14'56.16"E	Opposite Damac Academy
KYH 4	Household	15°26'02.7"S 28°15'02.8"E	Yalelo: Kanyama Fresh
KYH 5	Household	15°26'1.37"S 28°15'3.43"E	Kingdom Hall of Jehovah's Witnesses (Kanyama East)
KYH 6	Household	15°25'58.02"S 28°14'54.69"E	Muntantu Bantu Road (Muntanda Bantu Market)
KYH 7	Household	15°25'58.04"S 28°14'56.24"E	Pa Shadrick and Andrew Shop (opposite Muntanda Bantu Market)
KYH 8	Household	15°25'52.81"S 28°14'58.29"E	Muntanda Bantu Market

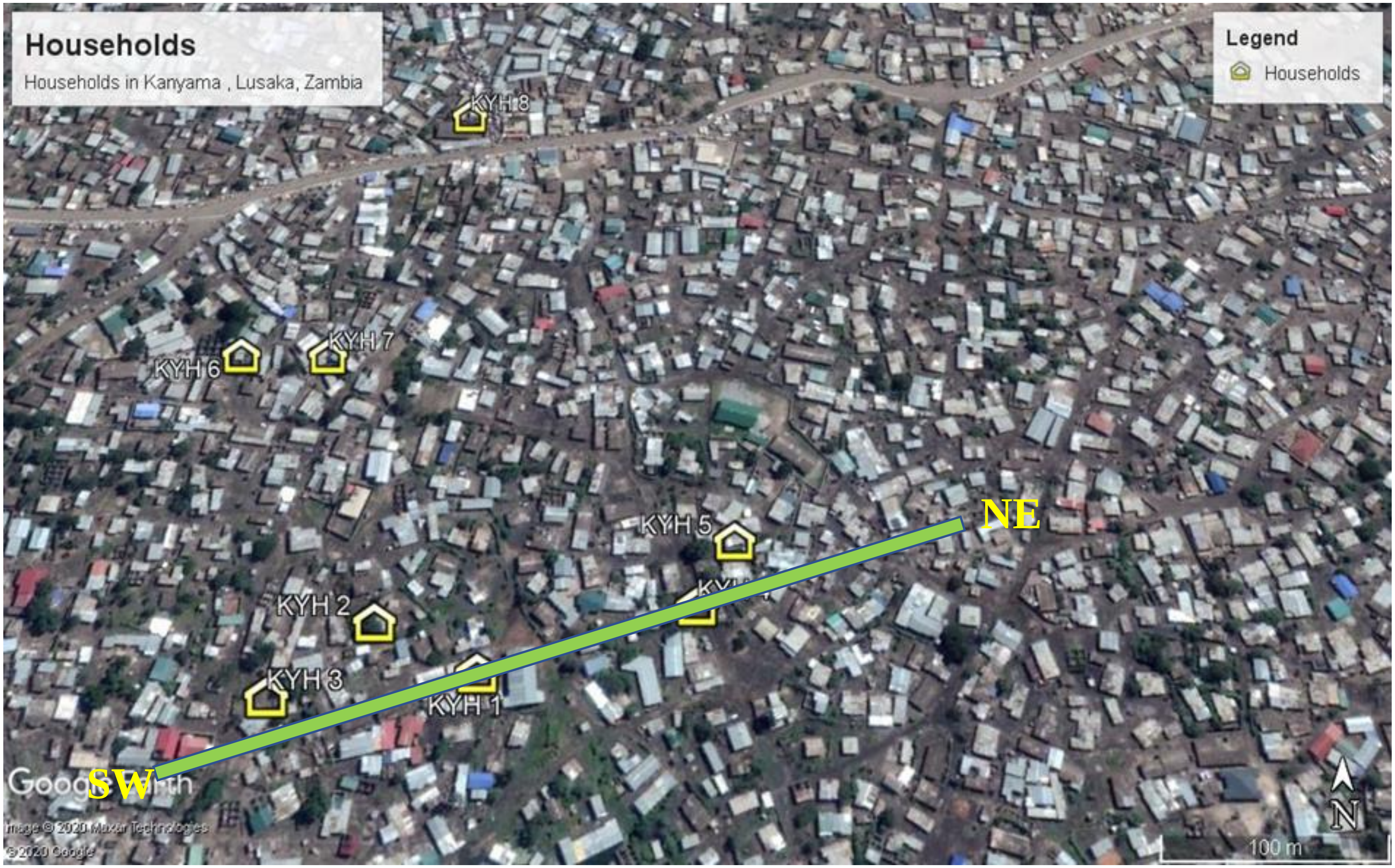


Figure 13: Transect from northeast (NE) to southwest (SW) direction passing through household sampling points (KYH 5, KYH 4, KYH 1, KYH 2 and KYH 3) in Kanyama, Lusaka, Zambia. Based on Bäumle and Kang'omba, (2012), groundwater flow direction is also from NE to SW

Figure 14: Transect from north (N) to south (S) direction passing through water sources (KYF – shallow-well, KYC - kiosk, KYG – shallow-well, KYB – municipal borehole and KYA – municipal borehole) in Kanyama, Lusaka, Zambia. Based on Bäumle and Kang'omba, (2012), groundwater flow direction is also from N to S

4.2.1.7 Sampling points in Ngombe

Eight water samples were collected from eight households in Ngombe (Table 6, Figure 15). In addition, seven water samples were collected from four privately-owned boreholes and three kiosks (Table 6, Figure 16). The coordinates of the sampling points were recorded using Google Earth's GPS system through photographs that were taken at each of the sampling points (Figure 15 and 16).

Table 6: Locations and descriptions of various water sources and households in Ngombe, Lusaka, Zambia

Sample ID	Source	Location	Description
NGK 1	Kiosk	15°21'45.2"S 28°19'22.1"E	Dr Coolnder Home Furniture home
NGK 2	Kiosk	15°21'33.0"S 28°19'29.5"E	Pamu Distributors Limited
NGK 3	Kiosk	15°21'54.8"S 28°19'32.7"E	Home Grocery Store
NGT1	Privately-owned borehole	15°21'42.2"S 28°19'26.8"E	Pamu Distributors Limited
NGT2	Privately-owned borehole	15°21'42.5"S 28°19'25.7"E	Opposite T1
NGT 3	Privately-owned borehole	15°21'57.4"S 28°19'33.2"E	Home Grocery Store
NGT 4	Privately-owned borehole	15°22'0.12"S 28°19'35.42"E	Opposite T3
NG 1	Household	15°21'48.68"S 28°19'20.40"E	Dr Coolnder Home Furniture home
NG 2	Household	15°21'47.43"S 28°19'25.75"E	Pamu Distributors Limited
NG 3	Household	15°22'2.71"S 28°19'37.47"E	Home Grocery Store
NG 4	Household	15°22'5.67"S 28°19'35.70"E	Home Grocery Store
NG 5	Household	15°22'5.80"S 28°19'30.77"E	Womba Ngulye Grocery

NG 6	Household	15°21'35.06"S 28°19'25.88"E	Pedahzur Anointed Ministries International
NG 7	Household	15°21'36.78"S 28°19'30.71"E	Zambezi Road
NG 8	Household	15°21'38.30"S 28°19'24.55"E	Chicken Restaurant

Figure 15: Transect from southeast (SE) to northwest (NW) direction passing through household sampling points (NG 4, NG 5, NG 2, NG 8 and NG 6) in Ngombe, Lusaka, Zambia. Based on Bäumle and Kang'omba, (2012), groundwater flow direction is also from SE to NW

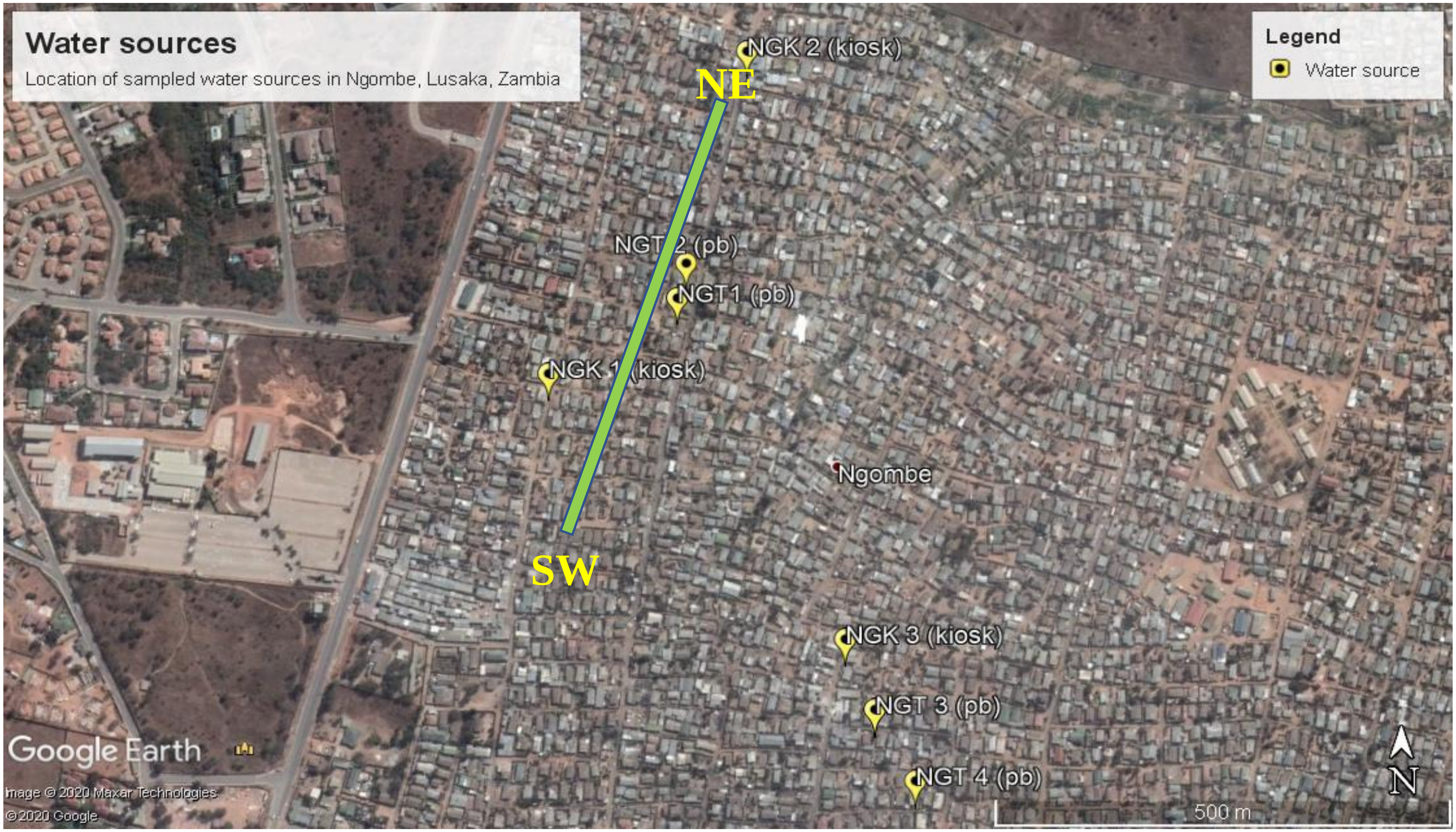


Figure 16: Transect from northeast (NE) to southwest (SW) to northeast direction passing through water sources (NGK 1 – kiosk, NGT 1 – private borehole, NGT 2 – private borehole and NGK 2 – kiosk and KYA – municipal borehole) in Ngombe, Lusaka, Zambia. Based on Bäumle and Kang'omba, (2012), groundwater flow direction is also from NE to SW

4.2.2 Secondary Data

The study also utilised secondary data regarding HWTS practices, policies and strategies of HWTS from other countries mainly Ghana and Tanzania.

A 2012 global survey done by the WHO was reviewed, and it mainly focused on HWTS-specific targets among the participating countries. Forty-six countries participated in the survey highlighted five key elements important for achieving scale-up of HWTS – national policy, HWTS target, coordinating structure, regulation and certification. The results of the study were key in understanding how the Government of Zambia can integrate some of the vital policy and certification guidelines in its National Water and Health policies.

4.2.2.1 Sources and Types of Data

Secondary data was collected from various books, magazines, journals, manuals, articles and reports related to the study. Furthermore, other relevant data was obtained through the use of the internet. Stipulated standards on consumable water were collected from ZABS and WHO literature. In addition, literature relating to the subject was reviewed in order to get a comprehensive understanding of the problem at hand. The literature review also sought to understand the geology of the study area, water sources and the various methods of HWTS that are being utilised in the different parts of the world.

4.3 Data Analysis

Data analysis involved a wide variety of techniques in order to meet the objectives of the study and arrive at meaningful research finding and conclusions.

Samples collected were analysed for physicochemical and bacteriological parameters. The results were subjected to statistical analysis using Excel 2016 and SPSS version 26. The results were further compared with the World Health Organization (WHO) and the Zambia Bureau of Standards (ZABS) minimum requirement of contaminants in water meant for drinking (Table 7).

Table 7: Guidelines for Drinking Water Quality by WHO and ZABS (WHO, 2011 and ZABS, 2010)

Parameter	Maximum permissible limit of drinking water	
	WHO	**ZABS**
pH	6.5 – 8.5	6.5– 8.0
Arsenic (mg/l)	0.01 mg/l	0.01 mg/l
Phosphates (mg/l)	5 mg/l	-
Nitrates (as NO_3 –N mg/l)	10 mg/l	10 mg/l
Turbidity (NTU)	5 NTU (Nephelometric Turbidity Units)	5 NTU
Fluoride (mg/l)	1.5 mg/l	1.5 mg/l
Chlorides (mg/l)	250 mg/l	250 mg/l
Faecal coliforms (#/100 ml)	Absent in 100 ml	Absent in 100 ml

4.4 Ethical Considerations

Ethical considerations were given during the study regarding confidentiality and consent. None of the respondent's details was asked while carrying out the primary research. The respondents were encouraged to not to include personal details such as name or age in the questionnaires.

4.5 Limitations of the study

During thesis research, several challenges were encountered regarding data collection. The main challenge was the lack of finances for analysis of more than 50 samples.

The Zambian Bureau of Standards labs were available during the closure of workplaces but their price list to pay for water analysis test was way above the funds that were made available by the institute (research grant). Other labs, such as the Water Resources Management Authority (WARMA) lab, was not operating. This, therefore, made it harder to compare prices for all labs and select one that would be affordable. Therefore, all collected samples were submitted and analysed at the University of Zambia Civil Engineering Department (Environmental Engineering Laboratory) and School of Mines Geochemical Laboratory.

Another challenge faced during data collection was security. The Covid-19 pandemic had caused a lot of insecurities among many residents in peri-urban townships of Lusaka. The samples were collected from Chaisa, Kanyama and Ngombe who were coming out of the gassing situation in Lusaka followed by Covid – 19 pandemic. Explaining to the residents in these townships was not an easy task. A few were afraid the sample bottles contained coronavirus hence collecting samples in their homes was futile. To resolve these challenges, a letter was written to the Managing Director, Lusaka Water Supply and Sanitation Company Limited (LWSC), Mr J. Kampata, for permission to seek authority from the Water Trust Managers, who in turn assigned people to help me. The Water Trust managers assigned Mr R. Jambo (Kanyama), Mr K. Lungu (Ngombe) and Mr S. Mwale (Chaisa) who are very familiar and well known in their communities to assist me in collecting the samples. A letter of approval from the Managing Director of LWSC, Mr J. Kampata, is attached in Appendix 4.

CHAPTER 5

RESULTS, INTERPRETATION AND DISCUSSION

5.1 General Remarks

This chapter presents results obtained in line with the study objectives, their interpretation and discussion. It is important to note that discussion is not a separate heading but follows the interpretation of each section.

5.2 Physico-chemical and Microbiological Analysis of Water in Chaisa, Kanyama and Ngombe

The water samples collected in the three study areas showed considerable variation in the water quality as described herein.

5.2.1 Physico-chemical and Microbiological Parameters of Household Water in Chaisa

As indicated in Chapter 4, in order to understand the variation in concentration, a transect was selected from southwest (SW) to northeast (NE) (Figure 12 above). This transect was selected following the direction of groundwater as reported by Bäumle and Kang'omba (2012) for easy comparison of household water and on the ground.

The selected households in Chaisa showed variation for several chemical parameters that were analysed. Variation was observed in nitrate, chloride and flouride concentration. The concentration of nitrates ranged from 4.20 to 6.50 mg/l with a mean of 5.21mg/l, chloride conentration ranged from 49 to 55mg/l with a mean of 51.3mg/l and flouride concentration ranged from 0.20 to 0.42mg/l with a mean of 0.31mg/l. However, the concentrations of arsenic (<0.002mg/l for all samples) and phosphates (<0.01mg/l for all samples) showed no variation in all households (Figure 17). The similarity in concentration of arsenic and phosphate is due to the very low levels of arsenic and phosphate ions in the water. It is important to note here that the levels of nitrates (mean 5.21mg/l) in all households in Chaisa were within the WHO (2011) and ZABS (2010) recommeded limits as high levels of nitratess can cause gastrointestinal infection to infants and pose significant health risk for young adults (Fewtrell, 2004). Therefore, the stored household water in Chaisa was not contaminated by nitrate pollutants. The absence of contaminants in groundwater of Chaisa is due to the area having less constructed pit latrines. The absence of contaminates in groundwater, also contributes to the absence of nitrate contaminants in household water.

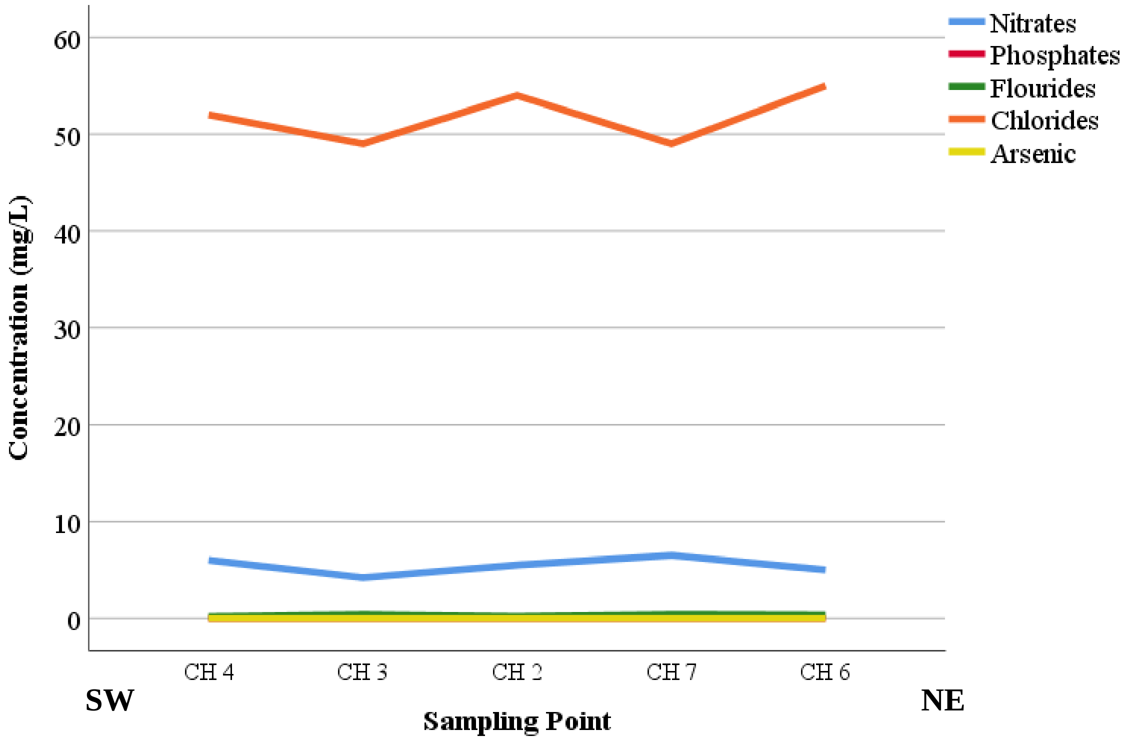
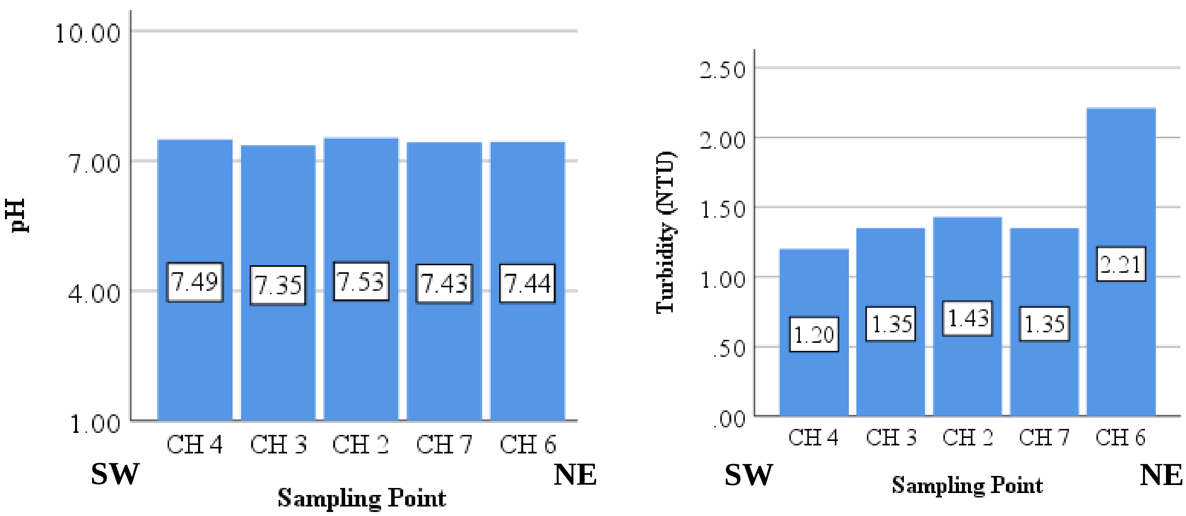


Figure 17: Concentration of nitrates, phosphates, fluorides, chlorides and arsenic in Chaisa, Lusaka, Zambia from southwest to northeast passing through households (CH 4, CH3, CH2, CH 7 and CH 6). SW – NE is also the given groundwater flow by Bäumle and Kang'omba, 2012

pH for the analysed household water showed variation in the households (Figure 18a). The pH ranged from 7.35 to 7.53 with a mean of 7.42 which is within the WHO (2011) and ZABS (2010) recommended limit for drinking water. The pH of water was observed to reduce then increase again from the southwest (SW) to northeast (NE) direction. This implies the acidity and alkalinity of the water in the households was not compromised either at the source or when stored in the house. A similar trend was observed in the samples collected from water sources along the same SW-NE transect. This implies residents were collecting water that had concentrations similar to the sources in the area. However, turbidity showed variation in the household samples (Figure 18b). Turbidity ranged from 1.20 to 2.21 NTU with a mean of 1.51 NTU. The variation for turbidity seemed to increase in the direction of groundwater flow from SW to NE (Figures 11 and 12 above). As indicated in the generalised geology map (Figure 2 above) of Lusaka District by Bäumle and Kang'omba (2012), the location of the selected water sources and households are in the SW to NE to direction which is similar to the direction of flow of groundwater. The variation in turbidity is as a result of increasing dissolved organic and non-organic substances in groundwater as it flows (Burlingame et al. 1998).



(a) (b)

Figure 18: (a) pH of water in households of Chaisa, Lusaka, Zambia (b) Turbidity of water in households of Chaisa, Lusaka, Zambia. SW – NE is also the given groundwater flow by Bäumle and Kang'omba, 2012

As indicated earlier, faecal coliform was analysed as an indicator for bacteriological contamination of water in households of Chaisa. Figure 19 shows that there is no variation of results obtained after analysis. Its cardinal to know that the concentration at 150 CFU/ml represents TNTC (Too Numerous to Count). Only two households had water which was not contaminated with faecal coliform. From the survey that was conducted, the two households stated that they treat their drinking water and cover their storage containers. The most common method used for treating their water was chlorination and boiling. HWTS practices such as boiling and chlorination yield improvements in drinking water quality and reductions in diarrheal disease (Diana, 2017).

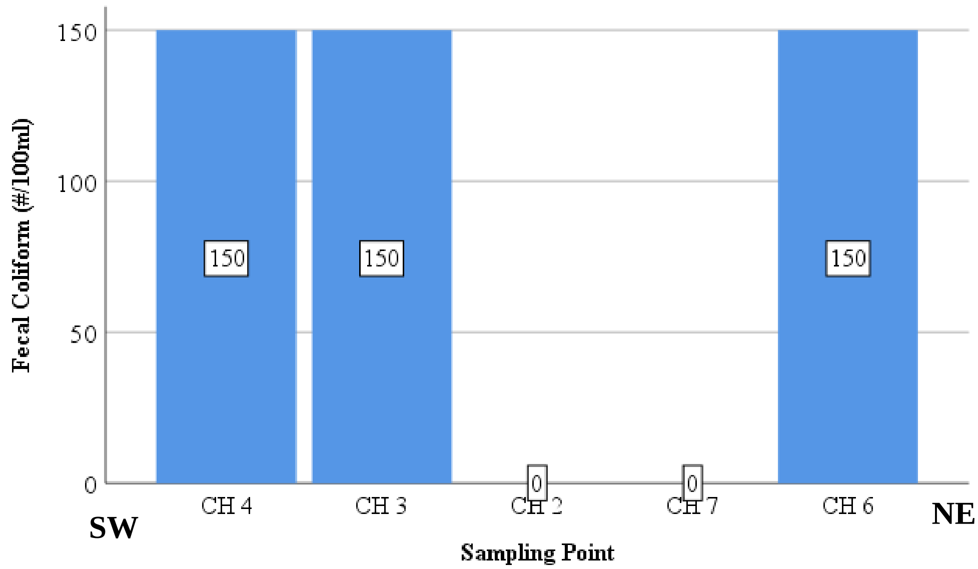


Figure 19: FC concentration of selected household water in north-east direction of Chaisa, Lusaka, Zambia. SW – NE is also the given groundwater flow by Bäumle and Kang'omba, 2012

Households that had water which showed the presence of faecal coliform in Figure 19 above did not treat their water using any method despite having covered storage containers. Microbial contamination of collected and stored household water is caused not only by the collection and use of faecally contaminated water that was not safe to begin with but also by contamination of microbiologically safe water after its collection and storage (Sobsey, 2002).

5.2.2 Physico-chemical and Microbiological Quality of water samples from various sources in Chaisa

From the sampled water from various water sources in Chaisa, it was observed that all the samples had concentrations of chemical parameters within the recommended limits. However, variation was observed for nitrate (3.4 to 7.3mg/l with a mean of 5.35mg/l), chloride (50 to 58mg/l with a mean of 54.2mg/l) and fluoride (0.11 to 0.42mg/l with a mean of 0.27mg/l) concentration from the SW to NE direction. Phosphates and arsenic showed no variation and all samples analysed had a similar range of <0.01mg/l and <0.002mg/l respectively (Figure 20).

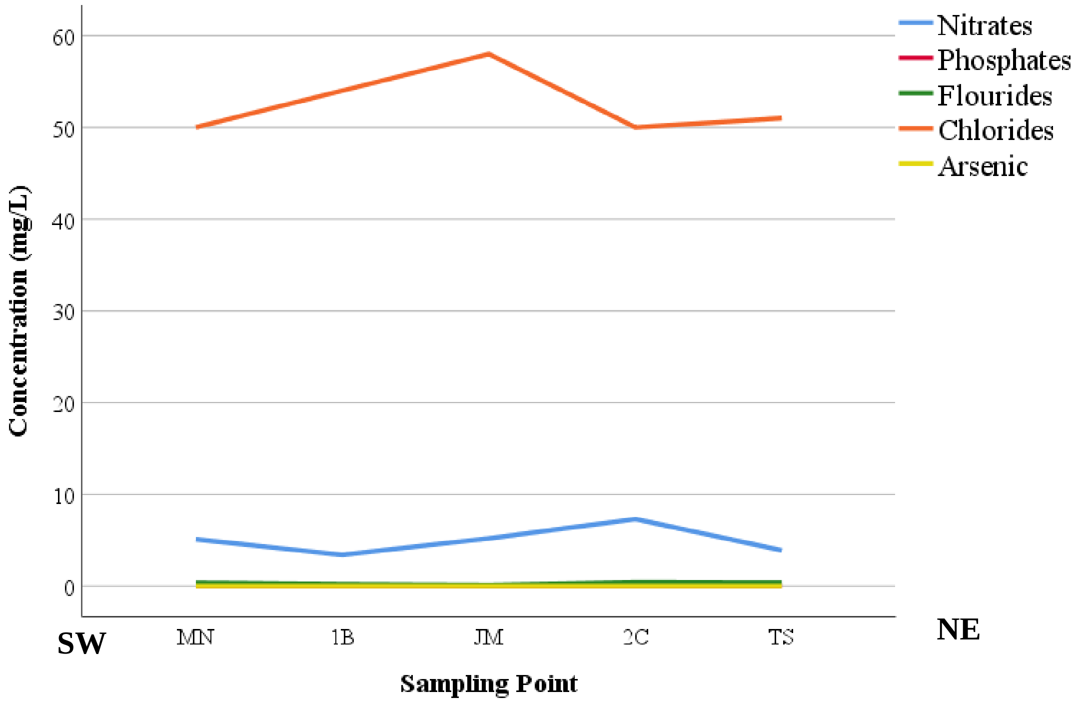
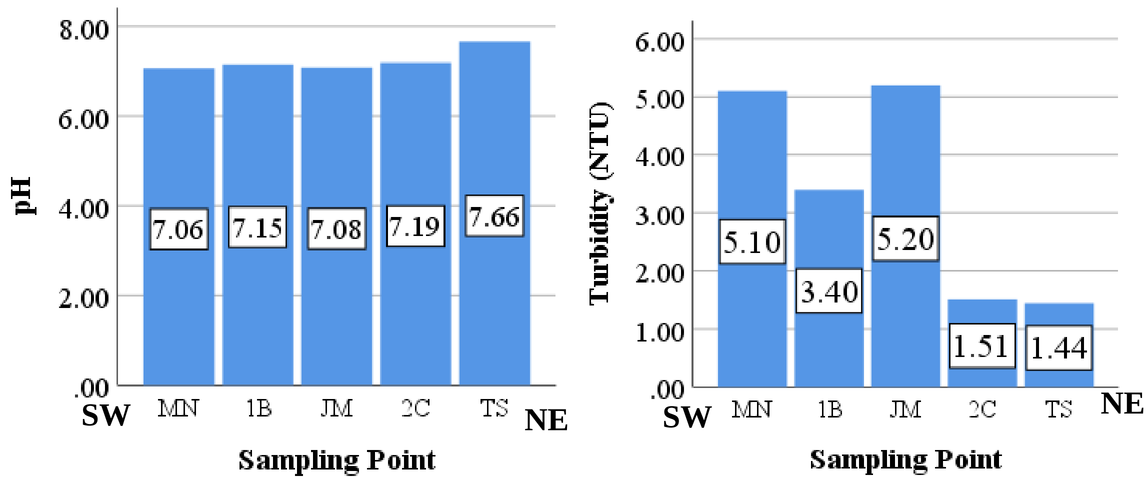


Figure 20: Concentration of nitrates, phosphates, fluorides, chlorides and arsenic along the transect SW – NE passing through water sources (MN-private borehole, 1B-kiosk, 1M private borehole, 2C-kiosk and TS-kiosk) in Chaisa Lusaka, Zambia. SW – NE is also the given groundwater flow by Bäumle and Kang'omba, 2012

Similarly, physical parameters showed variation. pH was observed to decrease from the SW to the NE direction (Figure 21a). pH values for water sources along the SW – NE transect ranged from 7.06 to 7.66 with a mean of 7.23 (Figure 21a). Despite the variation, pH for all water samples was within the recommended limits for drinking water.

Samples obtained from both privately-owned boreholes had turbidity values that are not in the recommended WHO and ZABS limit (Figure 21b). Turbidity of water collected from water sources ranged from 1.44 to 5.2 NTU with a mean of 3.33 NTU. Turbidity was observed to be reducing from the SW to the NE direction. In contrast, water samples collected from households were all within the permissible limits which could imply that the water stored in households could have been collected at other kiosks or private boreholes in the Kanyama area or treated.



(a) (b)

Figure 21: (a) pH of water sources in Chaisa, Lusaka, Zambia (b) Turbidity of water sources in Chaisa, Lusaka, Zambia. SW – NE is also the given groundwater flow by Bäumle and Kang'omba, 2012

The study revealed that 100% of the water samples that were collected from these sources were contaminated with faecal coliform bacteria. Three of the sources (two private boreholes and one kiosk) had an FC concentration of TNTC (Figure 22), which describes contaminated water and in addition is also above the ZABS and WHO permissible limit of nil (CFU/100 ml). Therefore, there was no variation in faecal coliform concentration from water sources in Chaisa. The presence of faecal coliform bacteria in the water sources could have been as a result of faecal matter contamination of groundwater as it was observed that some private boreholes were stationed very close (about 4.5 meters) to pit latrines (Figure 4b above). The presence of faecal coliform contamination could have also led to high turbidity in the water sources which correlates with LeChevallier's et al. (1991a, 1991b) findings. Research has shown that the principal risk to health is from ingestion of water contaminated with faeces containing pathogens that cause infectious diseases such as cholera and other diarrheal diseases, dysenteries, and enteric fevers (Ansa-Asare et al, 2009).

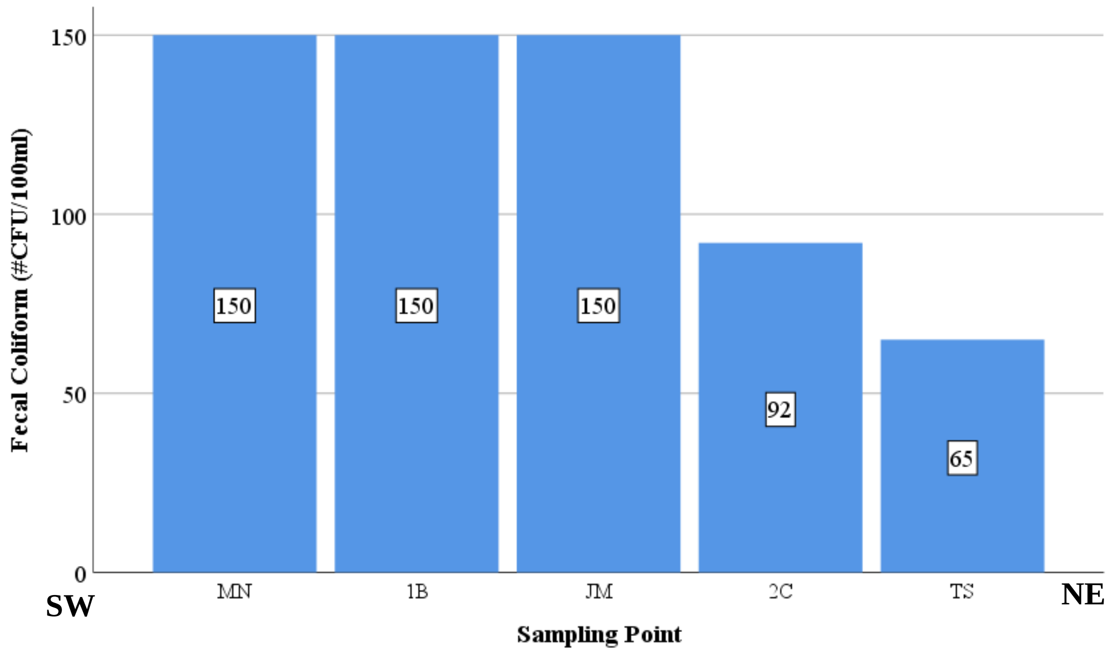


Figure 22: Faecal coliform concentration of water sources (MN-private borehole, 1B-kiosk, 1M private borehole, 2C-kiosk and TS-kiosk) along transect SW – NE in Chaisa, Lusaka, Zambia. SW – NE is also the given groundwater flow by Bäumle and Kang'omba, 2012

5.2.3 Household Survey of Water Use in Chaisa

The results from the household survey conducted in Chaisa are summarised in the form of pie charts which represent the selected responses regarding HWTS. The water sources most commonly used by the participating households in Chaisa include private boreholes (70%) and kiosks (30%) (Figure 23a). Water Kiosks have proven to be an appropriate and efficient solution, providing water to a large number of residents in various peri-urban areas including Chaisa. A study in Chaisa done by Reaver et. al (2016-in prep.) shows that about 37,360 people are served by kiosks in the area. Additionally, 42 kiosks were in use during the time of the study at which each kiosk served 890 users. From the study, more residents were obtaining water from privately constructed boreholes rather than from kiosks.

From the questionnaire results, only three (30%) of the participating households treated their water. The most common method of treating water was chlorination (20%) and the other households (10%) boiled their water. Seventy per cent of the participating households stated they did not treat their water (Figure 23b). Two of the households that treated their water by boiling and chlorination showed no presence of faecal coliform. Since a majority of the households do not treat their water, there is need for more households to treat their water to reduce occurrences of waterborne diseases.

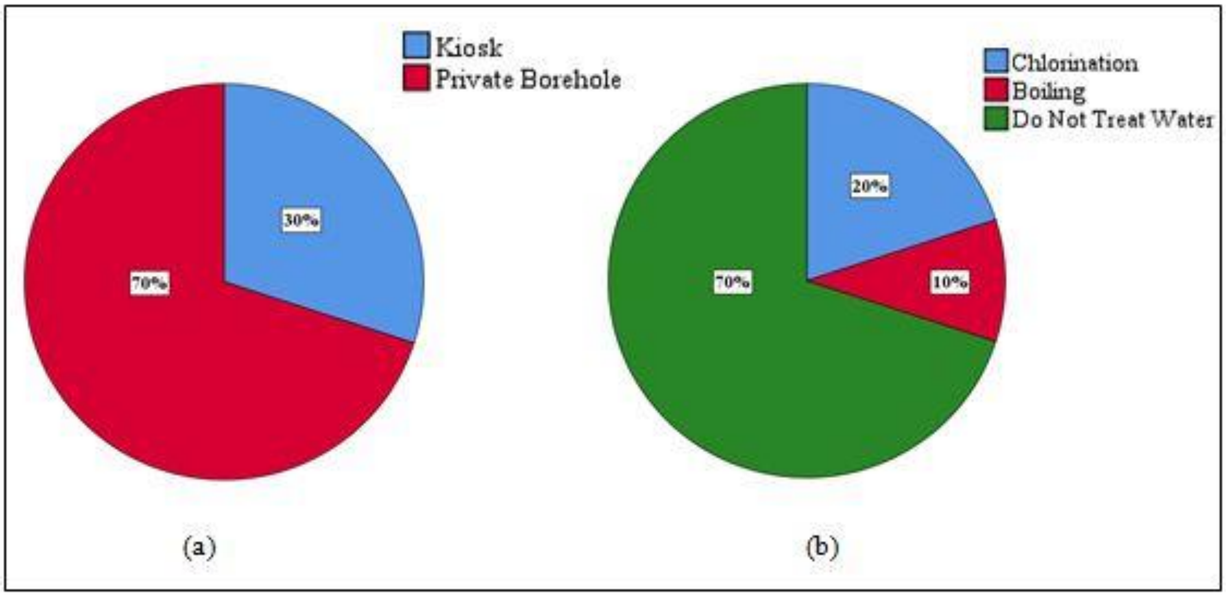


Figure 23: (a) Water sources from which water is collected from in Chaisa, Lusaka, Zambia (b) Water treatment methods practiced by households in Chaisa, Lusaka, Zambia

The participating households were also asked on the type of storage containers they use, and 70% of the respondents revealed that they store most of their water in both buckets and jerrycans. The remaining households stored their water in drums (10%), buckets (10%) and jerrycans (10%) (Figure 24a).

The study further revealed 40% of the household water was stored between six to twelve hours at the time of collection. Meanwhile, 30% of the households stored their water between one to six hours and the remaining 30% of households stored their water for more than twelve hours (Figure 24b). Three of the four households that had an FC of nil CFU/100 ml claimed to have stored their water 1 to 6 hours at the time of sampling. Only one household among the four that had an FC of nil CFU/100 ml stored their water 6 to 12 hours during the time of sampling. Therefore, there was a possibility that the water in households that was stored 1 to 6 hours prior to sampling could not have been contaminated by microbiological pathogens. Two households that had an FC of TNTC stored their water for more than 12 hours prior to sampling. In such a case, their water could have been contaminated with microbiological pathogens as it was stored for longer hours. Results of previous studies are in agreement with the findings that the quality of water may significantly deteriorate after collection i.e. contamination occurs in transport vessels (Wright et al., 2004; Gundry et al., 2006) or in the household domain in general (Jensen et. al, 2002).

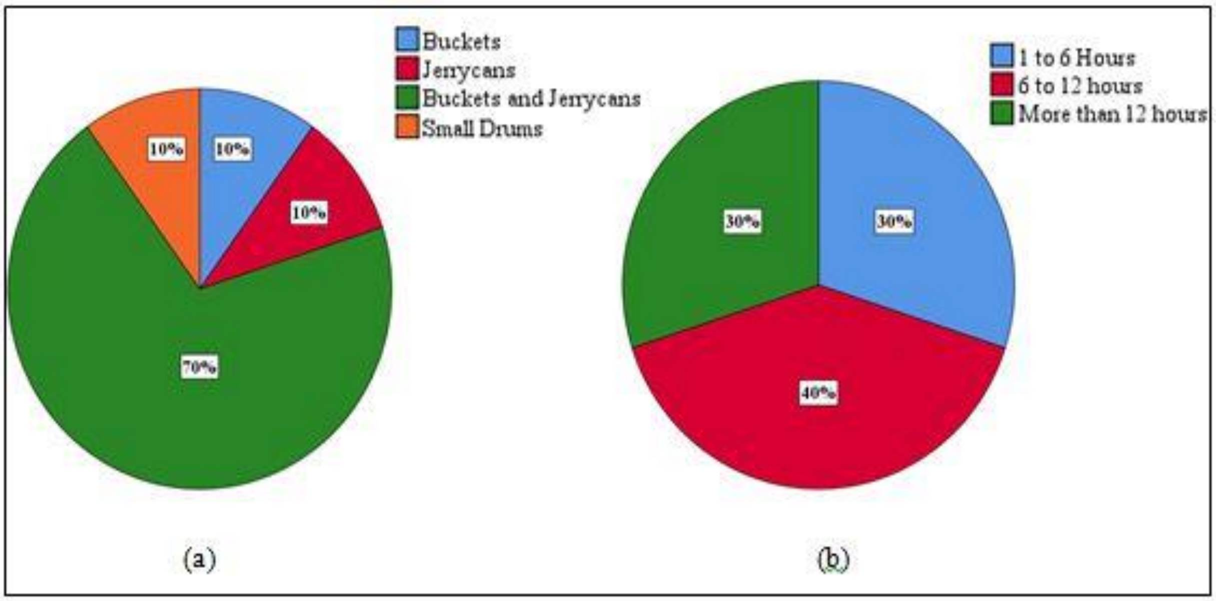


Figure 24: (a) Storage containers used for storing drinking water in households of Chaisa, Lusaka, Zambia (b) Duration of storage of water collected in households in Chaisa, Lusaka, Zambia

It's important to note that the contaminated water that was sampled from the households in Chaisa, Kanyama or Ngombe could have been exposed to faecal matter from sources the water was collected from, during collection and transportation or could have been contaminated household due to direct contact from hands that had microbiological contaminants. Contamination by hands has been shown to be the predominant cause of declining the quality of water. This pattern has been confirmed by previous studies of water contamination in rural Sierra Leone, rural Honduras, South Africa, and Zimbabwe (Schmidt and Cairncross, 2009). Therefore, while the detrimental effects of in-house contamination are known, the exact point of contamination remains still unclear.

Regarding illnesses related to the consumption of water (such as diarrhoea), households were asked on the occurrence of cases in their homes and if they noticed an increase or decrease in cases. The respondents also had the option of choosing ‘’none’’ in case they did not notice illnesses resulting from the consumption of water (Figure 25). Seventy percent of the households state they did not experience any illness from consuming water while 30% stated they noticed a decrease in illnesses related to contaminated water. Therefore, this shows the impact of treating water in homes that collect their water from potentially contaminated sources. During the study, it was observed that some house in Chaisa had poor sanitation facilities. Therefore, in addition to drinking contaminated water, some households were at risk of contracting waterborne diseases due to poor sanitation.

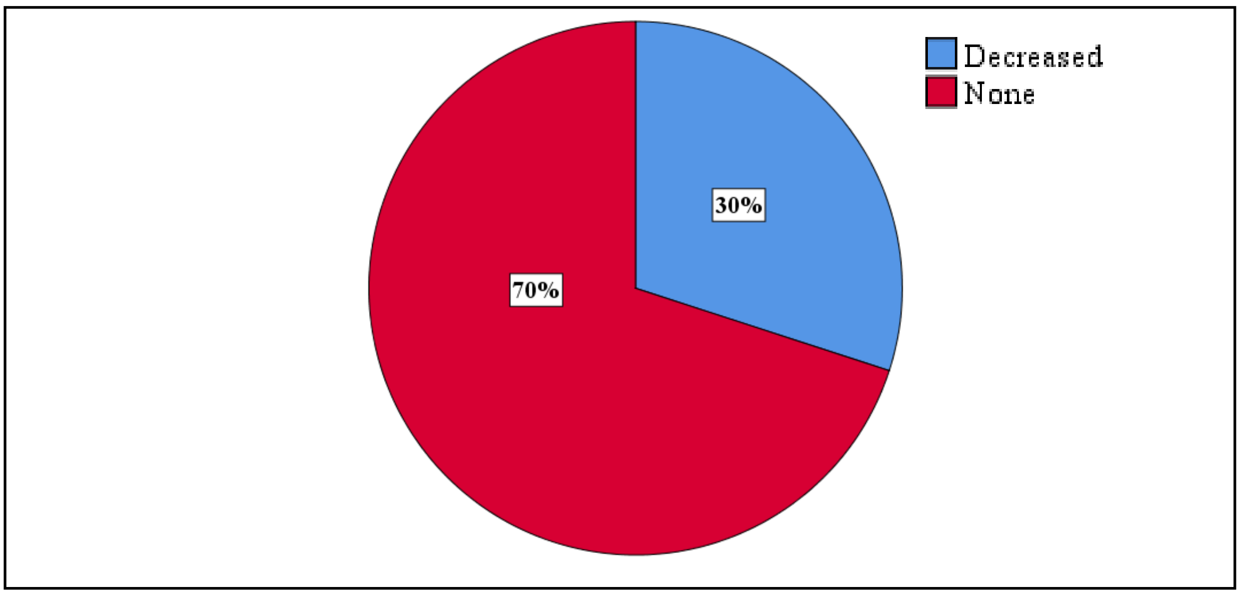


Figure 25: Occurrences of diarrhoea in households of Chaisa, Lusaka, Zambia

5.2.4 Physical, Chemical and Microbiological Parameters of Household Water in Kanyama

Sampling points for households in Kanyama are shown along a transect from SW to NE in Figure 13 above. As indicated earlier, the transect was selected following the direction of groundwater as reported by Bäumle and Kang’omba, 2012 for easy comparison of household water and groundwater sources.

The results from sampled water for physico-chemical parameters in households in Kanyama showed several variations. The concentration of chloride ranged from 130 to 186mg/l with a mean of 152.7mg/l. From the selected households, chloride concentration was reducing from households located in the NE to households located in the SW (Figure 26). Despite having higher chloride concentrations, all the sampled water from households had concentrations that were within the permissible range.

Nitrate concentrations among the selected households ranged from 16.20 to 20.20mg/l with a mean of 16.50mg/l. Therefore, all the samples that were analysed had high nitrate concentrations that were not within the recommended limits thus making the water unsafe to consume. There are many sources of groundwater nitrate pollution, such as improper disposal of waste, waste from animal farms or from the use of nitrogenous fertilizers (Adimalla et. al, 2019). Densely populated peri-urban areas such as Chaisa, Kanyama and Ngombe contribute to groundwater pollution due to lack of proper waste management practices and lack of sanitary facilities (Nyambe and Maseka, 2000). Furthermore, fluoride concentration among the households also showed variation. Fluoride concentration ranged from 0.38 to 0.80mg/l with a mean of 0.53mg/l, which is within the recommended standard range for drinking water.

Variation was not observed for phosphate and arsenic concentration in the sampled water from the households. All sampled had phosphate and arsenic concentration of less than 0.01mg/l and 0.002mg/l respectively.

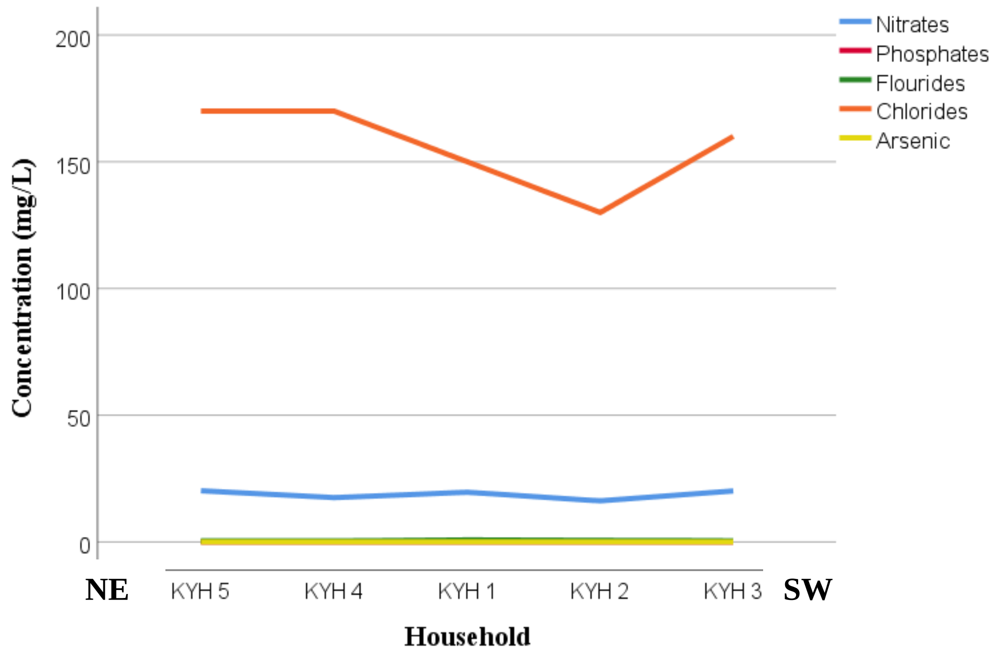
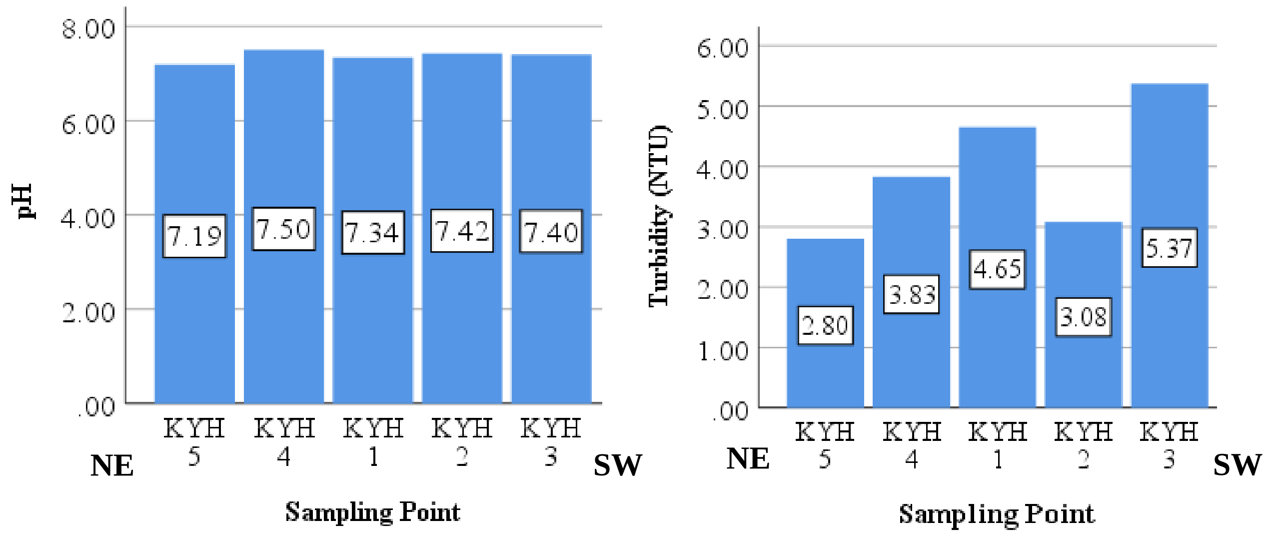


Figure 26: Concentration of nitrates, phosphates, fluorides, chlorides and arsenic along transect NE – SW passing through households (KYH 5, KYH 4, KYH 1, KYH 2 and KYH 3) in Kanyama, Lusaka, Zambia. NE – SW is also the given groundwater flow by Bäumle and Kang'omba, 2012

pH and turbidity showed variation (Figures 27 a and b). The pH of all water samples was in conformity with the standards for drinking water. pH showed variation with a range of 7.19 to 7.50 with a mean of 7.37 from the NE to the SW direction. pH was observed to be increasing then decreasing in the NE to SW direction. Similarly, turbidity showed variation with concentration ranging from 2.80 to 5.37 NTU with a mean value of 3.95 NTU. One sample had a value for turbidity above the recommended limit. This could have been due to household water contamination because all the samples collected (from both households and water sources) had turbidity values within the recommended limit.



(a) (b)

Figure 27: (a) pH of water samples collected in selected households of Kanyama, Lusaka, Zambia (b) Turbidity of water samples collected in households of Kanyama, Lusaka, Zambia. NE – SW is also the given groundwater flow by Bäumle and Kang'omba, 2012

5.2.5 Microbiological Status of Water in Kanyama

The results revealed all water samples from the sampled households were contaminated with faecal coliform bacteria, i.e. the concentration of faecal coliform was above nil CFU/100 ml which is not within the permissible ZABS and WHO limit. Three households among the selected households had faecal coliform concentration of TNTC which indicated a high concentration of bacterial contamination. From Figure 28, it can be observed that despite a slight reduction in faecal coliform concentration from the first three households, the remaining households had water that was highly contaminated. Therefore, this implies that water was contaminated in all water samples. Any presence of faecal coliform bacteria indicates contamination hence there is need to have drinking water that has no presence of the organisms. However, it can be noted that during the second phase of sampling, two houses showed no presence of faecal coliform. This was due to the fact that the water that was sampled was boiled and stored for a short period prior to sampling. The results of both the first and second phase of sampling are shown in Appendix 5.

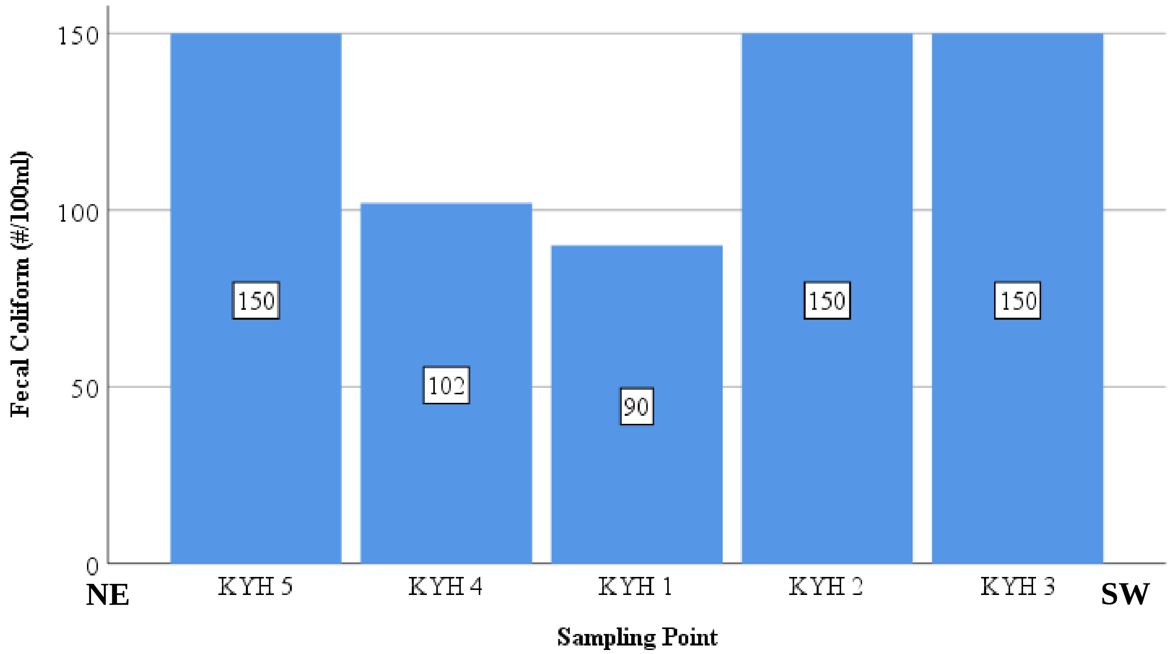


Figure 28: Faecal Coliform concentration of water samples collected in households in Kanyama, Lusaka, Zambia. NE – SW is also the given groundwater flow by Bäumle and Kang'omba, 2012

Analysis of some chemical parameters from water samples collected from Kanyama showed variation (Figure 29). From the results, it was observed that all the water samples had values of nitrate concentration above the recommended limit. The results of nitrate concentration ranged from 13.5 to 18.7mg/l with a mean of 16.4mg/l. This was similarly observed from the water sampled from households. The high nitrate concentration of water in the households was from the water sources. As indicated earlier, agricultural drainage, leachate from waste pile, and pollution from human and animal waste are responsible for a vast increase of nitrate concentrations in groundwater (Adimalla et. al, 2019). There was no variation for nitrate concentration in groundwater as all the samples had values in the same range.

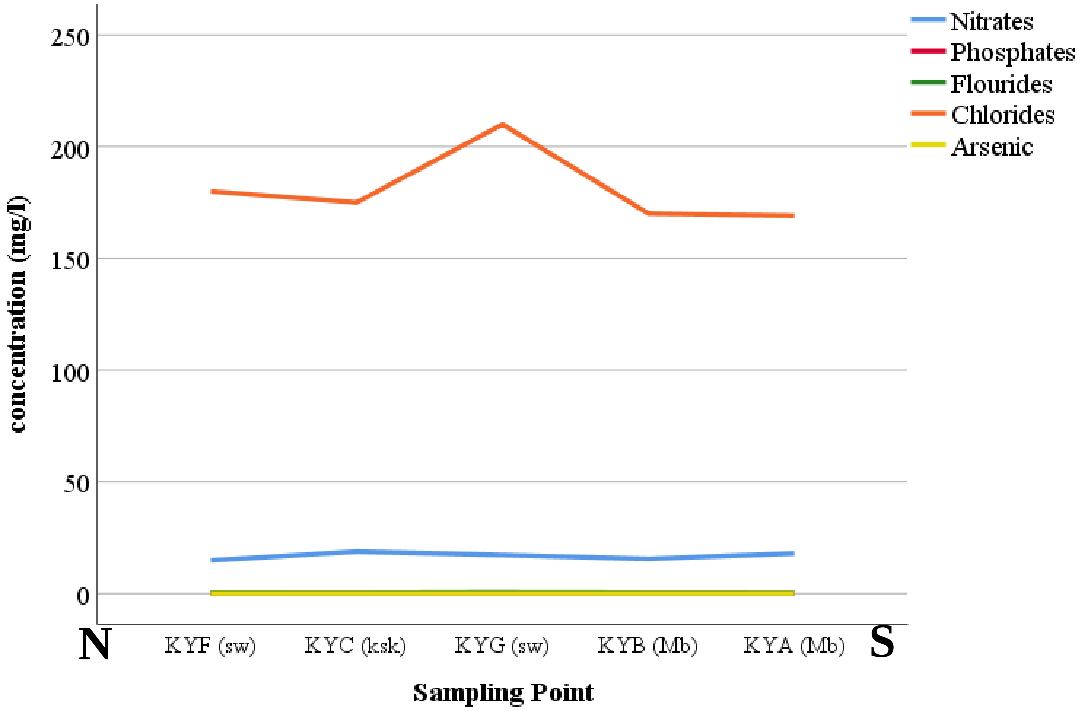


Figure 29: Concentration of nitrates, phosphates, fluorides, chlorides and arsenic along transect N – S passing through water sources (KYF-shallow well, KYC – kiosk, KYG – shallow well, KYB – municipal borehole and KYA – municipal borehole) in Kanyama, Lusaka, Zambia. N – S is also the given groundwater flow by Bäumle and Kang'omba, 2012

There was a slight variation in pH in the analysed water samples (Figure 30a) with a range of 7.06 to 7.23 and a mean 7.17. pH was high from samples collected in sources located in the N direction and was reducing in water collected sources towards the S direction. However, all the values of pH were within the WHO (2011) permissible range of drinking water. Phosphates and arsenic concentration from the water sources showed no variation and their values were in conformity with the drinking water standards. All samples had a phosphate concentration of less than 0.01mg/l and arsenic concentration of less than 0.002mg/l.

The results from water sources showed there was variation in turbidity concentration (Figure 30b). The concentration of turbidity was increasing from the north to south of Kanyama. Turbidity ranged from7.06 to 7.23 NTU with a mean of 7.17 NTU.

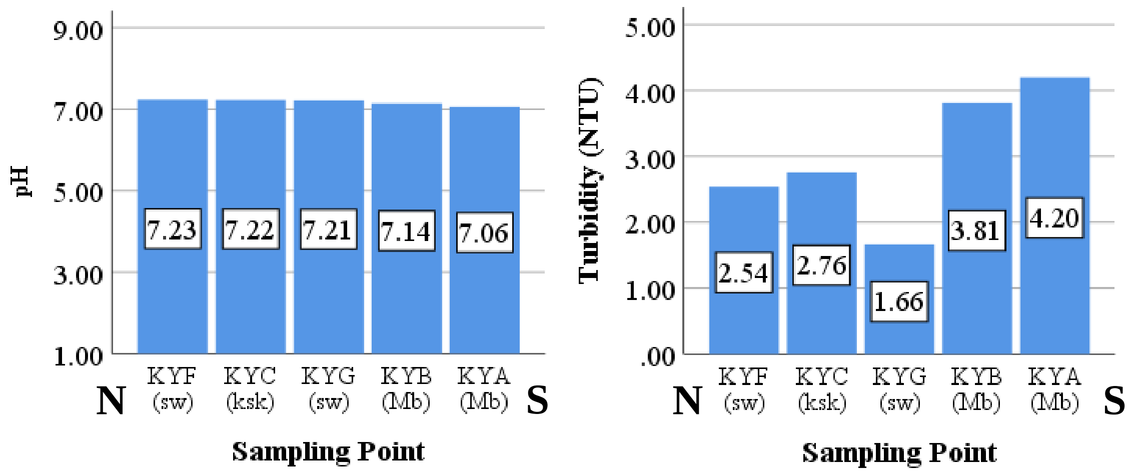


Figure 30: (a) pH for water sources in Kanyama, Lusaka, Zambia (b) Turbidity concentration for water sources in Kanyama, Lusaka, Zambia. N – S is also the given groundwater flow by Bäumle and Kang'omba, 2012

Of the seven samples collected from different water sources, none had values of FC concentration within the permissible WHO and ZABS limit of nil CFU/100 ml as all the water were contaminated with faecal coliform (Figure 31). Variation in faecal coliform concentration was observed as water sources in the north (N) had higher values than those in the south (S) direction. Similar to the water sources in Chaisa, the contamination of the groundwater in Kanyama is due to faecal matter originating from pit latrines. Kanyama is also among many peri-urban townships that have several pit latrines stationed close to water sources. Because of the increasing use of pit latrines in densely populated areas, there is concern that pit latrines may cause human and ecological health impacts associated with microbiological and chemical contamination of groundwater (Rosa and Clasen, 2010). Pit latrines generally lack a physical barrier, such as concrete, between stored excreta and soil and/or groundwater (van Ryneveld and Fourie, 1997). Additionally, contaminants from pit-latrine excreta may potentially leach into groundwater, thereby threatening human health through well-water contamination.

The study also revealed that 100% of the water samples that were collected from all the municipal boreholes were contaminated with faecal coliform bacteria. One of the shallow hand-dug wells was positioned about three meters from two pit latrines. The pit latrines that were close to water sources could have led to the contamination of the groundwater in shallow wells which is similar to findings of Wade et al. (2003). According to Wade et al., (2003), high concentrations of fecal coliforms were found in domestic wells located near pit latrines from a study site in India characterized by a shallow water table and fractured rock aquifer.

According to the Kanyama Water Trust Manager and the Field Assistant, many shallow wells throughout the area were buried to prevent further spread of disease; however, by mid-2019, many residents had dug new shallow wells.

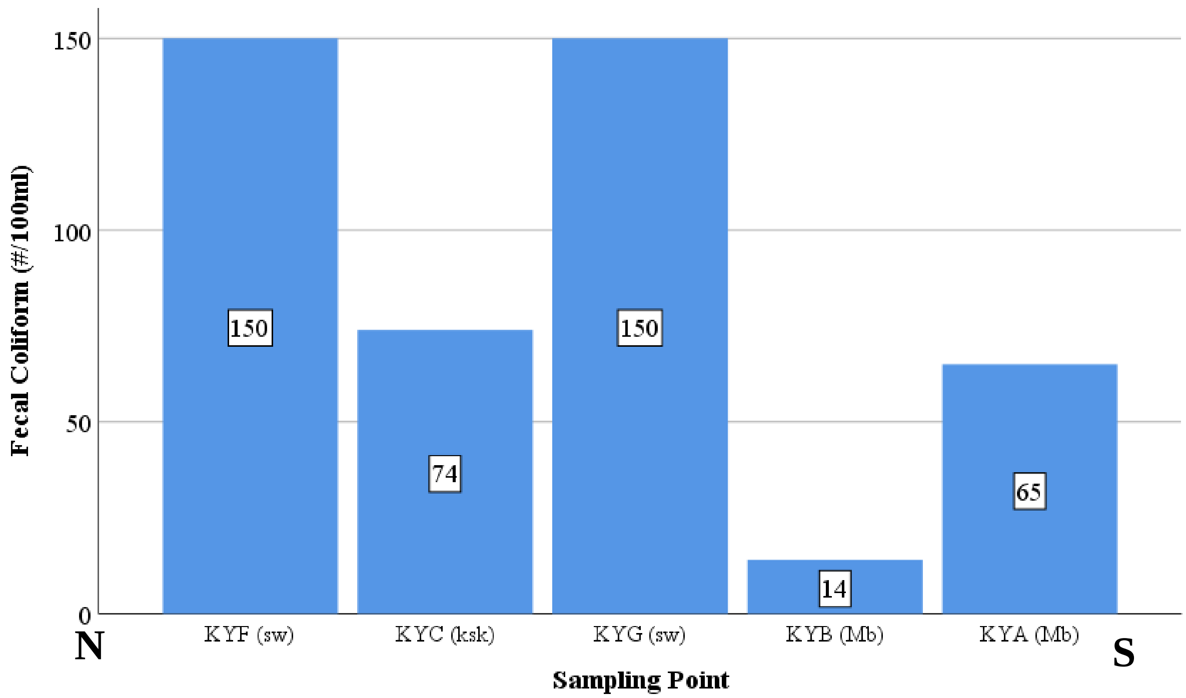


Figure 31: Faecal Coliform concentration of water samples collected from water sources in Kanyama, Lusaka, Zambia. N – S is also the given groundwater flow by Bäumle and Kang'omba, 2012

The water sources most commonly used by the participating households in Kanyama include private boreholes (38%), kiosks (3%) and shallow hand-dug wells (25%) (Figure 32a). Kanyama had the highest number of kiosks compared to the other study areas. It has 160 kiosks and 80,000 people are serviced by the water kiosks, which is about 420 people per kiosk (Reaver et. al, 2016 – in prep.). The study also revealed that there are several households that still use shallow hand-dug wells despite Water Trusts and Government officials burying them. Therefore, this poses a risk to individuals who consume the water that is contaminated with disease-causing pathogens.

Some households have privately-owned boreholes which were all contaminated with faecal coliform. This could have been due to the presence of pit latrines that were located very close to the boreholes.

From the questionnaire results, half of the participating households (50%) treated their water. The most common method of treating water was boiling (38%) and the other households (12%) chlorinated their water. The other half of the households did not treat their water using any method (Figure 32b). Despite some households treating their water, the water sampled was contaminated with faecal coliform. The water could have been contaminated during transportation or storage. However, observation from the results show that the water sources were also contaminated hence households were at risk at contracting waterborne diseases. Its also important to note here that in households that stated they boil their water, presence of faecal coliform was detected in their stored water. In one study, the researchers found that boiled water was more frequently contaminated when served in a drinking cup compared to water taken directly from a drinking water canister containing boiled water (Jensen et al., 2002).

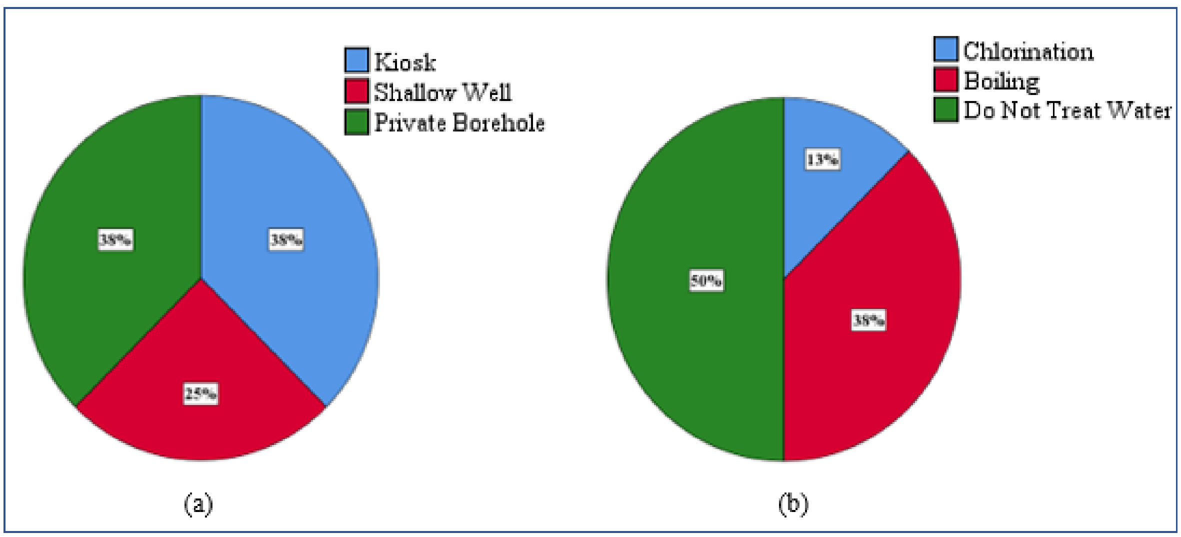


Figure 32: (a) Water sources from which water is collected from in Kanyama, Lusaka, Zambia (b)Treatment methods carried out in households of Kanyama, Lusaka, Zambia

Most of the participating households (88%) stated that they store their water in both buckets and jerrycans and 12% of the other households store their waster in jerrycans only (Figure 33a). During the household visits, it was observed that some households did not cover their buckets after collecting water. Therefore, this could have led to the water been contaminated with faecal coliform. From a study done by Quick et al., (1999), 31% of households that did not cover their storage containers had water contaminated with microbiological contaminants which supports the finding of this study. The study showed that 50% of the households stored water for more than 12 hours at the time of collection (Figure 33b). Meanwhile, 25% of the households stored their water between one to six hours and the remaining 25% of households stored their water between six and twelve hours. As indicated earlier, some households would not cover their buckets and if water is left to stand for several hours without covering, this exposes the water to various disease-causing pathogens.

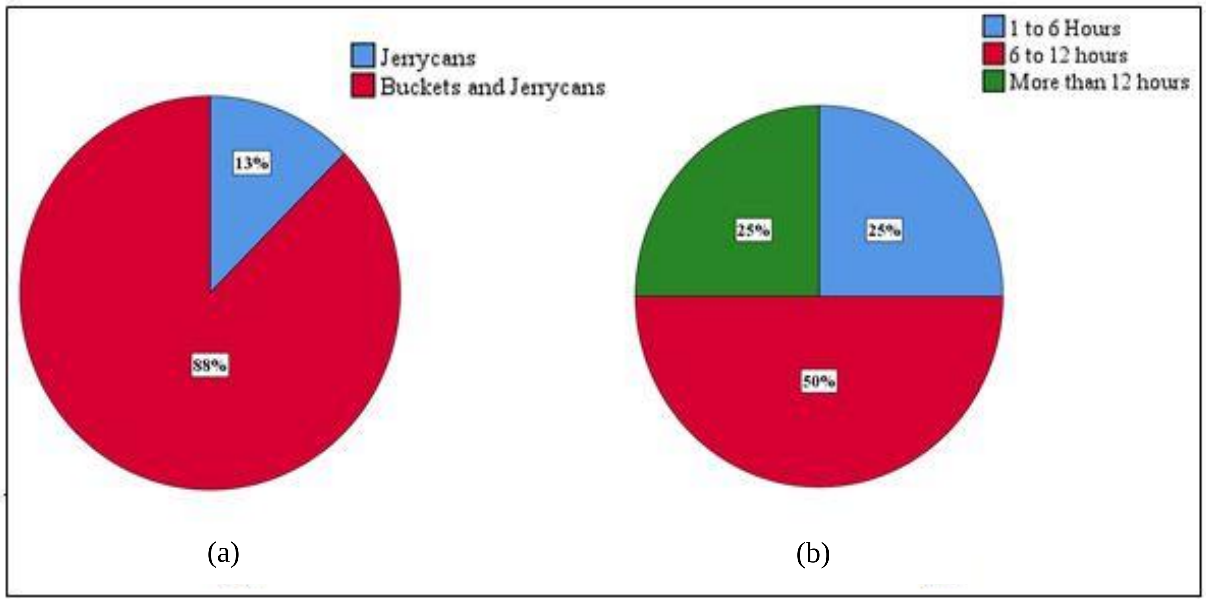


Figure 33: (a) Storage containers used in households of Kanyama, Lusaka, Zambia
(b) Duration of storage of water collected in households in Kanyama, Lusaka, Zambia

In terms of illnesses, such as diarrhoea that could have resulted due to the consumption of water, the participating households in Kanyama had varied responses. Most respondents (63%) mentioned there was no occurences of waterborne diseases in their households. This implied they've never experienced any type of waterborne illness from the water they consume. Twenty-five percent of the households stated they noticed the occurrence of waterborne illness reduced ever since they started treating their water. The remaining 13% of household mentioned the occurences of illness remained the same (Figure 34).

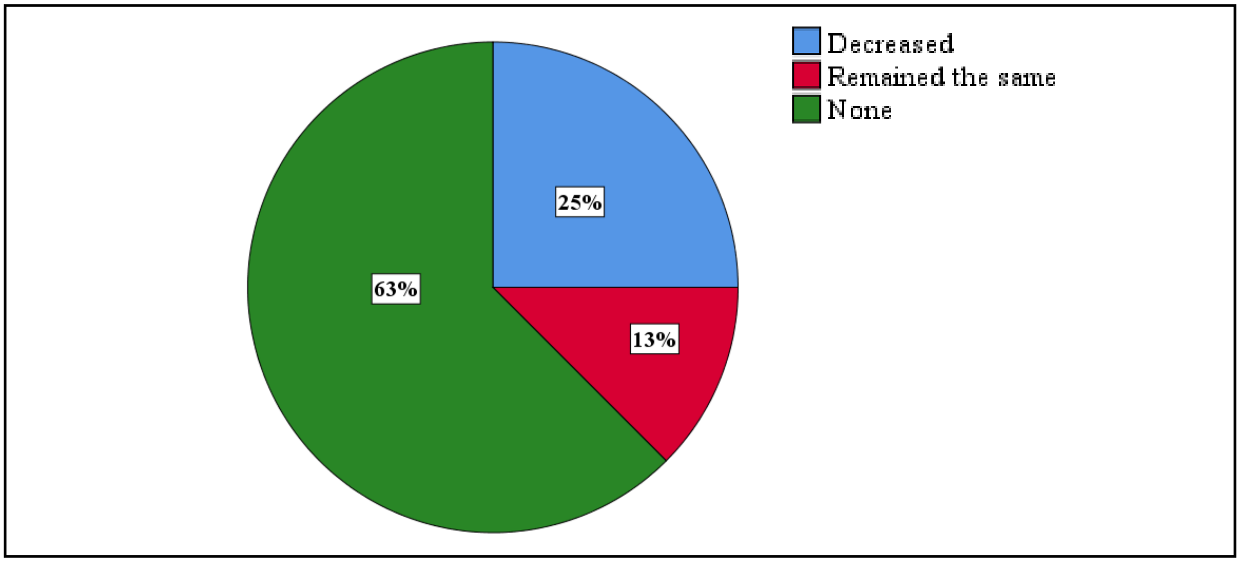


Figure 34: Occurrences of diarrhoea in households of Kanyama, Lusaka, Zambia

5.2.5 Physico-chemical and Microbiological Parameters of Household Water in Ngombe

In order to understand the variation in concentration, a transect was selected from southwest (SE) to northeast (NW) (Figure 15 above). As indicated earlier, this transect is selected following the direction of groundwater flow as reported by Bäumle and Kang'omba (2012) for easy comparison of household water and groundwater from water sources in Ngombe (Figure 16 above).

Ngombe showed variation in the water quality for some physicochemical parameters that were analysed. It was observed that there was variation of nitrate concentration among the sampled households (Figure 35). Nitrate concentration ranged from 1.20 to 2.60mg/l with a mean of 2.08mg/l. The concentration of nitrates was increasing in the water samples for households from the SE towards the NW direction. This means households located in the northern part of Ngombe had higher concentration of nitrate than households located in the south part. Fluoride concentration varied in the range of 0.26 to 0.33mg/l with a mean of 0.29mg/l while chloride concentration varied from 40mg/l to 45mg/l with a mean of 42mg/l. Other chemical parameters that were analysed such as phosphates and arsenic showed no variation and were all within the permissible WHO and ZABS standards (Figure 35).

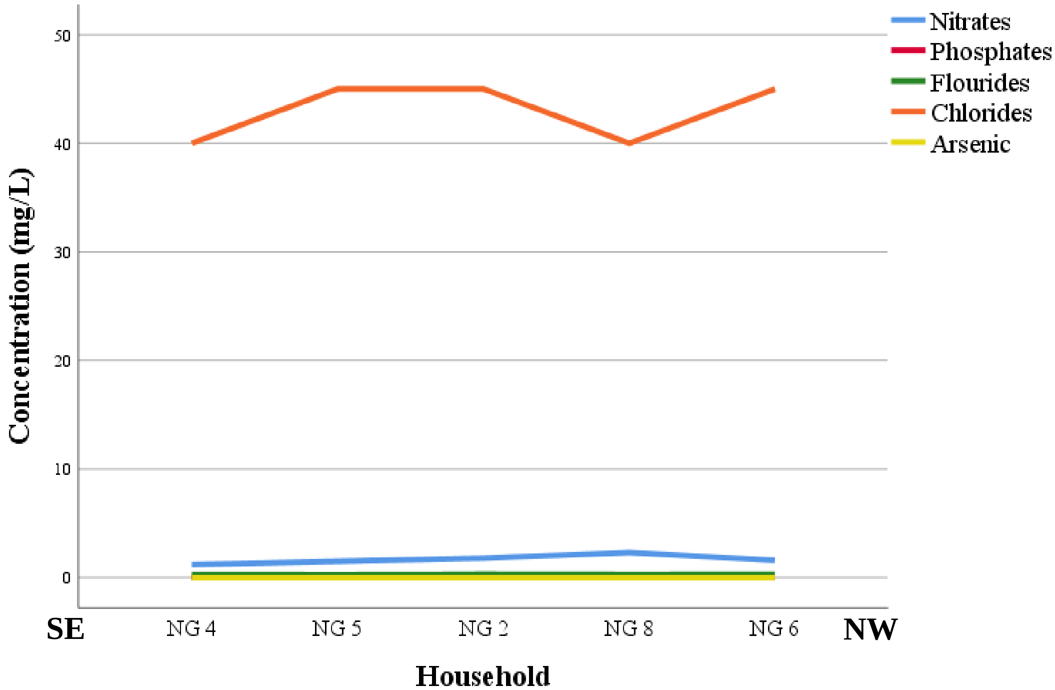
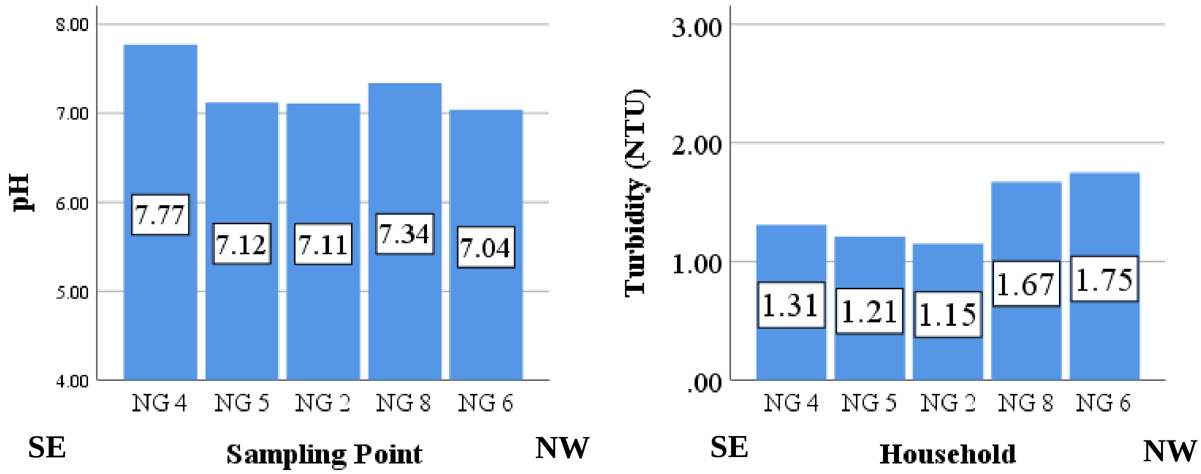


Figure 35: Concentration of nitrates, phosphates, fluorides, chlorides and arsenic along transect SE – NW passing through households (NG 4, NG 5, NG 2, NG 8, NG 6) in Ngombe, Lusaka, Zambia. SE – NW is also the given groundwater flow by Bäumle and Kang'omba, 2012

pH and turbidity variation are shown in Figure 36 (a) and Figure 36 (b), respectively. Variation was also observed for pH. Houses located in the southern part of Ngombe had lower pH values than those located in the northern part. pH was therefore decreasing from the southeast towards the northwest. This could have been caused by factor such as dissolving of sediments such as carbonate minerals in groundwater that increased its acidity (Ranjeeta, 2011). pH varied from a range of 7.11 to a range of 7.77 with a mean of 7.28. Turbidity values from SE to NW direction were decreasing then slightly increased. Turbidity ranged from 1.15 to 1.75 NTU with a mean of 1.42 NTU.



(a) (b)

Figure 36: (a) pH in selected households sampled in Ngombe, Lusaka, Zambia (b) Turbidity concentration in Nephelometric Units (NTU) in all samples from eight households sampled in Ngombe, Lusaka, Zambia. SE – NW is also the given groundwater flow by Bäumle and Kang'omba, 2012

5.2.6 Microbiological Status of Water in Ngombe

Only one water sample from the households was contaminated with faecal coliform bacteria in Ngombe (Figure 37). The other households had stored water free from faecal coliform. Therefore, there was no variation for microbiological contamination in the sampled household water. The household with contaminated water could have been due to contamination during transportation or storage. Inadequate cleanliness of storage and transport-containers has been described as a key source of drinking water contamination in many settings worldwide (Trevett et al, 2005). Therefore, as literature indicates, one possible cause for the contamination of previously safe water may be the presence of biofilms on the inner surfaces of containers, which emphasizes the need for repeated cleaning of the containers (Ahmed et. al, 1998).

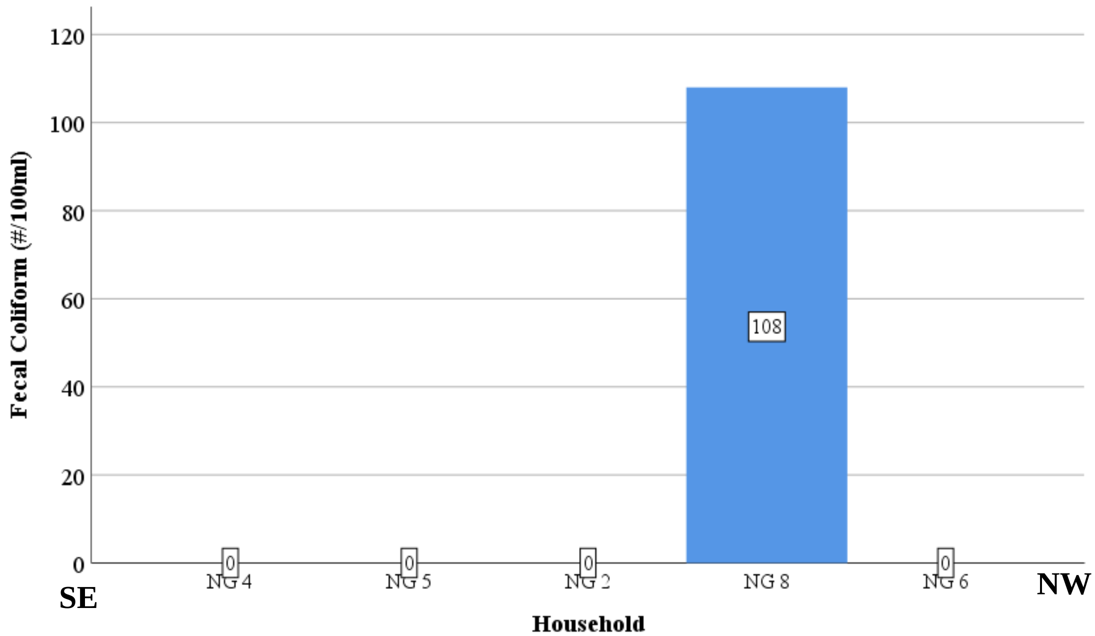


Figure 37: Faecal coliform concentration in CFU/100 ml in all samples from eight households sampled in Ngombe, Lusaka, Zambia. SE – NW is also the given groundwater flow by Bäumle and Kang'omba, 2012

Despite several variations, chemical parameters analysed for all water sources in Ngombe were within the recommended range for drinking water (Figure 38). Nitrate varied in the range of 0.50 to 2.20mg/l with a mean of 1.65mg/l. Chloride concentration range from 35 to 45 mg/l with a mean of 41.25mg/l and fluoride concentration ranged from 0.29 to 0.36mg/l with a mean of 0.32mg/l. The variation from the results can be compared to the flow of groundwater from the SE to the NW direction for the Ngombe area of study.

No variation was observed for phosphate and arsenic concentration. All analysed samples had phosphate concentration of less than 0.01mg/l and an arsenic concentration of less than 0.002mg/l. Therefore, this could have been as a result of limited existence of these elements in groundwater of this area.

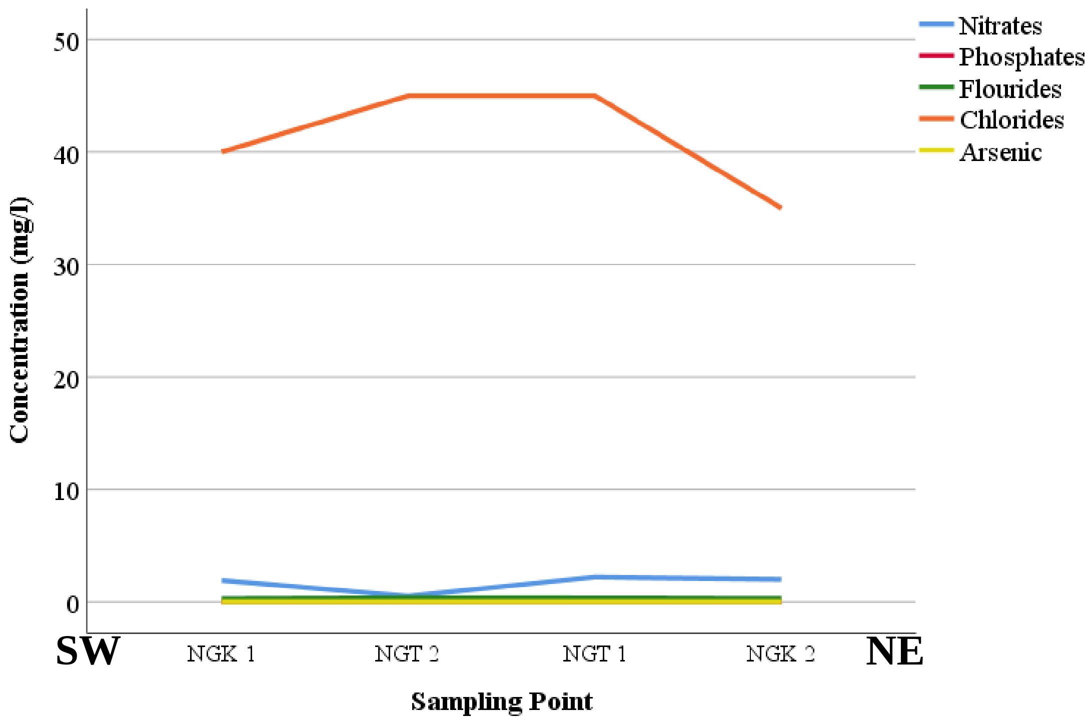
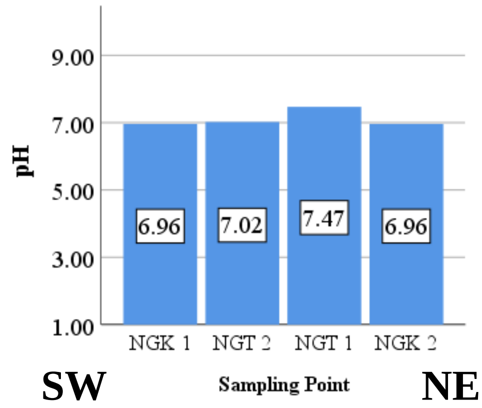


Figure 38: Concentration of nitrates, phosphates, fluorides, chlorides and arsenic along transect SW – NE passing through water sources (NGK 1 - kiosk, NGT 2 – private borehole, NGT 1 – private borehole and NG K 2) in Ngombe, Lusaka, Zambia. SE – NW is also the given groundwater flow by Bäumle and Kang'omba, 2012

Turbidity and pH showed variations in the analysed water samples (Figures 39a and b). pH ranged from 6.96 to 7.47 with a mean of 7.10. pH was observed to increase from the SW towards the NE direction. Turbidity ranged from 2.12 to 4.13 NTU with a mean of 2.85 NTU. Turbidity was increasing from the SW towards the NE direction and this can be explained by an increase in particulates in water as it flows from the SW to the NE direction. As water flows from the source, it tends to carry with it more suspended particles hence the increase in turbidity levels in the NE direction (Lemmo et al., 1983).



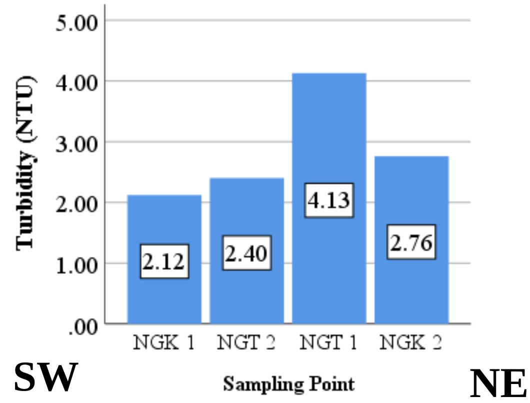


Figure 39: (a) pH in selected water sources sampled in Ngombe, Lusaka, Zambia (b) Turbidity concentration in Nephelometric Units (NTU) in all samples from eight households sampled in Ngombe, Lusaka, Zambia. SW – NE is also the given groundwater flow by Bäumle and Kang'omba, 2012

Of the seven samples collected from the water sources, none had values of FC concentration above the permissible WHO and ZABS limit of nil CFU/100 ml. None of the water samples collected from these sources were contaminated with faecal coliform (Figure 40).

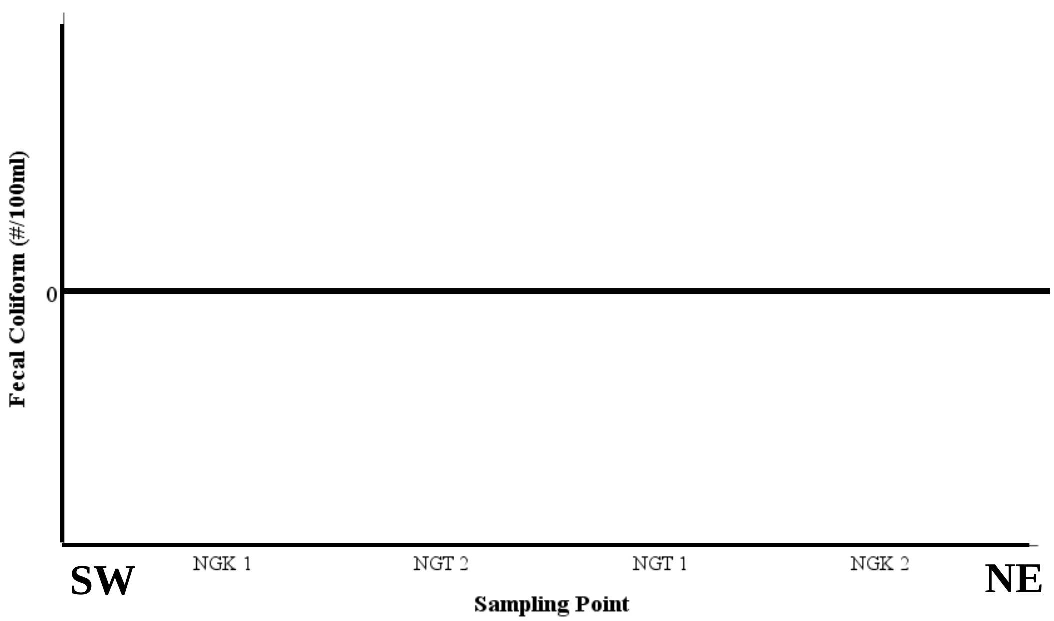


Figure 40: Faecal coliform concentration in CFU/100 ml in all samples from eight households sampled in Ngombe, Lusaka, Zambia. SW – NE is also the given groundwater flow by Bäumle and Kang'omba, 2012

5.2.7 Household Survey of Water Use in Ngombe

The result show that 63% of the participating households in Ngombe collect their water from kiosks while 38% of the other households collect their water from private boreholes (Figure 41a). According to Reaver et. al (2016-in prep.), 11,000 people are serviced by 67 kiosks stationed throughout Ngombe. In addition, each kiosk services about 167 people in the area. The high percentage of respondents that use kiosks implies that there are more people in Ngombe that use kiosks compared to those that use other sources such as private boreholes.

From the questionnaire results, 63% of the households did not treat their water. Ngombe was the only community having a household that treats water using SODIS. As indicated earlier, results from microbiological analysis showed that water in Ngombe was mostly free from contamination, therefore, a majority of the respondents stated they did not treat their water at household level. From the survey, all the respondents did mention they cover their storage containers to prevent any contamination during transport from the source or in the house. The most common method of treating water were boiling (13%), chlorination (13%) and SODIS (13%) (Figure 41b). Although water supplied by the Water Trust is usually safe, 39% of the respondents mentioned they often treat their water.

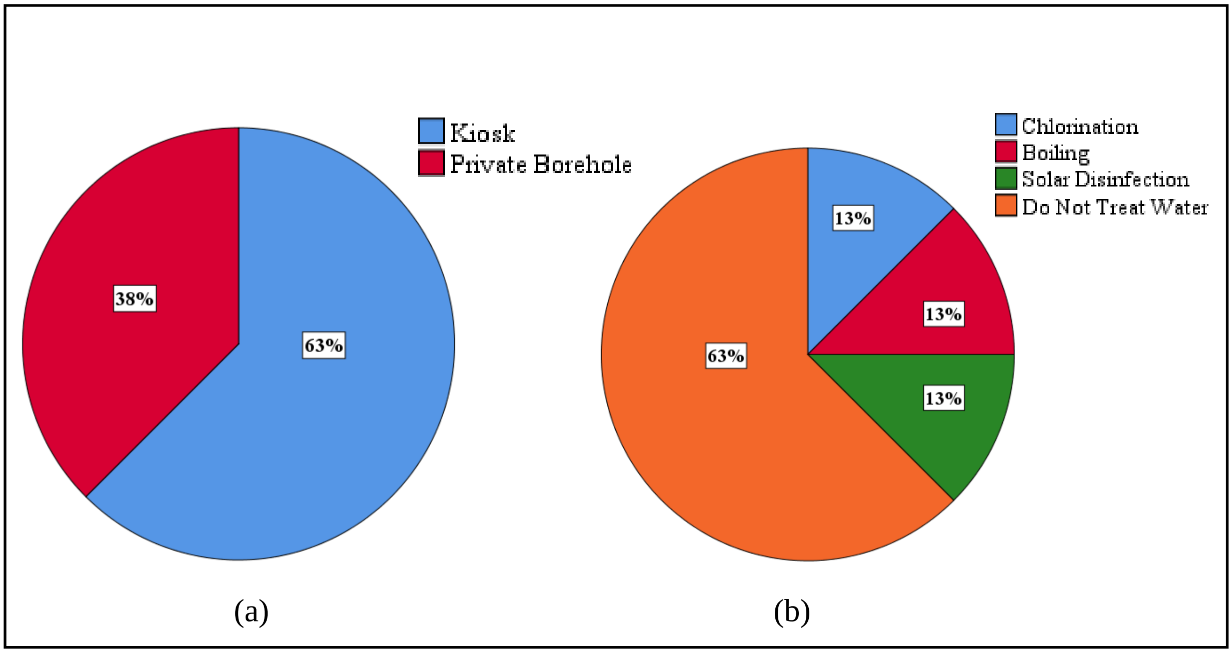


Figure 41: (a) Water sources from which water is collected from in Ngombe, Lusaka, Zambia
(b) Water treatment methods carried out in Ngombe, Lusaka, Zambia

Sixty-three per cent of the participating households in Ngombe stated they store their water in both buckets and jerrycans while 25% and 13% of the other households stated they store their water in buckets and jerrycans respectively (Figure 42a). From the survey, it can be observed that all the respondents stored their water mostly in 10l and 20l containers. All participating households stated they cover their storage containers to avoid contamination. Its important to note that many households stated they ensure that their containers are thoroughly cleaned before water collection and storage.

The study revealed that 50% of the household water was stored between one to six hours at the time of collection. Meanwhile, 35% of the households stored their water between six to twelve hours and the remaining 13% of households stored their water for more than twelve hours (Figure 42b). Since more of the participating households stored their water one to six hours prior to sampling, this could have resulted in the low levels of faecal coliform. Risk of contamination is usually higher if water is stored for longer hours in the house.

Many researchers have observed that storing water in the household leads to a deterioration of water quality because of recontamination in the home. Even if families have a source of clean drinking water, water may become contaminated in the home because of poor hygiene and water-handling practices (Lindskog and Lindskog 1988). Factors known to affect recontamination of water in the home include the size of the storage vessel mouth (Mintz et al. 1995), transfer of water between containers from collection to storage, hand-to-water contact and dipping of utensils (Hammad and Dirar 1982; Trevett et al. 2005), and bacterial regrowth within the storage container

(Momba and Kaleni 2002). However, most of the participating households in Ngombe mentioned they consume water not more than 24 hours after collection.

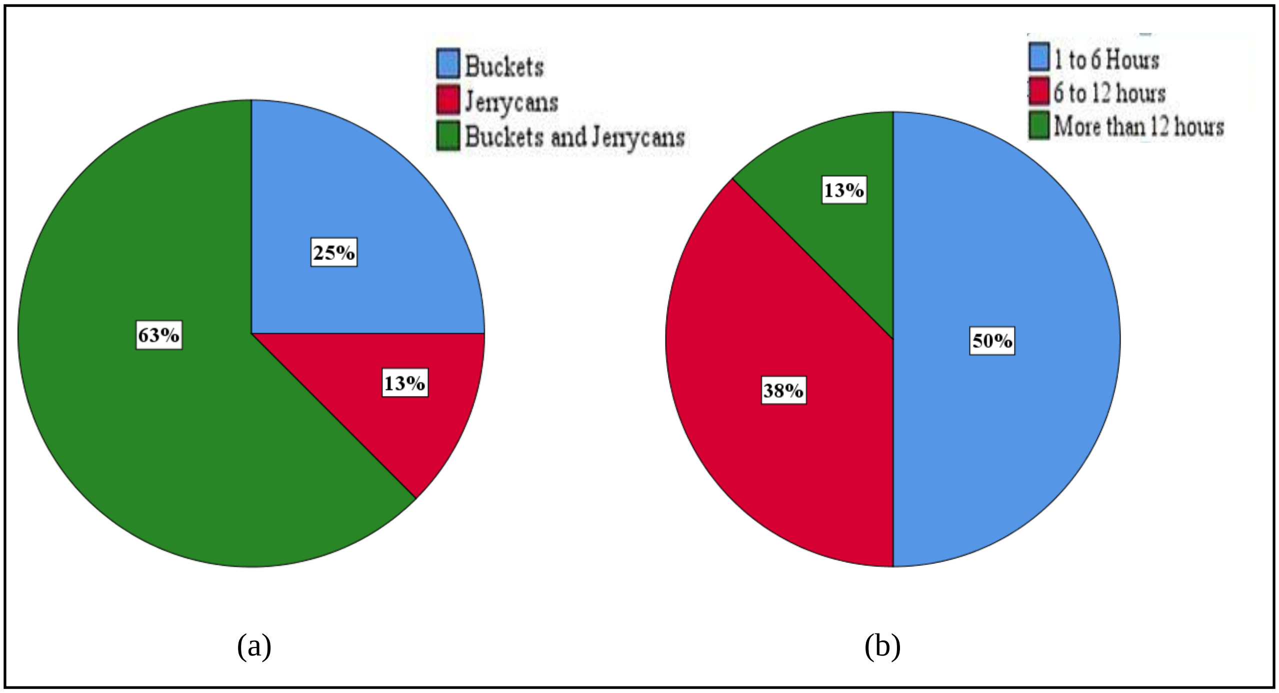


Figure 42: (a) Storage containers used in households of Ngombe, Lusaka, Zambia (b) Duration of storage of water collected in households in Ngombe, Lusaka, Zambia

The study also revealed that 38% of the households that treat their water observed a reduction in diarrhoeal incidences in their homes. Meanwhile, 50% of the households stated they did not notice any changes in diarrhoea incidences in their homes and 13% of the households stated the occurrence of diarrhoeal incidences remained the same (Figure 43). During the survey, other respondents further mentioned incidences of diarrhoea have never occurred in their households. This was a result of safe water provided by Water Trust and the safe storage methods they practiced. They mentioned they mostly stored their water in covered containers and ensured all containers are stored safely to avoid contamination by contact.

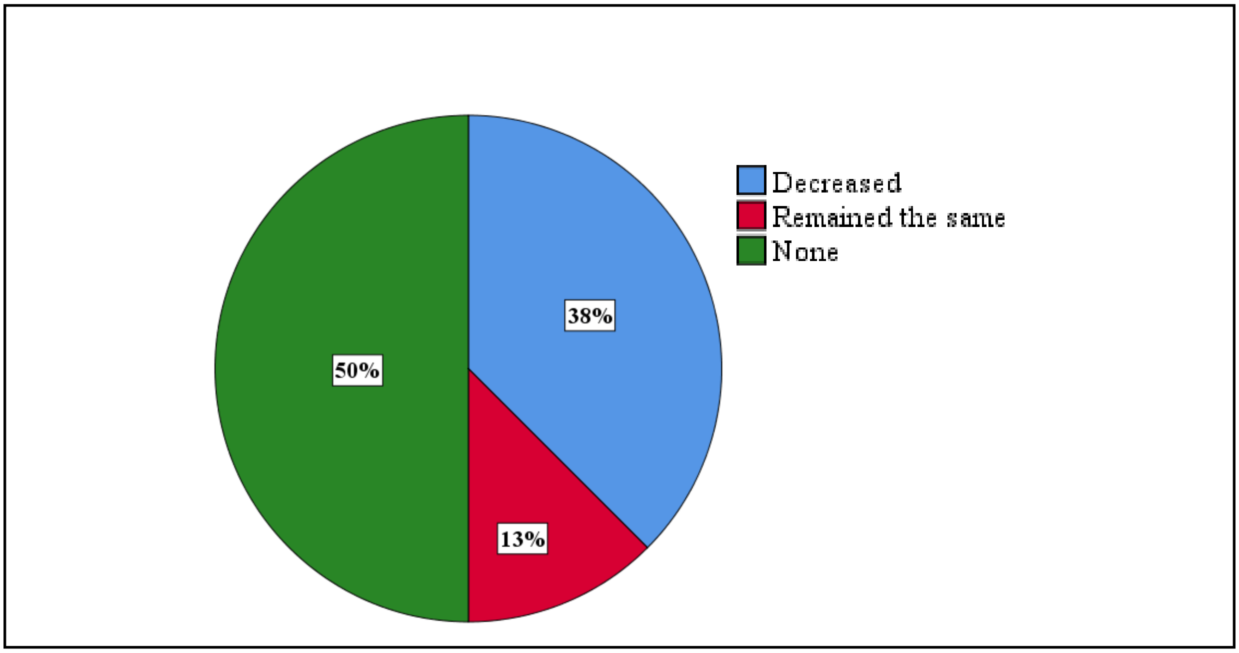


Figure 43: Occurrences of diarrhoea in households of Ngombe, Lusaka, Zambia

5.3 Performance of HWTS in Improving the Quality of Water and Reduction of Diarrhoeal Disease

The study revealed that from the 26 participating households, only 10 (38%) treated their water using either boiling (19%), chlorination (15%) or SODIS (4%) methods. Sixteen (62%) participating households stated they did not treat their water using any methods as they believed the Water Trusts disinfected the water before distribution hence were very confident their water was safe to drink. Among the 11 households that treated their water, it was observed that five of the households had water that was not contaminated with faecal coliform bacteria, i.e. the water was not above the ZABS and WHO permissible limit of nil CFU/100ml. The water samples that were collected from the other six households were contaminated with faecal coliform, and this could have been due to contamination during storage. As mentioned earlier, the stored water can easily be contaminated with microbiological pathogens, especially if stored for longer hours. As indicated earlier, contamination can also originate from the type of storage container used or direct contact of the water by a user having contaminated hands (Schmidt and Cairncross, 2009). Another factor that could have led to the contamination of water is improper handling of sample bottles during sampling.

Sobsey (2002) showed the importance of treating water using different HWTS technologies and the effectiveness of these practices on water quality. Several authors have also investigated the use of different HWTS and their impact on health and a majority of the HWTS technologies investigated have been proven to be effective in treating contaminated water and improving health (Clasen et al., 2007). Therefore, this shows the effectiveness of practicing HWTS to reduce the impact of waterborne diseases.

From the study, 73% of the households that treat their water mentioned that treating water in their homes has resulted in a reduction of diarrhoeal illnesses that could have resulted from consumption of contaminated water. Since 58% of the participating households stated they did not treat their water, they were not questioned further on the occurrence of diarrhoeal illnesses in their homes. The question regarding the treatment of water was directly linked to diarrhoeal diseases so as to assess the effectiveness of using HWTS on preventing waterborne diseases. The success of HWTS interventions in preventing disease is a function of many factors including efficacy of the practiced method at removing or inactivating pathogens of concern, rates of consistent and correct use, and the presence of other pathogen exposure routes (Enger et al., 2013, Brown and Clasen, 2012).

5.4 Zambian National Water Policy 2010 and the Zambian Bureau of Standards Policy Documents

Zambia's National Water Policy 2010 and the Zambian Bureau of Standards Policy documents were reviewed, and it was observed that none of the documents mentions HWTS. The Ministry of Health Policy 2012 also does not mention the use of HWTS to improve the quality of water and reduce the burden of waterborne diseases in Zambia. The Seventh National Develop Plan 2017 to 2021 was also reviewed, and although it mentions the target of improving water quality, it does not specify on HWTS. In addition, the National Water and Supply Council (NWASCO), whose main role is to regulate the provision of water supply and sanitation services for efficiency and sustainability throughout the country does not have specific documents that highlight HWTS.

5.5 Challenges Towards Policy Formulation of HWTS in Zambia

The challenges to HWTS policy formulation and implementation in Zambia are many and compounded by the fact that some peri-urban areas where the need for HWTS is greatest are also the most economically impoverished. From the literature review, it was observed that very few studies had been conducted, which are directly linked to HWTS in Zambia. Most of the studies carried out were aimed at analysing the water quality from various water sources in peri-urban areas. Therefore, with inadequate research carried out on HWTS, one of the challenges to HWTS policy formulation and implementation in Zambia is limited surveying and research of HWTS been practiced in Zambian households.

Regulation and performance evaluation is another important policy formulation and implementation challenges. While the Ministry of Health already takes some action associated with the use of household water treatment during waterborne disease outbreaks, it does not include HWTS in any of its policies and strategies. They could use this to input HWTS in their policies and strategies to compel citizens and households to consistently treat the drinking water using various HWTS methods. The Ministry could move even further by making into a law.

Finally, limited coordination among ministries and awareness within the Government of the role of HWTS is an important challenge in policy formulation and implementation. While some countries have found various mechanisms to improve coordination such as an inter-ministerial task force (Kenya) and formal signatures of a memorandum of understandings among relevant ministries (Tanzania), there is no mechanism put in place to improve ministerial coordination with regards to HWTS among ministries in Zambia. Zambia could learn from these mechanisms in other countries.

5.6 National Policies and strategies on HWTS from Ghana and Tanzania

In a 2011 study conducted by the WHO, several countries such as Ghana, Sudan, Ethiopia, Sudan, Tanzania and The Gambia were asked to provide details on their national policies related to HWTS. The results of the survey showed that most of the countries have policies focused on water quality and supply or disease prevention and control. Within these policies, HWTS is not necessarily mentioned, but rather the importance of safe drinking water is highlighted (WHO, 2011). Only two of the responding countries (Ghana and Tanzania) indicated that they have a national strategy for HWTS that bridges the many national water and health efforts where HWTS is included.

5.6.1 HWTS in Ghana

Ghana's National Policy (2007) was developed by Ghana's Ministry of Water Resources, Works and Housing (MWRWH, 2007). However, in analysing the policy document, it was observed that it does not include HWTS but only mentions the importance of safe water supply for domestic water use, rainwater harvesting methods for households and importance of sanitation and hygiene.

Ghana's Ministry of Local Government and Rural Development then developed the National Strategy for Household Water Treatment and Safe Storage in 2014. The goal of this strategy was to contribute to achieving improved health for all by 2025. To achieve this goal by 2025, the Ministry plans to pursue sustainable and effective promotion and adoption of HWTS as a behaviour through the use of appropriate technologies that make drinking water safe at the point of use (MLGRD, 2014).

By 2025, the government of Ghana also plans to have 100% of the population in all regions to be aware of HWTS; 90% of the entire population to have adequate knowledge about the use and benefit of HWTS in reducing WASH-related diseases; and that 75% of the entire population to consistently practice safe HWTS methods consistent with their environment and circumstances (MLGRD, 2014). Since the formulation of its strategic plan, information regarding the progress on implementation has not been provided in any report.

5.6.2 HWTS in Tanzania

Tanzania's Water Policy (2002) was developed by the Government of Tanzania (MWLD, 2002). In analysing the policy document, it was observed that it does not necessarily include HWTS but mentions the importance of safe water sources near households of poor communities for the reduction of waterborne diseases.

The Government of Tanzania developed a clear strategy on HWTS entitled "Comprehensive Country Plan for Scaling Up Household Water Treatment and Safe Storage 2011-2016" (MoH, 2012). Similar to the Ghanaian Strategy, this document recognised the need for HWTS in Tanzania and set clear, attainable goals to achieve. Specifically, Tanzania aimed "to increase by 20% the usage of acceptable [HWTS] methods by 2016" and in doing so, aimed "to empower people to manage their drinking water in households to prevent and control diarrhoea and other waterborne diseases" (MoH, 2012).

Tanzania's efforts to achieve this include introducing incentives for HWTS products, integrating HWTS into existing interventions such as HIV/AIDS home care and school health programmes, conducting a national campaign advocating for HWTS and establishing performance evaluations for HWTS products (MoH, 2012). However, the Government of Tanzania has not published any report on the implementation of the strategy.

5.6.7 Requirements for certification of HWTS technologies in Zambia

In Zambia, the Zambian Bureau of Standards (ZABS) is responsible for standard formulation, quality control and certification of products. However, ZABS does not address HWTS in any of its documents (MWED, 2010; ZABS, 2010; MoH; 2012; ZABS, 2017). Therefore, this presents an opportunity for the bureau to consider HWTS in this certification and quality control analysis.

In order for HWTS practitioners to have their HWTS products certified by ZABS, the list below outlines the procedures that must be followed (ZABS, 2017):

i. Manufacturer applies to ZABS for the license to apply the mark on their product;
ii. ZABS begins a series of systematic inspections of the manufacturers' factory and laboratory;
iii. Samples are randomly selected for testing;
iv. Submission of audit report to client;
v. Closure of corrective actions (if any);
vi. Certification decision by independent committee;
vii. Issuance of certificate of conformity;
viii. Surveillance audit;
ix. Market surveillance; and
x. Re-certification (after 1 year).

All products certified by ZABS must have a ZABS Product Certification Mark stamped on the product. The Product Certification Mark is shown in Figure 44.

Figure 44: ZABS Product Certification Mark, Zambia

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 General Remarks

This chapter concludes the findings of the study on the use of HWTS in households of Chaisa, Kanyama and Ngombe. A conclusion on the research and some recommendations on the scaling-up of HWTS in Zambia are also outlined. A summary of the results are presented in Appendix 6.

6.2 Conclusion

The study revealed that from the 26 participating households in Chaisa, Kanyama and Ngombe, only 10 (38%) households treated their water using either boiling, chlorination or SODIS (Solar Disinfection) methods. Sixteen (62%) participating households stated they did not treat their water using any methods. Sixteen of the water sampled in all households showed the presence of faecal coliform, which is an indicator of microbiological contamination.

The study revealed that 73% of the 11 households that treat their water observed a reduction of diarrhoeal illnesses. The study also revealed that 50% of the households obtained their water from private boreholes, while 42% and 8% of the households collected their water from kiosks and shallow hand-dug wells respectively. Seventy-three per cent of the households stated they store their water in buckets and jerrycans, 12% stored their water in buckets while 4% of households stored water in drums.

The Zambia National Water Policy 2010 and the Zambian Bureau of Standards (ZABS) Policy documents do not mention HWTS. The Ministry of Health Policy 2012 also does not mention the use of HWTS to improve the quality of water and reduce the burden of waterborne diseases in Zambia.

There are various challenges associated with HWTS policy formulation and implementation in Zambia. The most important challenge observed was the monitoring of use and impact of HWTS technologies. Regulation and performance evaluations were important policy formulation and implementation challenges that were observed.

There are several countries in Africa and other continents that have developed policies regarding HWTS. As indicated earlier, Ghana and Tanzania have both strategy on HWTS. Ghana enacted the National Strategies for Household Water Treatment and Safe Storage, and that Zambia can learn from the two countries.

In terms of certification of HWTS, the Zambia Bureau of Standards (ZABS) is responsible for the certification of all HWTS products. However, ZABS does not have a coherent certification policy for HWTS.

6.3 Recommendations

The recommendations are as follows:

i. The local authorities, Ministry of Water Development, Sanitation and Environmental Protection, Ministry of Health and Lusaka Water Supply and Sanitation Company should enhance and ensure that water quality monitoring activities are routinely done in peri-urban areas of Lusaka. The monitoring of water quality must not only be done at the sources but must also at the point of use in households;

ii. The local authorities, Ministry of Health and Lusaka Water Supply and Sanitation Company, should ensure that chlorination of boreholes in peri-urban areas of Lusaka district is enhanced so as to control microbiological pollution in the water to be supplied to residents in the areas;

iii. The Ministry of Water Development, Sanitation and Environmental Protection, the National Water Supply and Sanitation Council (NWASCO) and the Ministry of Health must include HWTS in their strategic plans and National Policy documents to encourage residents in peri-urban areas to use HWTS. This will also encourage stakeholders to manufacture and supply various HWTS technologies, to distribute their products in communities affected by waterborne disease outbreaks and will also help the attainment of Sustainable Development Goal 6 (clean water and sanitation);

iv. The Government of Zambia should consider policy aspects during the review and development of other national health, water, sanitation and hygiene policies. In addition, the Government of Zambia must support the formulation and implementation of national HWTS policies and programmes by developing regional HWTS integration workshops by the Ministry of Health or the Ministry of Water Development, Sanitation and Environmental Protection;

v. In Zambia, public health funding is limited and combining more efficient use of public funds, through integration, with other financings may alleviate this challenge. In many situations willingness to pay for HWTS is less than the cost of the technology and thus partial subsidies, through the use of vouchers redeemed at local businesses or sales through local health workers, may increase affordability while still creating a revenue chain;

vi. Zambian Government must integrate HWTS into key public health policies as this can be an important way to achieve greater health gains. Integration can be supported by a variety of mechanisms including recognising HWTS as an essential medicine which will enable HWTS to more easily reach health care centres, including HWTS as a possible intervention in funding grants for disease prevention and control and encouraging partnering of health officials with those in water and community development. The Government of Zambia must facilitate the integration of HWTS into disease prevention and control efforts. This can be done by focusing on cholera prevention and control, HIV/AIDS prevention and care, nutrition and maternal and child health; and

vii. The Government of Zambia must develop disseminating tools on HWTS that will be focused on monitoring and evaluation of HWT microbial performance.

viii. Research in HWTS by various academic and research institutes must be conducted so as to inform decision-makers on the importance of HWTS in waterborne disease prevention.

ix. Government must establish a coordination mechanism if HWTS is to be included in new policies and strategies as learned from Ghana and Tanzania.

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APPENDICES

Types of treatment technologies and chemicals used by households in Zambia

(a) Membrane filters (left and right) used to purify water

(b) Water purifier that uses UV to treat water

(c) Bottled chlorine commonly found in households of different communities in Lusaka, Zambia

(d) Water purifier that uses activated carbon, sand and rocks to purify contaminated water

Appendix 2: Questionnaire for household survey of residents of Chaisa, Kanyama and Ngombe, Lusaka, Zambia

Date of Visit:	Time of Interview:
Community	

A. Current Scenario

HOUSEHOLD	1	2	3	4	≥5
How many people live in this house?					
# of children under 5 Yrs.					

1. Where do you get water for filtering?

Tap		
Kiosk		
Shallow Well		
Other (specify)		

2. Who collects the water for your family?

Girl/Age	
Boy/Age	
Female/Adult	
Male/Adult	

3. How many containers do you have for water collection and storage?

Collection

Storage

4. How long does it take to get water?

Time to go, get water and return (# minutes for each trip):

B. Household Practices

1. Do you treat water after collecting?

2. Which method do you use to treat water?

3. What are all the purposes you use treated water?

Drinking	
Food preparation	
Washing Hands	
Bathing	
Other (specify)	

4. Do family members drink only treated water? Y/N

5. Does the treatment method produce enough clean water for the entire household?

Yes	
No/Why	

6. Have you had any problems with treating water?

7. Tell us about the taste of treated water – is it better, worse or the same as before you treated it?

Taste	Better	
	Worse	

	About the same	

8. What about the smell of the treated water?

Smell	Better	
	Worse	
	About the same	

9. How does the water look after treatment?

Appearance	Better	
	Worse	
	About the same	

10. Since you started treating water, do you think your family's health has improved, stayed the same, or become worse?

Better	
Worse	
About the same	

11. Do you store water in the household?

Yes	
No	

12. Do you have a safe water storage container?

Yes	
No	
If No explain	

13. What type of containers are these?

Jerry Cans	
Buckets	
Clay pot	
Other	

14. Do you ever use your safe water storage container for anything else?

No	
If Yes explain?	

C. User's Perception

15. Has the number of times family members had diarrhoea increased or decreased or stayed the same?

Increased	
Decreased	
Stayed the Same	

16. Are the containers covered?

All	
None	
Some	

Other comments or observations

Appendix 3: Selected responses from household survey in Chaisa, Kanyama and Ngombe, Lusaka, Zambia

Township: Chaisa
Date of Visit: 28th April, 2020
Time of interview: 10am – 3pm

	Number of people in HH	**Source of water***	**Collection of water done by**	**No. of containers for collection**	**No. of containers for storage**	**Duration since water collected**	**Type of storage container**	**The volume of storage containers (Litres/L)**	**Storage containers covered or uncovered**	**Treatment of water after collection (Y/N)**	**Type of treatment**
CH 1	3	Kiosk	Girl and Adult Female	4	4	1 to 6 Hours	Buckets and Jerrycans	5, 10 and 20	Covered	N	-
CH 2	4	Tap	Girl and Boy	3	4	1 to 6 Hours	Buckets and Jerrycans	2.5, 5, 10 and 20	Covered	Y	Chlorination
CH 3	4	Tap	Girl and Adult Female	4	5	More than 12 hours	Buckets	10 and 20	Covered	Y	Chlorination
CH 4	6	Tap	Girl and Adult Female	4	6	6 to 12 hours	Buckets and Jerrycans	5, 10 and 20	Covered	N	-
CH 5	6	Tap	Girl and Adult Female	3	4	More than 12 hours	Jerrycans	5 and 10	Covered	N	-
CH 6	5	Kiosk	Adult Male and Adult Female	3	3	6 to 12 hours	Buckets and Jerrycans	5, 10 and ≥20	Covered	N	-

CH 7	7	Tap	Adult Male and Adult Female	3	4	1 to 6 Hours	Small Drums	5, 10 and ≥20	Covered	Y	Boiling
CH 8	6	Kiosk	Adult Male and Adult Female	4	3	6 to 12 hours	Buckets and Jerrycans	10 and 20	Covered	N	-
CH 9	4	Tap	Girl and Adult Female	4	4	More than 12 hours	Buckets and Jerrycans	5, 10 and 20	Covered	N	-
CH 10	5	Tap	Girl and Adult Female	4	6	6 to 12 hours	Buckets and Jerrycans	2.5, 5, 10 and 20	Covered	N	-

*** Tap – Private boreho**

Township: KANYAMA Date of Visit: 5th May, 2020 Time of interview: 11 am – 3 pm											
	Number of people in HH	**Source of water***	**Collection of water done by**	**No. of containers for collection**	**No. of containers for storage**	**Duration since water collected**	**Type of storage container**	**Volume of storage containers (Litres/L)**	**Storage containers covered or uncovered**	**Treatment of water after collection (Y/N)**	**Type of treatment**
KYH 1	4	Kiosk	Adult Female	4	4	6 to 12 hours	Buckets and Jerrycans	5, 10 and 20	Covered	N	-
KYH 2	5	Kiosk	Adult Female	3	4	6 to 12 hours	Buckets and Jerrycans	10 and 20	Covered	N	-
KYH 3	4	Kiosk and Shallow well	Adult Female	4	4	More than 12 hours	Buckets and Jerrycans	10 and 20	Covered	Y	Boiling
KYH 4	6	Tap	Girl and Adult Female	3	4	1 to 6 Hours	Jerrycans	5, 10 and 20	Covered	Y	Boiling
KYH 5	4	Tap	Girl and Boy	3	4	6 to 12 hours	Buckets and Jerrycans	10 and 20	Covered	N	-
KYH 6	6	Kiosk	Adult Male and Adult Female	3	3	More than 12 hours	Buckets and Jerrycans	5, 10 and 20	Covered	Y	Boiling

KYH 7	5	Tap and Shallow well	Girl and Adult Female	4	5	6 to 12 hours	Buckets and Jerrycans	5, 10 and 20	Covered	Y	Chlorination
KYH 8	4	Tap	Adult Male and Adult Female	4	3	1 to 6 Hours	Buckets and Jerrycans	5, 10 and 20	Covered	N	-

*** Tap – Private borehole**

Community: NGOMBE Date of Visit: 4th May, 2020 Time of interview: 10 am – 2 pm											
	Number of people in HH	**Source of water***	**Collection of water done by**	**No. of containers for collection**	**No. of containers for storage**	**Duration since water collected**	**Type of storage container**	**Volume of storage Containers (Litres/L)**	**Storage containers covered or uncovered**	**Treatment of water after collection (Y/N)**	**Type of treatment**
NG 1	5	Kiosk	Adult Female	3	3	1 to 6 Hours	Buckets	10 and 20	Covered	N	-
NG 2	5	Kiosk	Adult Female	2	4	More than 12 hours	Bucket and Jerry cans	20	Covered	N	-
NG 3	6	Tap	Girl and Boy	3	4	1 to 6 Hours	Buckets, jerrycan and drum	10, 20 & >20	Covered	N	-
NG 4	4	Kiosk	Girl and Adult Female	3	4	6 to 12 hours	Jerrycans	20	Covered	Y	Boiling
NG 5	5	Tap	Girl and Adult Female	4	4	6 to 12 hours	Buckets and jerrycans	10 and 20	Covered	Y	SODIS
NG 6	7	Tap	Adult Male and Adult Female	2	3	1 to 6 Hours	Buckets and small jerrycans	5, 10 and 20	Covered	Y	Chlorination
NG 7	3	Kiosk	Adult Female	4	4	1 to 6 Hours	Buckets	10 and 20	Covered	N	-

NG 8	6	Kiosk	Adult Male and Adult Female	3	3	6 to 12 hours	Buckets, jerrycans	<10, 10 and 20	Covered	N	-

*** Tap – Private boreholes**

Appendix 4: Approval from LWSC Managing Director to conduct study in Chaisa, Kanyama and Ngombe, Lusaka, Zambia.

Scheme mgrs. - KWT, CHAISA & ~~[illegible]~~ NGOMBE
Kindly facilitate collection of ~~water~~ samples from identified customers. Student has been allowed to collect samples
MPU
27/4/2020

UNIVERSITY OF ZAMBIA IWRM CENTRE
c/o SCHOOL OF MINES

April 15th, 2020

LUSAKA WATER AND SEWERAGE COMPANY
MANAGING DIRECTOR'S OFFICE
RECEIVED
15 APR 2020
REFERRED TO: M-PU
PLOT No. 871/2, KATEMO ROAD,
RHODES PARK, LUSAKA.
P.O. BOX 50198, LUSAKA.

F.Y.A
Put conditions that Report be shared
JKapata.

The Managing Director,
Lusaka Water and Sewerage Company Limited,
Plot 871, Katemo Road, Rhodes Park,
P.O. Box 50198.

Dear Sir,

RE: Request for Research Study Permission in Kanyama, Ngombe and Chaisa

Mr. Claydon Mumba Kanyunge is a masters student at Pan African University Institute of Water and Energy Sciences (including Climate Change) in Algeria, an initiative of the African Union and all member states, supervised by Professor Imasiku Nyambe here in Zambia.

I would like to request for your permission to conduct a research study entitled "Integrating Household Water Treatment and Safe Storage Practices in Zambia's National Water Policy for effective regulation, evaluation and suitable water provision" to access and do sampling in Kanyama, Chaisa and Ngombe.

He is interested to conduct research on the quality of stored household water and carry out analysis on several water quality parameters for the purpose of knowing if the quality of the water stored in homes of these communities is safe to consume and meets World Health Organization and Zambia Bureau of Standard's guidelines. Therefore, we are requesting for permission to collect not more than a total of 100 household water samples from homes in these communities.

The data we will gather is only to be used on academic purposes and the samples will be handled properly to avoid any health risks on any individual and to the environment.

I hope that you are interested in our study as a way of learning and improving potable water quality conditions in the Zambian peri-urban communities and so we are open to share the results of the study with you.

Your approval to conduct this study will be greatly appreciated. For further questions, please do not hesitate to contact me.

Yours Sincerely

Prof. Imasiku. A. Nyambe
Coordinator, UNZA IWRM Centre
Local Supervisor for Student

* Claydon Mumba Kanyunge
* Tel: +260-976644943
claydonmumba@gmail.com

Appendix 5: Analysis results from water collected in Chaisa, Kanyama and Ngombe, Lusaka, Zambia

SCHOOL OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT
ENVIRONMENTAL ENGINEERING LABORATORY
P.O Box 32379, Lusaka

PHYSICAL/BACTERIOLOGICAL/CHEMICAL EXAMINATION OF WATER

Attn: Claydon Mumba **Sampled by**: Client **Sampling date**: 28.04.2020 **Report date**: 07.05.2020 **Location**: Chaisa, Lusaka

Laboratory Results

	CH 1	**CH 2**	**CH 3**	**CH 4**	**CH 5**	**CH 6**	**CH 7**	**CH 8**	**CH 9**	**CH 10**	**TS (ksk)**	**2C (ksk)**	**1B (ksk)**	**JM (pb)**	**MN (pb)**
pH	7.55	7.53	7.35	7.49	7.65	7.44	7.43	7.54	7.51	7.31	7.66	7.19	7.15	7.08	7.06
Arsenic (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Phosphates (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrates (as NO_3–N mg/l)	1.30	5.50	4.20	6.00	5.50	5.00	6.50	6.80	6.00	3.60	3.90	7.30	3.40	5.20	5.10
Turbidity (NTU)	1.75	1.43	1.35	1.20	1.92	2.21	1.35	1.05	0.81	0.96	1.44	1.51	3.40	5.20	5.10
Fluoride (mg/l)	0.34	0.21	0.41	0.20	0.28	0.35	0.42	0.31	0.49	0.52	0.38	0.42	0.21	0.11	0.37
Chlorides (mg/l)	35.0	54.0	49.0	52.0	51.0	55.0	49.0	52.0	51.0	52.0	51.0	50.0	54.0	58.0	50.0
Bacteriological results															
Feacal coliforms	0	0	TNTC	TNTC	10	TNTC	0	0	TNTC	74	65	92	TNTC	TNTC	TNTC

Tests carried out in conformity with " Standard Methods for the Examination of Water and Wastewater APHA, 1998".

NOTE- TNTC: Too numerous to count, CH: Household, Ksk: Kiosk, Pb: private borehole

Tested by: D. Mkandawire (Lab. Technician) ………
Approved by: Dr Ian Banda (Lab. Manager)……
Checked by: Joshua Liyungu (Co-ordinator) ………

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ENVIRONMENTAL ENGINEERING LABORATORY
P.O Box 32379, Lusaka

PHYSICAL/BACTERIOLOGICAL/CHEMICAL EXAMINATION OF WATER

Attn: Claydon Mumba **Sampled by**: Client **Sampling date**: 28.04.2020 **Report date**: 07.05.2020 **Location**: Kanyama, Lusaka

	KYH 1	**KYH 2**	**KYH 3**	**KYH 4**	**KYH 5**	**KYH 6**	**KYH 7**	**KYH 8**	**KYA (Mb)**	**KYB (Mb)**	**KYC (ksk)**	**KYD (pb)**	**KYE (pb)**	**KYF (sw)**	**KYG (sw)**
pH	7.34	7.42	7.40	7.50	7.19	7.34	7.09	7.06	7.06	7.14	7.22	7.19	7.45	7.23	7.21
Arsenic (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Phosphates (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrates (as NO_3 –N mg/l)	19.60	16.20	20.10	17.50	20.20	13.40	18.50	23.10	17.90	15.50	18.70	16.90	13.50	14.80	17.20
Turbidity (NTU)	4.65	3.08	5.37	3.83	2.80	1.37	1.64	1.73	4.20	3.81	2.76	2.17	1.49	2.54	1.66
Fluoride (mg/l)	0.80	0.59	0.44	0.38	0.42	0.27	0.51	0.38	0.20	0.32	0.29	0.30	0.44	0.38	0.52
Chlorides (mg/l)	150	130	160	170	170	180	170	186	169	170	175	180	185	180	210
Bacteriological results															
Feacal coliforms	90	TNTC	TNTC	102	TNTC	20	50	42	TNTC	14	74	28	28	TNTC	TNTC

Laboratory Results

Tests carried out in conformity with " Standard Methods for the Examination of water and Wastewater APHA, 1998".

NOTE- TNTC: Too numerous to count, KYH: Household, ksk: Kiosk, Pb: private borehole, Mb: Municipal borehole, SW: Shallow well
Tested by: D. Mkandawire (Lab. Technician) ……… **Approved by**: Dr. Ian Banda (Lab. Manager)……

Checked by: Joshua Liyungu (Co-ordinator) ………

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ENVIRONMENTAL ENGINEERING LABORATORY
P.O Box 32379, Lusaka

PHYSICAL/BACTERIOLOGICAL/CHEMICAL EXAMINATION OF WATER

Attn: Claydon Mumba **Sampled by**: Client **Sampling date**: 04.05.2020 **Report date**: 07.05.2020 **Location**: Ngombe, Lusaka

Laboratory Results

	NGK 1	NGK 2	NGK 3	NGT 1	NGT 3	NGT 2	NGT 4	NG 1	NG 2	NG 3	NG 4	NG 5	NG 6	NG 7	NG 8
pH	6.96	6.96	7.30	7.47	7.14	7.02	7.17	7.16	7.11	7.01	7.77	7.12	7.04	7.26	7.34
Arsenic (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Phosphates (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrates (as NO_3–N mg/l)	1.90	2.00	2.20	2.20	2.50	0.50	1.70	0.20	1.80	1.70	1.20	1.50	1.60	2.60	2.30
Turbidity (NTU)	2.12	2.76	1.46	4.13	2.09	2.40	1.02	3.40	1.15	1.23	1.31	1.21	1.75	2.05	1.67
Fluoride (mg/l)	0.29	0.30	0.22	0.34	0.28	0.36	0.30	0.26	0.31	0.33	0.29	0.27	0.30	0.31	0.29
Chlorides (mg/l)	40.0	35.0	50.0	45.0	40.0	45.0	35.0	45.0	45.0	40.0	40.0	45.0	45.0	40.0	40.0
Bacteriological results															
Feacal coliforms	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108

Tests carried out in conformity with " Standard Methods for the Examination of Water and Wastewater APHA, 1998".

NOTE- TNTC: Too numerous to count, NG: Household, NGK: Kiosk, NGT: private borehole

Tested by: D. Mkandawire (Lab. Technician) ……… **Approved by**: Dr. Ian Banda (Lab. Manager)……

Checked by: Joshua Liyungu (Co-ordinator) ………

SCHOOL OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT
ENVIRONMENTAL ENGINEERING LABORATORY
P.O Box 32379, Lusaka
PHYSICAL/BACTERIOLOGICAL/CHEMICAL EXAMINATION OF WATER

Attn	:	Claydon Mumba Lusaka
Sampled by	:	Client
Sampling date	:	14.05.2020
Report date	:	15.05.2020

Laboratory Results (Second stage of Sampling)

Tests carried out in conformity with " Standard Methods for the Examination of water and Wastewater APHA, 1998".

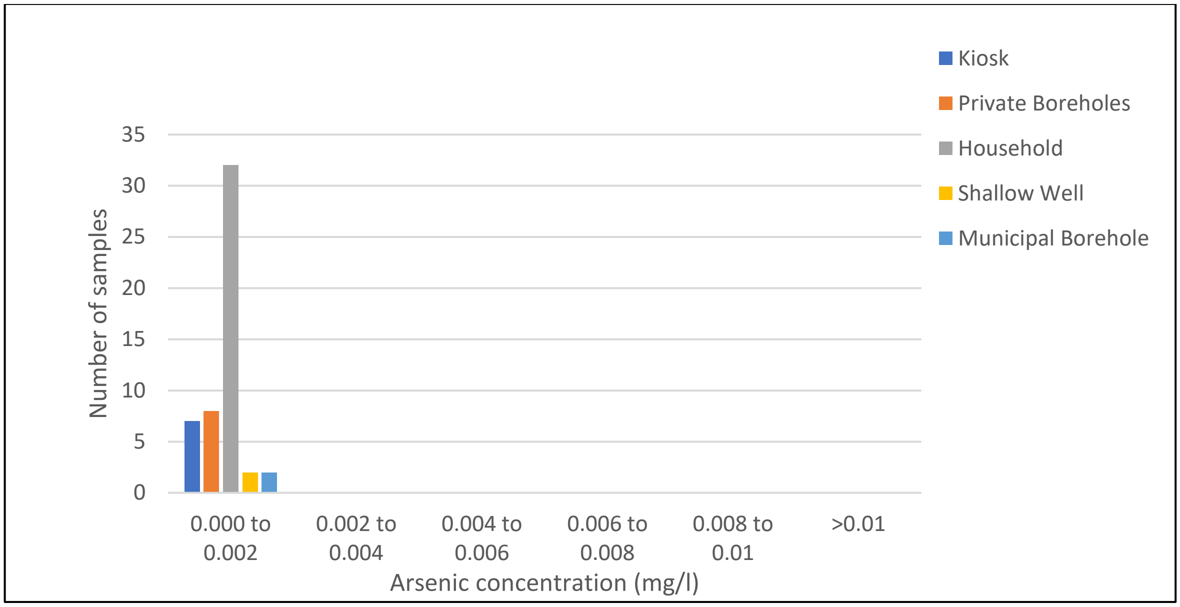
Tested by: D. Mkandawire (Lab. Technician) ……… **Approved by**: Dr. Ian Banda (Lab. Manager)……

	NG 7	**NG 8**	**KYH 5**	**KYH 8**	**CH 4**	**CH 12**
pH	7.00	7.02	7.07	7.05	7.11	7.08
Arsenic (mg/l)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Phosphates (mg/l)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrates (as NO_3 –N mg/l)	2.70	2.10	19.60	19.40	1.30	4.20
Turbidity (NTU)	2.12	2.10	0.84	0.74	1.53	0.92
Fluoride (mg/l)	0.44	0.22	0.48	0.74	0.33	0.42
Chlorides (mg/l)	40.2	39.2	166	190	49.0	52.0
Bacteriological results						
Feacal coliforms (#/100 ml)	0	0	28	0	0	0

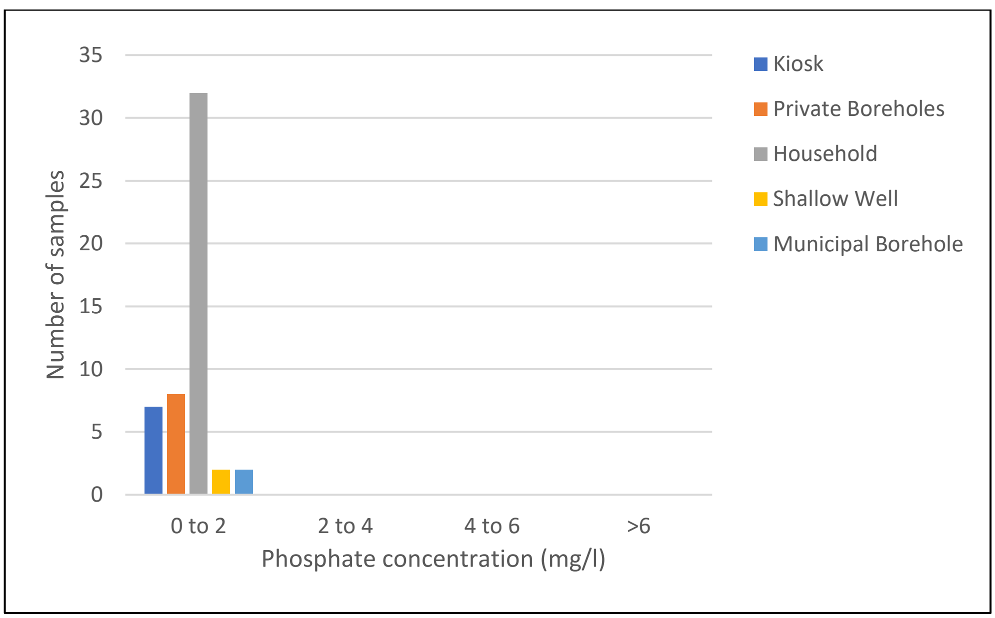
Checked by: Joshua Liyungu (Co-ordinator) ……

Appendix 6: Total samples collected for analysis of physical, chemical and microbiological parameters from various sources in Selected responses from household survey in Chaisa, Kanyama and Ngombe, Lusaka, Zambia

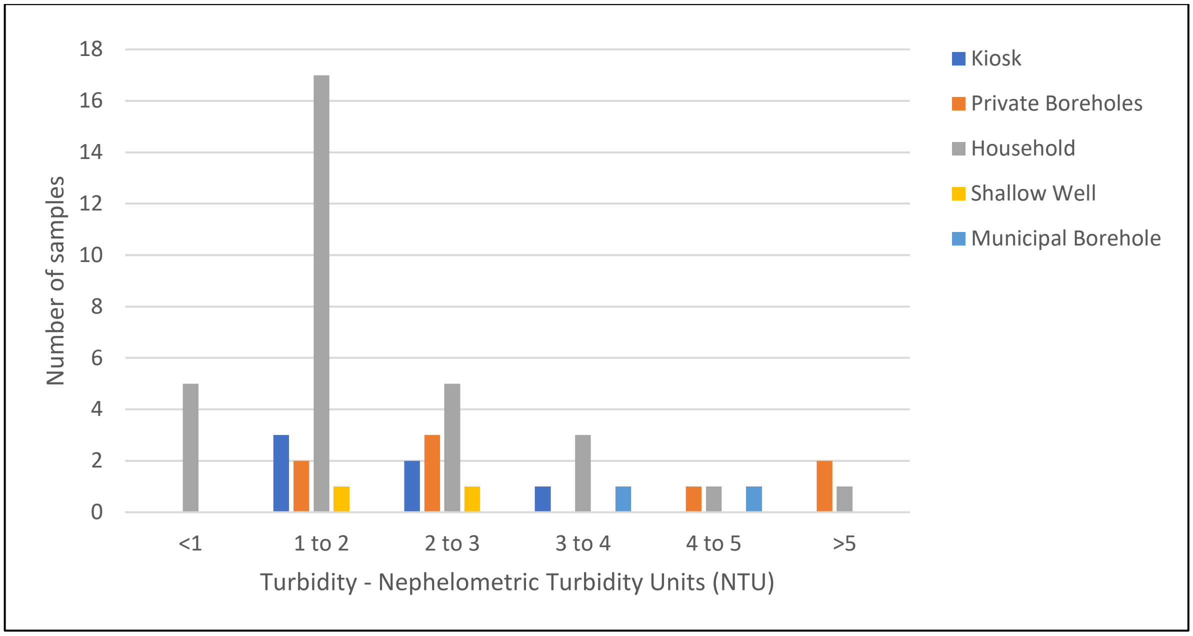
(a) Arsenic concentration



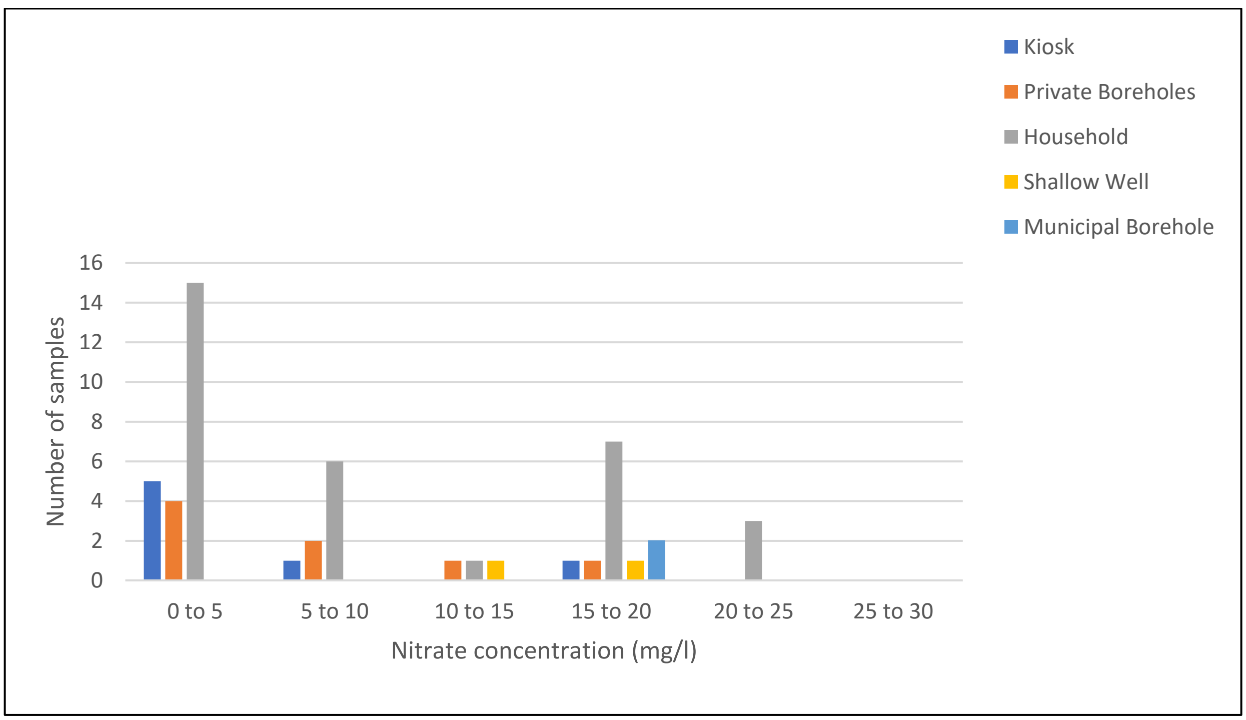
(b) Phosphate concentration



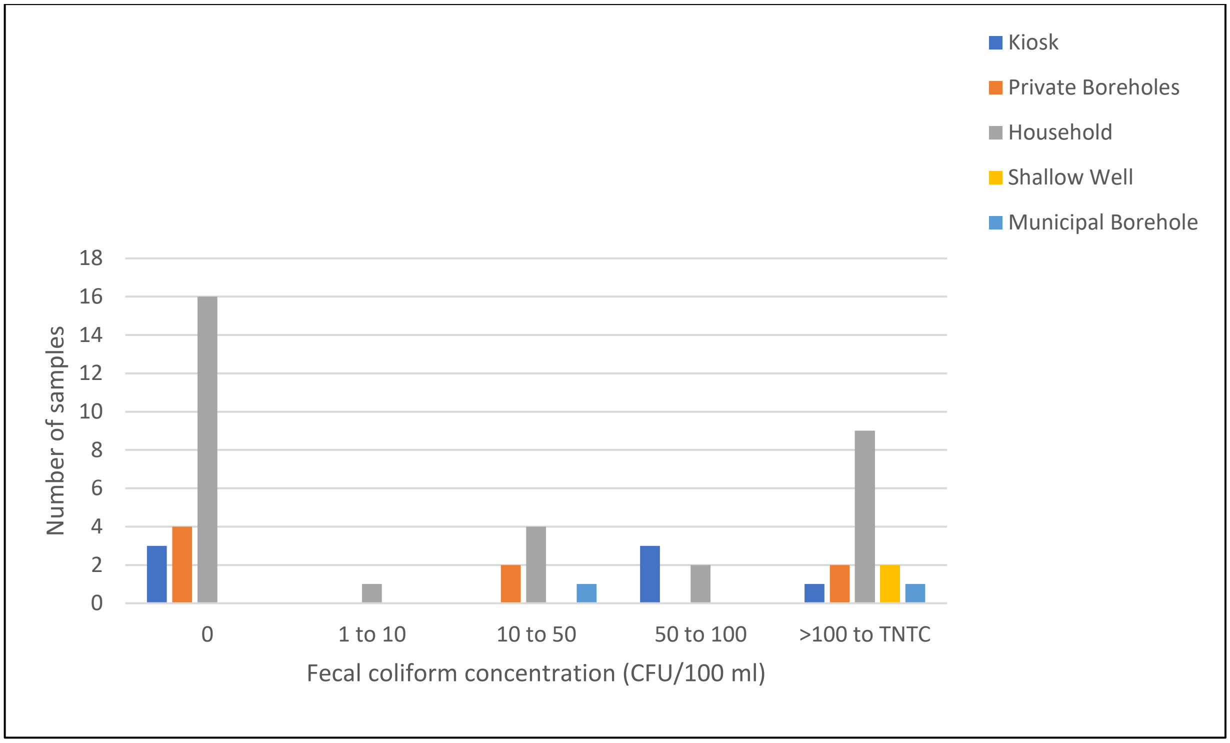
(c) Turbidity concentration



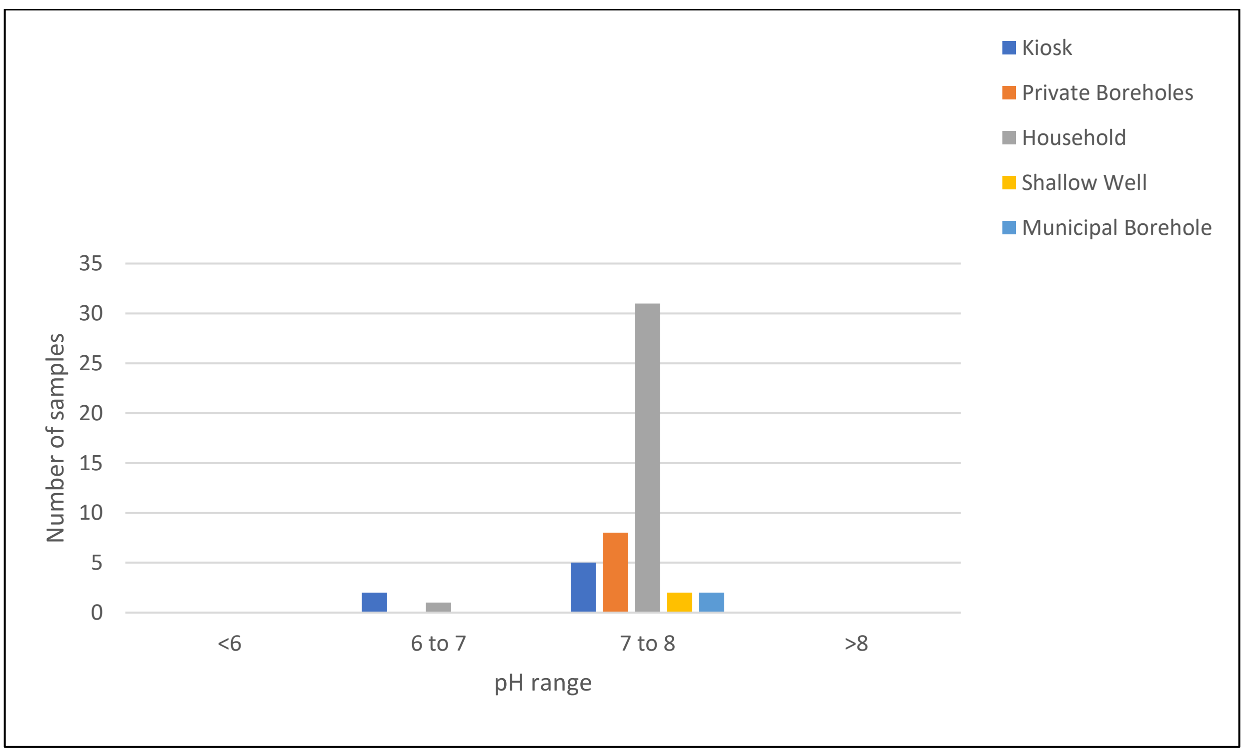
(d) Nitrate concentration



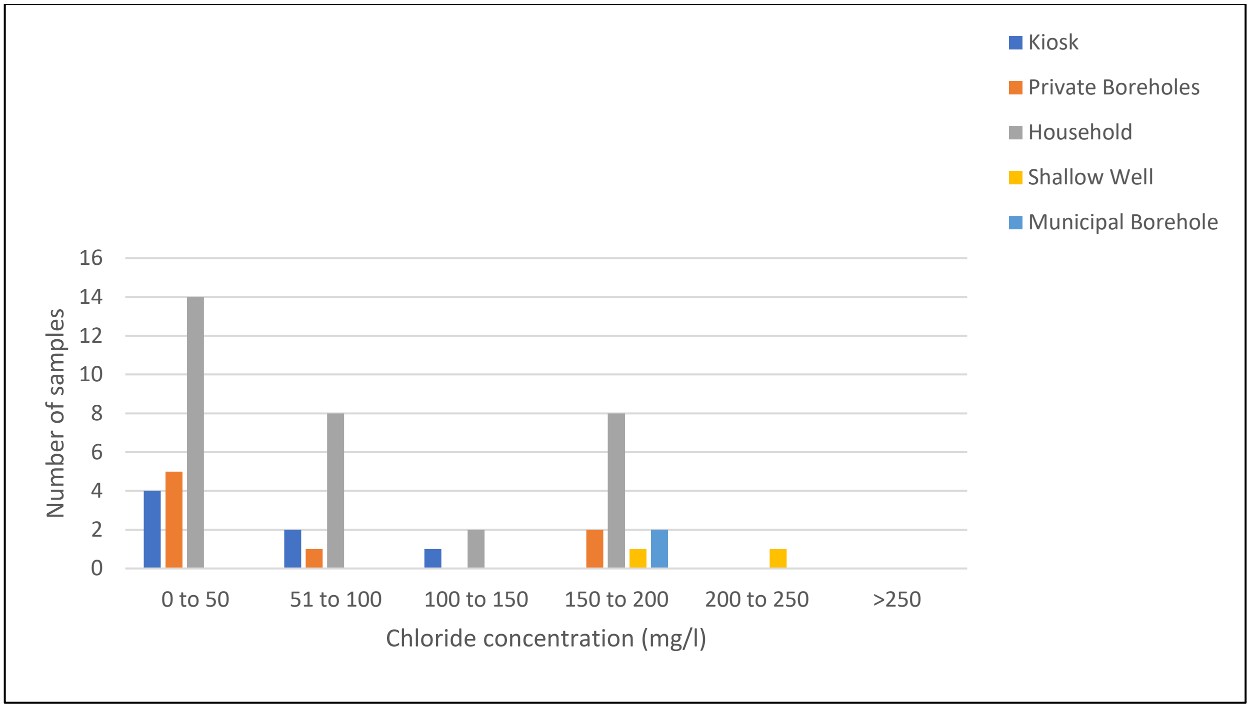
(e) Faecal coliform concentration



(f) pH concentration



(g) Chloride concentration



(h) Fluoride concentration