ASSESSMENT OF WATER QUALITY AND THE USE OF SANITARY SURVEYS IN IDENTIFYING WATER SOURCE RISK FACTORS IN KISII COUNTY

A Thesis Submitted to Graduate School in Partial Fulfillment of the Requirements for the Award of Master of Science Degree in Environmental and Occupational Health of Egerton University.

EGERTON UNIVERSITY

MARCH, 2017

DECLARATION AND RECOMENDATION

I, the undersigned, hereby declare that this is my original work, which all sources used or quoted have been acknowledged by means of complete references and has not been presented for the award of any other degree elsewhere.

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RECOMMENDATION

This thesis has been submitted with our approval as supervisors.

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DEDICATION

I dedicate my thesis work to my loving parents, Jeremiah Misati and Elidah Kwamboka for their encouragement and continual support throughout graduate school and my brothers Vincent, Amos and Eddy. This work is also dedicated to all my friends, especially Evelyn Orembo for the encouragement.

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ABSTRACT

Safe drinking water is defined by the World Health Organization (WHO) as water that meets WHO guidelines or national standards for physical, chemical and microbial characteristics. Microbial contamination of drinking water can cause diarrheal and other waterborne diseases that cause morbidity and even mortality. Sanitary surveys which are observational checklists highlighting potential risks of contamination can be used because they are easier to implement than microbiological testing. The sources of contamination of water sources identified from sanitary surveys will help local authorities, develop corrective actions to prevent contamination and highlight key aspects of water source improvements. The study focused on the use of sanitary surveys in complementing water testing programmes where fecal coliform concentrations were measured, specific risk factors influencing microbiological water quality determined and household safe water management determined. This was achieved through a descriptive cross sectional study design and a stratified random sampling to arrive at the three administrative divisions of Kisii County (Keumbu, Mosocho and Kiogoro). A sanitary survey designed according to the WHO 1997 was used in collecting data and water samples were collected and analyzed in the laboratory using membrane filtration technique. A total of 25 springs, 20 wells and 16 rainwater tanks were sampled. Wells had the highest levels of contamination by fecal coliform (median=2.4CFU/100ml) and highest concentrations of TDS and turbidity compared to other sources. The median Risk of Contamination (ROC) score for wells was the highest at 59.5%. There were no significant relationships between fecal contamination concentrations and increasing risk of contamination score. Springs were predominantly used as the main source of water with 97% of the households using them and over half (58%) of the sampled households never treated their drinking water. The research study presented an up to date evidence based dataset testing microbiological water quality against source type and potential risk factors of water sources. Basic treatment of the water at the community or household level should be promoted and creation of awareness on the possibilities of spring water being contaminated should also be carried because of the assumption that spring water is safe and does not need to be treated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

CAWST	Centre for Affordable Water and Sanitation Technology
CFU	Colony Forming Unit
DALYs	Disability Adjusted Years
FC	Fecal Coliform
GoK	Government of Kenya
GUWASCO	Gusii Water and Sanitation Company
JMP	Joint Monitoring Programme
MDGs	Millennium Development Goals
MFU	Membrane Filtration Unit
NGOs	Non-governmental Organizations
ROC	Risk of contamination
TDS	Total dissolved Solids
TNTC	Too Numerous to Count
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations Children’s Fund
WASREB	Water Services Regulatory Board
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background information

Safe and clean drinking water and sanitation was declared a human right on the 28th July 2010 by the United Nations General Assembly who voiced their deep concern over 900 million people who lacked access to safe drinking water (WHO, 2011; Tsega 2013) because of the dangers this poses to the public health. Contaminated drinking water can lead to the risk of intestinal and other infectious diseases that can cause high morbidity (Davraz and Varol, 2011). Microbial contamination with pathogens can also result in diarrhoea and other intestinal and stomach illness, and even lead to death (Gwimbi, 2011). Lui (2012) stated that apart from causing diseases, poor drinking water quality lead to costly reactive measures in addressing waterborne outbreaks such as emergency responses.

The recent WHO and UNICEF Joint Monitoring Programme (2014) update puts the figure of people still lacking access to improved sources of drinking water at 700 million, nearly half of which are in the Sub-Saharan Africa. In spite of the reduction from 900 million in 2010 for those lacking access to safe drinking water, the challenge of microbiological risk still exists more so, in sub-Saharan countries. Globally, 80% of diarrheal cases are due to unsafe water, inadequate sanitation and insufficient hygiene, which result to 1.5 million deaths each year. In developing countries, the total Disability-adjusted life years (DALYs) due to unsafe water is more than 20% (Ustun, 2008).

Programmes to monitor water quality that test for fecal indicator organisms (e.g. total coliform, fecal coliform), physico-chemical parameters, and nutrients have been rolled out by NGOs and governments to ensure the safety of drinking water. Due to the high rates of waterborne diseases in many developing countries, microbiological contamination of drinking water has been of the most significant concern (Patz *et al.*, 2005; Ferretti *et al.*, 2010).

Developing countries are challenged in acquiring the necessary equipment and consumables for conducting microbiological tests (Butterfield & Camper 2004; Mushi *et al.*, 2012). This has made water quality analysis an expensive and complicated process. However, there is an opportunity to develop a complementary strategy that is less expensive and easier to implement so that the risks of contamination of water sources can be identified for effective water management.

In Kenya significant gains have been made in water infrastructure development. According to the Joint Monitoring Programme estimates 2015, indicated 63% of Kenyans (82% in urban areas and 57% in rural areas) had access to improved drinking water sources. Due to incomplete data and different definitions being used, collecting reliable data on water and sanitation in Kenya is difficult. The only data collected which is analyzed by the JMP only assess the availability of water and sanitation infrastructure and do not assess whether water is safe to drink. Sanitary surveys also have not been done to predict water quality in assessing their suitability for complementing water testing programmes. The sanitary survey studies have mostly focused on assessing the possible sources of water contamination and no correlation has been established between water testing results and the sanitary survey results. This study therefore focused on sanitary surveys as a risk assessment tool that can be used to predict water quality and complement water-testing programmes.

1.2 The statement of the problem

In Kenya alone, 80% of all hospital cases are preventable with 50% being as a result of water related diseases. This calls for simple, less expensive ways through which microbiological water quality can be determined and appropriate action taken. Use of a multiple approach that is complementing each other will help in quick realization of safe drinking water sources.

The 2009 census report indicated that the majority of Kenyans depend on water from surface waters such as dams, rivers and ponds which are regarded as unsafe. Many water sources are not tested because of their wide geographic distribution and many other water testing constraints, which include financial constraints, technical capacity and lack of adequate equipment. The water testing is often reactive whereby it is done in cases of a disease outbreak or suspected contamination. Sanitary surveys are less expensive, simple, and do not require highly skilled personnel, and can help in addressing the shortcoming of water testing.

Kisii County is one of the most densely populated regions in Kenya with a growth rate of 3.6%. This population growth rate and associated anthropogenic activities may result in microbial contamination of water sources. Among the top five prevalent diseases (Malaria, diarrhoea, pneumonia, URTI infections and HIV/Aids) in the County, diarrheal diseases are ranked second thus the need to assess microbiological water quality and sanitation in the study area.

1.3 Objectives

1.3.1 Broad objective

To assess drinking water quality and use of sanitary surveys in identifying water source risk factors contributing to achieve universal and equitable access to safe and affordable drinking water for all.

1.3.2 Specific objectives

1. To measure the fecal coliform concentrations of drinking water sources in Kisii County.
2. To determine specific risk factors influencing microbiological water quality using sanitary surveys in the study area.
3. To determine variations in sanitary risk score of the different drinking water sources in the study area.
4. To compare sanitary survey results and conventional water testing results.
5. To determine household safe water management in Kisii County.

1.4 Research questions

1. What is the fecal coliform concentration of sources of drinking water in Kisii County?
2. What specific risk factors have an influence on the microbiological water quality of the different water sources?
3. What are the variations in sanitary risk score of the different drinking water sources in the study area?
4. What is the comparison between sanitary survey results and conventional water testing results?
5. What are the practices of household safe water management in Kisii County?

1.5 Justification

The microbiological quality of various water sources and potential risk factors were assessed during this study. The sources of contamination of water sources were identified from sanitary surveys which will help local authorities develop corrective actions to prevent contamination and highlight key aspects of water source improvements.

The research study also informed data collection by the World Health Organization and UNICEF Joint Monitoring Programme based on the microbiological water quality results against source type and the identified potential risk factors, helpful in the monitoring of water safety (WHO, 2014).The results from the research also contributed to the WHO strategy's vision of providing up-to-date, evidence-based guidance and coordination, and support for water, sanitation and hygiene interventions. (WHO, 2013)

Water quality may be improved through sanitary surveys by understanding the identified potential risk factors. This will help to put interventions which will help in meeting the sustainable development goal 6 which aims at ensuring access to water and sanitation for all by 2030. Water service providers or surveillance agencies could opt to use sanitary surveys for quick surveillance to determine water safety plans. This will not mean neglecting water testing, but the sanitary surveys should be used in complementing other water testing techniques.

1.6 Scope and limitations of the study

1.6.1 Scope

The study was done in three administrative divisions of Kisii County namely Keumbu, Kiogoro and Mosocho. It focused on the microbiological quality of water and a short household survey on safe water management at the household level. Microbiological quality of water was done through testing of fecal coliform, which was tested using membrane filtration method with a WagtechPotalab kit. The Wagtech kit which has the membrane filtration unit comes with consumables that include the lauryl sulphate broth adequate for approximately 140 microbiological tests. Therefore, the number of samples measured was limited to 140 samples from 70 randomly selected water sources factoring in the different types of sources. Sanitary surveys were also conducted for the sampled water sources using a set of questions modified from the WHO (1997) version.

1.6.2 Limitations of the study

The study did not focus on water quality at point of use and the extremes of weather may have affected the collection of samples. The study also involved selected sub-counties and the results obtained are specific to the study area and cannot be applied elsewhere.

1.9 Definition of terms

Drinking water: That which does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. (WHO, 2006).

Sanitary survey: An onsite review of the water source, facilities, equipment, operation and maintenance of a public water system for the purpose of evaluating the adequacy of such source, facilities, equipment, operation and maintenance for producing and distributing safe drinking water." (WHO, 1997).

Sanitary Inspection: An onsite inspection and evaluation by qualified individuals of all conditions, devices, and practices in the water-supply system that pose an actual or potential danger to the health and well-being of the consumer. (WHO, 1997).

Sanitary risk factor: Every insanitary situation that could increase the risk of water contamination (WHO, 1997).

Sanitary risk scores: A score based on all 'Yes' answers in a sanitary inspection form which can be converted into a percentage to indicate the category of risk. (WHO, 1997)

Water quality: A measure of the condition of water relative to the requirement of one or more biotic species or human need and it refers to the chemical, physical, biological, and radiological characteristics of water (CAWST, 2009).

Microbiological water quality: A measure of water quality in terms of bacteriological pollutants (CAWST, 2009).

Indicator organisms: these are organisms used to measure potential fecal contamination of environmental samples e.g. fecal coliform, which is a common indicator of fecal contamination (CAWST, 2009).

Improved drinking water source: defined as a water source that by nature of its construction or through active intervention, is likely to be protected from outside contamination, in particular from contamination with fecal matter. (WHO and UNICEF, 2012).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Safe drinking water is defined by the WHO as water that is of an acceptable quality in terms of physical, chemical and bacteriological parameters (WHO, 2004; Gwimbi 2011). Safe drinking water is important in maintaining health, dignity and essential in breaking the cycle of poverty through improvement of people's health and strength to work. It has been reported that more lives are claimed as a result of the global water crisis compared to lives lost in any wars through guns (UNDP, 2006).

An understanding of environmental contamination is required to also understand the transmission patterns of waterborne pathogens. Environmental contamination may result from different human and animal activities which lead to the contamination of water sources especially during rainy seasons. Al-Bayatti *et al.*, (2012) stated that human or animal activity within the body of water or within the watershed affected the raw water quality.

This section focuses on the overall progress of water and sanitation in both a global and Kenyan context. The three qualities considered in water testing is highlighted and the categories of pathogens in water discussed. This is important in order to understand the process of assessing water quality. Also the commonly used indicator organisms which include total coliform, *E. coli* and thermotolerant coliform bacteria are discussed to understand their importance in water quality. Lastly the methodologies employed during a sanitary survey together with the existing literature on sanitary surveys are discussed.

2.2 Water and sanitation global situation

Despite the importance and strong overall progress of water and sanitation, 748 million people worldwide lacked access to improved drinking water in 2012, 325 million (43%) of whom live in Sub-Saharan Africa (UNICEF and WHO, 2012). This translates to two out of five people without access to an improved drinking water source who live in Africa in 2012. In reference to the Millennium Development Goals, 45 countries most of which are in sub-Saharan Africa are not on track to meet the MDG target by 2015 while the rest of the world met the same target in 2010. Figure 1 shows the global picture of the progress towards the MDG drinking water target.

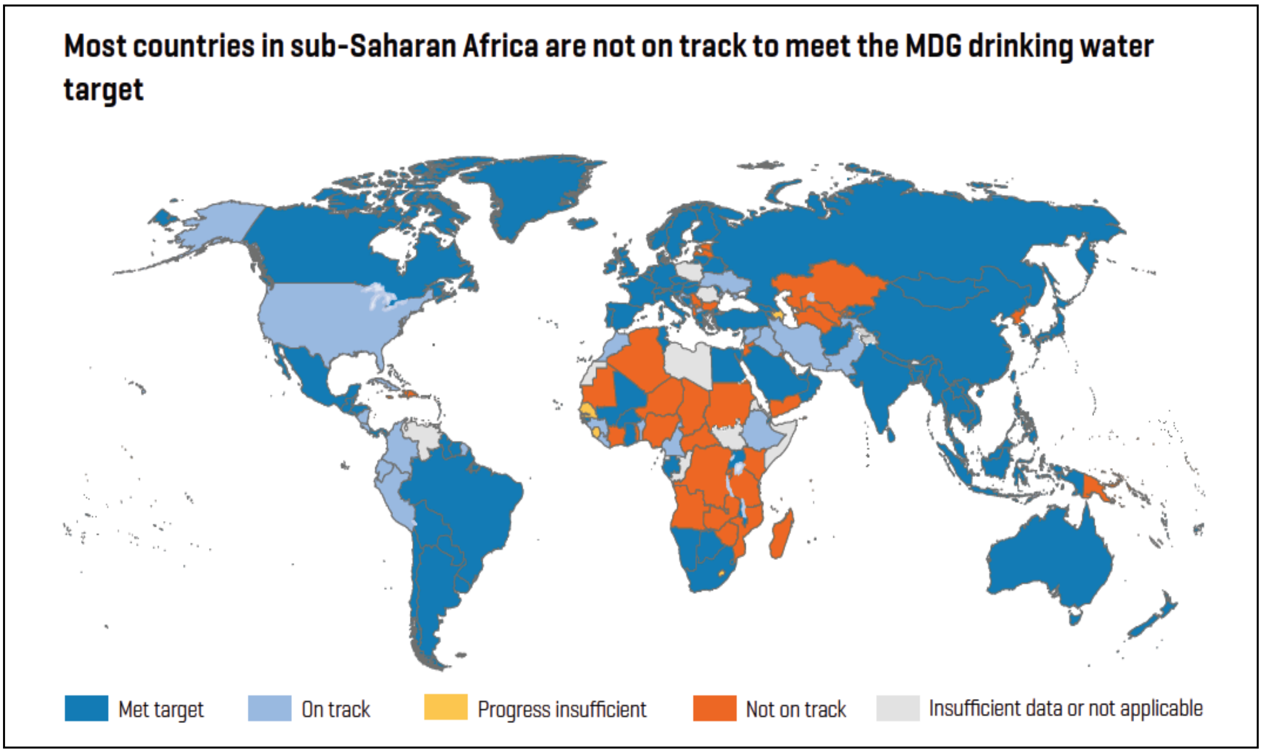

Figure 1: Progress towards the MDG drinking water target

Source: (WHO, 2014)

WHO statistics estimate that 1.6 million people – mostly children under the age of five - die each year due to contamination of drinking water (WHO, 2005; Rufener *et al.*, 2010). Other reports indicate that 88% of the 1.4 million children deaths worldwide each year from preventable diarrheal diseases are related to unsafe water and inadequate sanitation (Cheng *et al.*, 2012)

2.3 Water coverage and sanitation coverage in Kenya

According to Joint Monitoring Programme (JMP) estimates in 2015, 63% of Kenyans (82% in urban areas and 57% in rural areas) had access to improved drinking water sources. The sanitation situation is better compared to the rural water supply but the sanitary facilities used are mainly un-improved pit latrines. The sewerage coverage is nonexistent in rural areas whereas urban coverage is low. The tables 1 and 2 show the water supply and sanitation coverage in Kenya.

Table 1: Estimates on the use of water sources (1990 - 2015) in Kenya

TOTAL WATER					
Estimated coverage 2015 update					
Year	**Total improved**	**Piped onto premises**	**Other improved**	**Other unimproved**	**Surface water**
1990	43%	17%	26%	16%	41%
1995	47%	18%	29%	16%	37%
2000	52%	19%	33%	15%	33%
2005	56%	20%	36%	15%	29%
2010	60%	21%	39%	15%	25%
2015	63%	22%	41%	15%	22%

Source: (WHO, 2015)

Table 2: Estimates on the use of sanitation facilities (1990 - 2015)

TOTAL SANITATION				
Estimated coverage 2015 update				
Year	**Improved**	**Shared**	**Other unimproved**	**Open defecation**
1990	25%	20%	36%	19%
1995	26%	21%	36%	17%
2000	27%	22%	35%	16%
2005	28%	24%	33%	15%
2010	29%	25%	33%	13%
2015	30%	27%	31%	12%

Source: (WHO, 2015)

2.4 Water quality testing

There is a need for water quality testing because much information will be gotten which will help in mitigation measures, as with little water quality information, little will be done to mitigate contamination problems (Gwimbi 2011). The clear appearance of water does not mean the water is safe and the following three qualities are usually considered to determine safety of water:

1. Microbiological – bacteria, viruses, protozoa, and worms
2. Chemical – minerals, metals and chemicals
3. Physical – temperature, color, smell, taste and turbidity

Water testing can be done using several methods: observation, testing using portable kits, using a mobile laboratory and specialized laboratory testing. Analyses for many physico-chemical and microbiological contaminants can be carried out in the field using portable testing kits. This ensures testing of fresh samples whose characteristics have not been altered as a result of being stored or transported over long distances. The cost of testing at about US$2-4 with some tests such as using coliquant membrane filtration at about US$10.60 per test make the exercise not affordable. This relatively high cost, unavailability of resources and infrastructure for performing standardized methods makes testing difficult and impractical (CAWST, 2009).

2.5 Microbiological quality of drinking water sources

WHO guidelines for drinking water quality links widespread health effects to infectious diseases caused by pathogenic bacteria, viruses, protozoa and helminthes common in drinking water (WHO, 2011). Presence of these pathogens is determined through testing although other indicators such as the incidence of diarrheal diseases and general health of the local population can provide insight into the quality of the community drinking water.

The WHO guidelines for drinking water quality recommend zero fecal contamination in any 100ml sample for water intended for drinking purposes (WHO, 2011). Kenya national drinking water standards recommend that fecal coliform should be absent in 250ml (table 3). The risk of fecal contamination in drinking water using *E. coli* as an indicator organism is shown in the table below.

Table 3: WHO and National drinking water quality standards.

Characteristic	Guideline values	
	WHO	**Kenya**
E.coli	Absent in 100ml sample	Absent in 250ml
Temperature	No value	No value
Turbidity	5 NTU	5 NTU
pH	No health based guideline	6.5 – 8.5
TDS	No health based guideline	1500mg/l

Source:(Wasreb, n.d.; WHO, 2011)

Table 4: Risk of fecal contamination using *E. coli*

E. coli **(CFU/100ml sample)**	**Risk(WHO 1997)**	**Recommended Action(Harvey, 2007)**
0 – 10	Reasonable quality	Water may be consumed as it is
10 – 100	Polluted	Treat if possible, but may be consumed as it is
100 – 1000	Dangerous	Must be treated
1000	Very dangerous	Rejected or must be treated thoroughly

Source: (CAWST, 2009).

The four main categories of pathogens found in water include: bacteria, viruses, protozoa, and helminthes.

a) Bacteria

Most common microorganisms found in human and animal feces and the primary cause of water-borne infections. They are transmitted through the fecal-oral route and with some, only a few are needed to cause infection. Most common water-borne diseases caused by bacteria are cholera and typhoid. Cholera is caused by ingestion of food or water contaminated with the bacterium *Vibrio cholera* resulting in 1.4 - 4.3 million cases and 28,000 – 142,000 deaths per year worldwide (Ali *et al.,* 2012). Typhoid is also transmitted through ingestion of contaminated food or drink caused by *Salmonella typhi*.

b) Viruses

They are the smallest of pathogens and invade host cells disrupting the functions or cause death of the host cell. Those transmitted by water result in diarrhea, hepatitis A and E. Less is known about viruses than the other pathogens because they are difficult and expensive to study. These viruses are transmitted through the fecal oral route linked to contaminated food and water. Hepatitis A virus can survive in water for a relatively long period and remain infective after 12 weeks. Other viruses are transmitted by vectors that depend on water to survive such as mosquitoes which spread rift valley fever, west Nile fever etc.

c) Protozoa

These are single celled organisms some of which form cysts to allow the organism stay dormant and survive in harsh environments. For example cryptosporidium which causes the diarrheal disease cryptosporidiosis. The parasite can form a cyst resistant to chlorine disinfection. It can be spread in several different ways but drinking water is the most common way the parasite is spread. Infections of amoebic dysentery are the most common which is caused by *Entamoeba histolytica* transmitted through contaminated food and water.

d) Helminthes

They are parasites that spend part of their life in a suitable host that live in water before being transmitted to humans. An example is trematode flatworm which causes schistosomiasis also known as bilharzias. The disease is often associated with stagnant water which provides ideal breeding grounds.

2.6 Indicator organisms

Measuring pathogens directly may be costly and also inefficient and indicator organisms have been used to detect presence of fecal contamination (Levy and Brownell 2004). Some of the common indicators used include total coliform bacteria, *E. coli* and thermotolerant coliform bacteria.

a) Total coliform bacteria

Include a wide range of aerobic and facultative anaerobic, Gram-negative, non-spore forming bacilli and lactose fermenters with production of acid within 24 hours at 35-37°C. Used to assess the cleanliness and integrity of distribution systems and presence of biofilms. Presence in distribution systems and stored water supplies reveal regrowth and biofilm formation or contamination through ingress of foreign material. Total coliform bacteria are naturally present in the environment therefore does not always indicate presence of fecal contamination. However they are still valuable indicators especially for risk assessment in lower-risk waters when *E. coli* is not present.

b) <u>*Escherichia coli* and thermotolerant coliform bacteria</u>

Total coliform that are able to ferment lactose at 44-45°C. In most waters, the predominant genus is *Escherichia*. *E. coli* is one indicator of fecal contamination because of its specificity (JMP 2008; Plate *et al.,* 2004; Zvidzai *et al.,* 2007; Gwimbi, 2011) and therefore an acceptable indicator of fecal pollution.

2.7 Sanitary surveys

Sanitary inspection is one strategy that has been adapted in integrated risk assessment and management in recognition of threats such as pollution from domestic and industrial sources (UNICEF, 2011) and has been recommended by the World Health Organization for risk-based assessment of drinking water quality (WHO, 2004; Luby *et al.,* 2008). These take the form of sanitary surveys, which also allow for rapid qualitative risk assessment due to their simplicity and the resulting systematic reporting (Reid *et al.*, 2001; Fabio and Deborah, 2011). Sanitary surveys may be less expensive than water testing while still being able to identify problems within a water source. They also don't require any specialized equipment or knowledge. However, there is limited knowledge on how effective sanitary inspections can be, as few previous studies have either involved few samples or focused on specific water sources (Parker, 2010 and Mushi, 2012).

Sanitary inspection as a tool in water and sanitation risk assessment has some set methodologies. The format established by WHO (1997) for sanitary inspection forms consist of a set of questions which have 'yes' or 'no' answers scoring 1 point and 0 point, respectively. A 'yes' answer indicates a reasonable risk of contamination while a 'no' answer will indicate negligible risk. The points for each question are then totalled to yield a sanitary inspection risk score, with a higher risk score representing a greater risk of contamination (Lloyd & Batram 1991; WHO 1997; Godfrey *et al.,..* 2006; Luby *et al.*, 2008; Vaccari *et al.*, 2009; Parker *et al.,* 2010; Mushi *et al.,* 2012)

Several studies have been conducted to understand whether sanitary surveys can predict water quality. For example, a study by Parker *et al.,* (2010) found that boreholes had the highest microbiological water quality, followed by open dug wells and protected springs, and open water with the lowest quality. However, there was a weak correlation between thermotolerant coliforms and variation in the sanitary score. Parker *et al.,* (2010) recommended a need to conduct sanitary surveys in more types of sources, as past studies focused only on protected springs and covered hand dug wells. Another study by Bacci and

Chapman (2011) did not find any correlation between borehole hazards or site hazards and thermotolerant coliforms, which they explained as too few contaminated samples to make an adequate comparison. There is, therefore, a need to further determine and understand how sanitary surveys complement water testing programmes by addressing the shortcomings pointed out by previous authors by collecting samples from a range of water sources with varying levels of contamination.

Contrary to the previous two studies, a study in Uganda showed a positive correlation between the sanitary scores and the coliform counts, which provides evidence for the use of sanitary inspection as a tool for risk management of drinking water sources (Howard *et al.*, 2003; Tsega, 2013). By using multi-parametric microbial pollution parameters, a correlation between the risks of contamination categories with the levels of fecal bacteria pollution was also observed in another Tanzanian study by Mushi *et al.*, (2012). In this same study, a regression analysis by using *Escherichia coli* to further investigate the predictive capacity of the risk of contamination scoring, the ROC was able to predict up to 87.4% of the *E. coli* concentrations.

There is evidence to suggest that water quality tests and sanitary surveys can complement each other (Chilton 1996; WHO 2008; Bacci and Chapman 2011). This will ensure safe water for the many households relying on the various water sources by quickly detecting water quality and putting timely interventions in place.

In Kenya, previous studies have examined microbiological water quality by determining the bacterial load through testing without attempting to identify and quantify the potential risk factors contributing to contamination. In the case of Kisii Central sub-county, the risk factors for contamination of water sources is largely unknown. The study determined several potential risk factors and also it compared between microbiological testing results and the sanitary survey results.

2.8 Conceptual framework

The study focused on assessment of water quality, sanitary surveys and household safe water management practices. Reliance only on water testing programmes limits the achievement of increased sustainable access to a safe water supply; hence a sanitary survey is needed which does not compete with water testing but works alongside to identify potential risk factors. To address the research objectives, the two key concepts of microbiological water testing and sanitary risk score were used to determine the quality at the source. The variables of the study were encompassed in general parameters of water quality, which are indicators of potential problems.

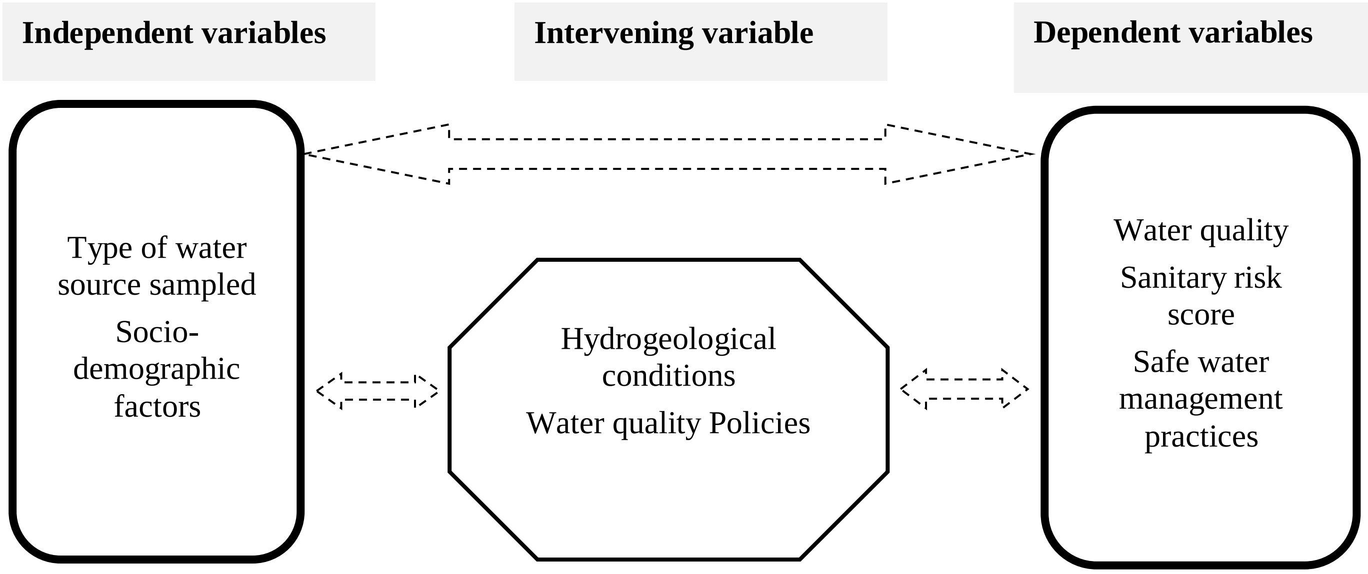

Figure 2: The conceptual framework showing the relationship between variables

Variations in fecal coliform concentration and sanitary scores may be influenced by type of water source sampled while socio-demographic factors may influence water handling practices. Intervening variables such as hydrogeological conditions and policies may influence the dependent variables.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study area

3.1.1 Geographical location

The study location was Kisii Central Sub-county, Kisii County. Kisii county is located south east of Lake Victoria and it borders six counties which are; Narok to the south, Migori to the West, Homabay to the North West, Kisumu to the north, Bomet to the south East and Nyamira to the East (Figure 2). The county lies on latitude 0^{o} 41' 0 S and longitude: 34^{o} 46' 0 E.

3.1.2 Physical and Topographic features

The topography is hilly with several ridges and valleys divided into three main topographical zones. The first zone covers areas lying between 1500-1800m above sea level located in the western boundary and includes parts of Suneka, Marani and Nyamarambe. The second zone covers areas lying between 1500-1800m above sea level located in the Western parts of Keumbu and Sameta divisions, Eastern Marani and Gucha River basin. The third zone covers areas lying above 1800m above sea level in parts of eastern and southern Keumbu, Masaba and Mosocho. The land slopes from east to west dissected by permanent rivers flowing westwards into Lake Victoria. Among the notable ones are Kuja, Mogusii, Riana and Lyabe rivers.

3.1.3 Socioeconomic activities

Seventy five percent of the county has red volcanic soils which are rich in organic matter. The rest of the county has clay soils which have poor drainage, red loams and sandy soils. In the valley bottoms, there exist cotton soils and organic peat soils. The growth of cash crops such as tea, coffee, pyrethrum and subsistence crops such as maize, beans and potatoes are supported by the red volcanic soils.

The main economic activities of the area include: subsistence agriculture, vegetable farming, small scale trade, dairy farming, tea and coffee growing, commercial business and soapstone carvings. 51% of the population live below the poverty line.

3.1.4 Climate and population

It experiences an average rainfall of 1500mm annually which recharges dozens of springs in the area and has a population of 1,152,282.(kisii.com/counties accessed 8th July 2014).

3.1.5 Map

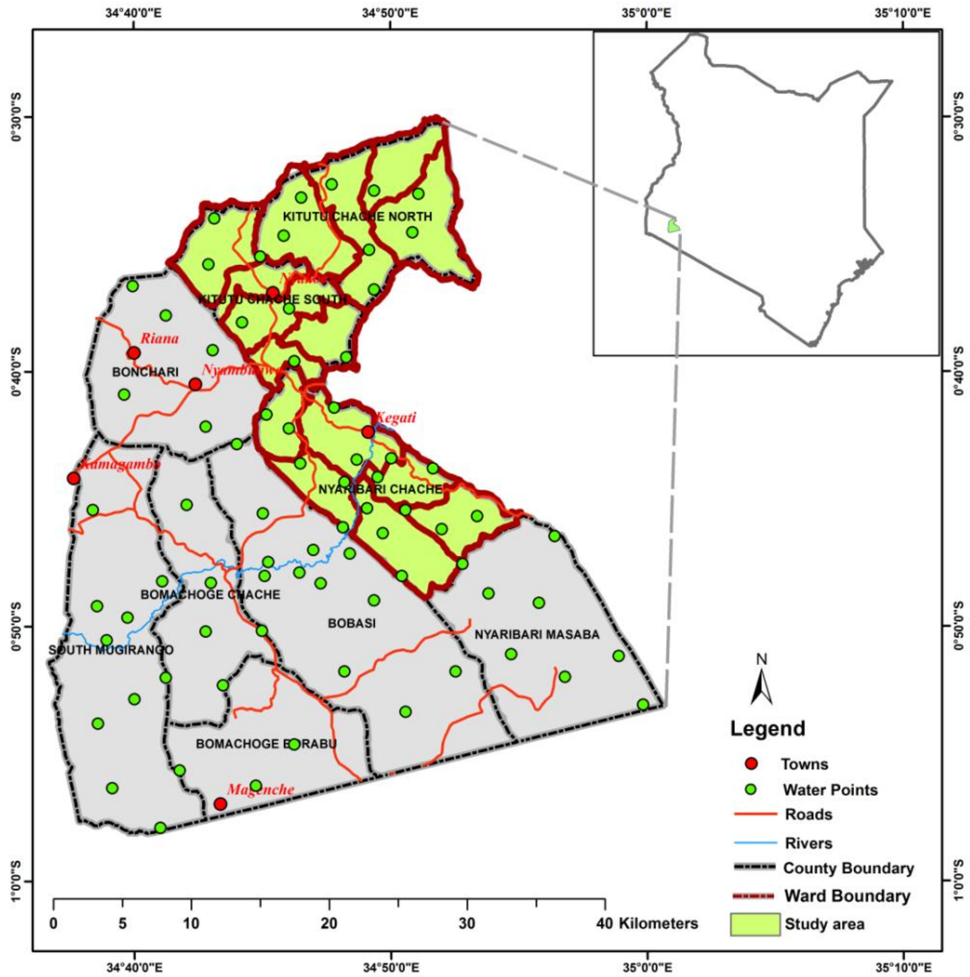

Figure 3: Study area map

3.2 Research design

Cross sectional study design was used and the data was only collected once for each event. Using this design I was able to measure the differences in fecal contamination between the different sources and to identify potential risk factors for contamination of the water sources using the sanitary survey tool.

3.3 Sampling technique

3.3.1 Water samples

Stratified random sampling was employed whereby the study area was divided into three administrative divisions of Kisii County (Keumbu, Mosocho and Kiogoro). The existing inventory of drinking water sources contained 3,981 sources at Mosocho, 2,188 at Keumbu and 1,231 at Kiogoro giving a total of 7,300 drinking water sources. 40 water sources were sampled from Mosocho, 20 from Keumbu and 10 from Kiogoro proportionate to the number of water sources in each strata based on the available water sources inventory. Since there were many water sources within each stratum, simple random sampling was also employed to arrive at the specific water sources to be sampled. To further arrive at the number of specific source type to sample e.g. springs, wells etc. the existing inventory which specified the source type was used to select the proportion of the different water source types that were sampled. All the selected water sources were sampled twice during the dry season and the wet season.

3.3.2 Selection of households

The sample households were arrived using the fisher et al formula:

$n= z^2pq/ d^2$

$n= (1.96)^2(0.5)\ (0.5)/\ (0.05)^2 = 384.16$

384 Households

A total of 346 (90%) households were able to participate in the study out of the 384 that were targeted in the study. The 346 households were selected as follows: starting from one randomly selected household and then picking every sixth household. This number was arrived at by dividing the total sample size (384) with the total number of water sources sampled (70) because of the nature of the water sources whereby many people shared one source of water.

A questionnaire containing questions on drinking-water and sanitation for household surveys was administered according to WHO (2006). The questions aimed at determining the following key issues:

1. The main source of drinking water.
2. The proximity of the water source and the one responsible for fetching water.
3. Whether drinking water was treated and the treatment methods used.

This information as part of the water quality data was useful in assessing risks related to household water management. In addition, strict observations were made to ensure information given in the household questionnaire corresponded to the actual observations in the surrounding.

3.4 Sample collection

At the field, the samples from the various drinking water sources were collected using 100ml whirl packs. The samples were then chilled to about 4° C in a cooler box and then processed within six hours using the portable field test kit (Wagtech) at GUWASCO laboratory. Aseptic procedures were used such as sterilization of taps for the rainwater tanks with a flame to kill fecal coliform bacteria present within the tap to prevent contamination of the water coming out for accurate measurement of the concentrations in water itself.

3.5 Sanitary survey

A sanitary survey was carried out for each selected water source using a form with a set of questions having parameters to be observed. It was performed according to the questions proposed by the WHO (1997) with some modifications (Appendices). The modifications were informed by a pilot visit that helped include risk factors cited by the community and exclude questions not applicable to the area under study. The set of questions with a 'yes' answer scored 1 point while those with a 'no' answer scored 0 point. The points for each question in the form were totaled to yield the sanitary inspection risk score which was then converted into a percentage of the total number of questions in the form. The sanitary inspection risk score ranged from low risk (scores= 0-30%), through a medium risk (31-50%) or high risk (51-70%), to a very high risk (71-100%).

3.6 Water Sample analysis

Fecal coliform was measured using the membrane filtration technique, whereby 100ml of the sample was filtered through a 0.45µm membrane. For suspected highly contaminated water 50ml of the sample was used. After filtration, the membrane discs were then removed and put onto absorbent pads saturated with lauryl sulphate broth at the base of the petri dishes. The petri dishes were then incubated at 44˚C for 24 hours to allow testing for fecal coliform. The yellow forming colonies were then counted and the results expressed as Colony Forming Units per 100ml of water- CFU/100ml.

On-site measurement of water temperature, pH, conductivity and turbidity

Physico-chemical parameters were measured onsite using the available probes that came with the portable Wagtech kit. The water temperature and pH was measured using the pH meter which was calibrated using pH 4 and pH 7 standard buffer solutions. The conductivity was measured using the conductivity meter and the turbidity using the turbidimeter. Care was taken to make sure that the probes were rinsed using de-ionized water between samples.

3.7 Statistical methods and analysis

The data was entered into an excel sheet then converted to a csv file which was imported to the R software (R Core Team, 2014) where analysis and statistical tests were performed. Log transformation of the fecal coliform data was done to make it normal and also to be able to plot the very high concentrations of fecal coliform. Since the data failed to meet the assumptions for normality and homogeneity of variance non-parametric tests: Wilcoxon Rank Sum test and Kruskal-Wallis test were used to determine the statistical differences in the tested parameters among the different water sources and the statistical significance was set at a probability of $p<0.05$ for all the tests. Using R software correlation was performed to check if there existed a correlation between the bacteriological parameters and the sanitary survey risk score.

3.8 Data analysis summary table

Table 5: Data analysis of variables

Research questions	Variables	Statistical analysis tools
What is the fecal coliform concentration of the sources of drinking water in Kisii County?	Fecal coliform per 100ml	Descriptive statistics (median) Kruskal-Wallis
What specific risk factors have an influence on the microbiological water quality of the different water sources?	Sanitary conditions Water quality	Wilcoxon rank sum test
What are the variations in sanitary risk score between different drinking water sources?	Risk of Contamination	Median
What is the correlation between sanitary survey results and conventional water testing results?	Sanitary conditions Fecal coliform	Wilcoxon rank sum test
What are the practices of household safe water management in Kisii County?	Available Practices	Frequencies

CHAPTER 4

RESULTS

4.1 Water sources positive for fecal coliforms

All water samples from the wells tested positive for fecal coliforms while rainwater tanks had the least (61.3%) samples testing positive .(Table 4).

Table 6: Number and percent of water samples positive for fecal coliforms in Kisii County

Facility	Water samples (n)	Fecal coliform, n (%)
Spring	41	39 (95.1%)
Well	34	34 (100%)
Rainwater tank	31	19 (61.3%)
Overall	106	92 (86.8%)

It was observed that the fecal coliform counts between the first and the second sampling periods of the same water sources were not homogeneous. This can be attributed to the on and off rainfall episodes during the collection of samples. When there is heavy rainfall, recharge of underground water sources such as the wells and springs may occur thus affecting the water quality between two sampling periods from the same source.

4.2 Different water sources fecal coliform concentrations in CFU/100ml

None of the wells met the WHO guideline of 0 CFU/100ml for both the first and the second sampling session. Only some of the rainwater tanks and springs met the WHO guideline (Figure 3).

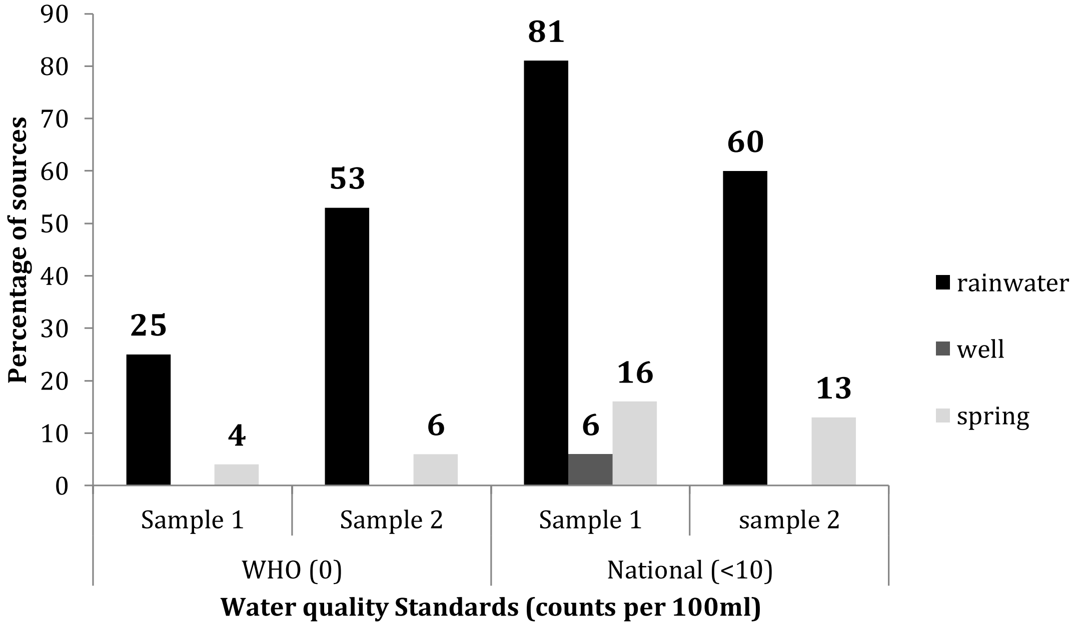

Figure 4: Drinking water quality in Kisii County compared to WHO and National water quality guidelines.

Table 7: Comparison of the bacteriological quality of the different water source types in Kisii County

Fecal coliform (CFU/100ml sample)	Sampling session	Springs (n_1=25, n_2=16)	Wells (n_1=18, n_2=16)	Rainwater tanks (n_1=16, n_2=15)
0 -1	Sampling 1	4	1	13
	Sampling 2	2	0	9
11 - 100	Sampling 1	9	3	1
	Sampling 2	6	1	3
101 -TNTC	Sampling 1	12	13	2
	Sampling 2	8	15	3

n_1 sample size for first sampling session

n_2 sample size for second sampling session

The wells had the highest median fecal coliform counts while rainwater tanks had the least. The log fecal coliform counts of wells was the highest with a median of 2.4 CFU/100ml followed by springs (1.9 CFU/100ml) then rainwater tanks at 0.5 CFU/100ml. The variability of fecal coliform concentration in springs was high compared to rain water tanks and wells (Figure 4).

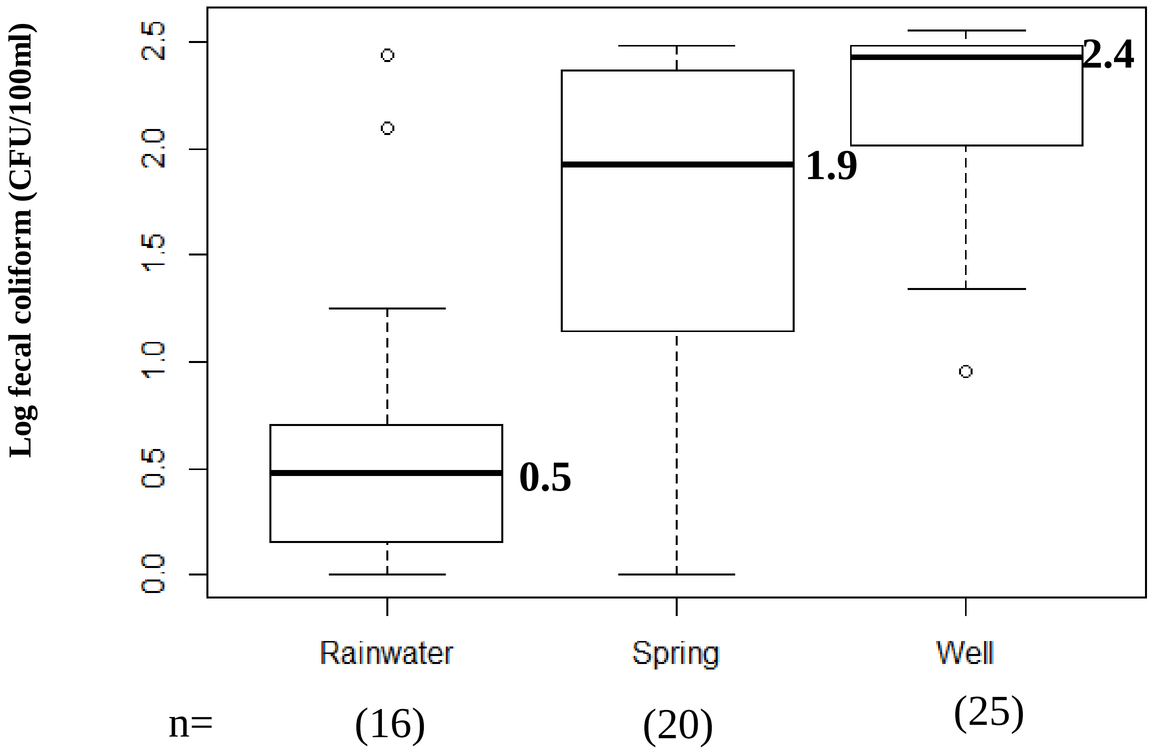

Figure 5: Variability of fecal coliform counts in different water sources in Kisii County

4.3 Effects of protection verses unprotection of springs and wells

Protection of springs and wells is a very important aspect in preventing possible contamination pathways. Unprotected springs were more contaminated indicated by the higher median fecal coliform concentration in unprotected springs as compared to that of protected springs (Figure 5). There was no difference in contamination between the protected and unprotected wells as shown in Figure 6. There was a significant statistical difference between the median fecal coliform for protected springs and unprotected springs (Wilcox. Test, p=0.03924).

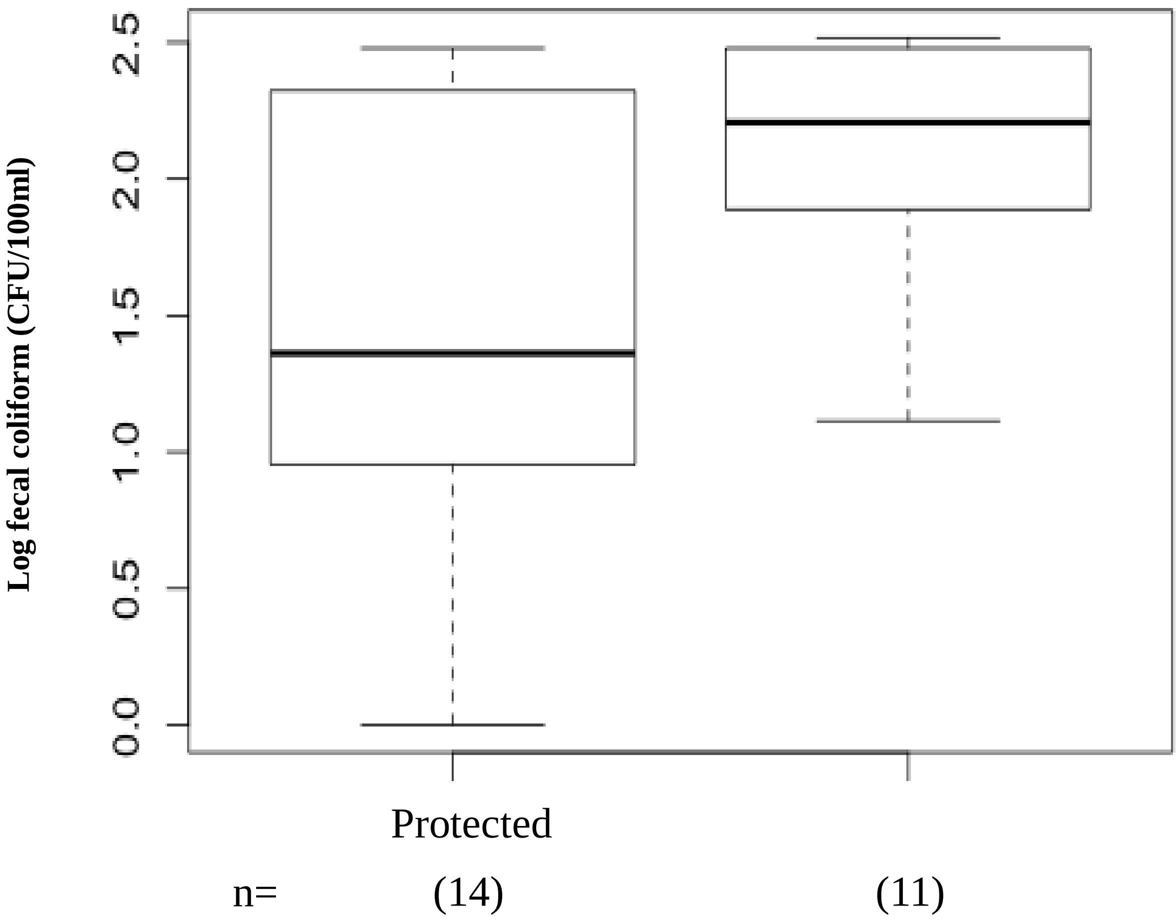

Figure 6: Variation between protected and unprotected springs

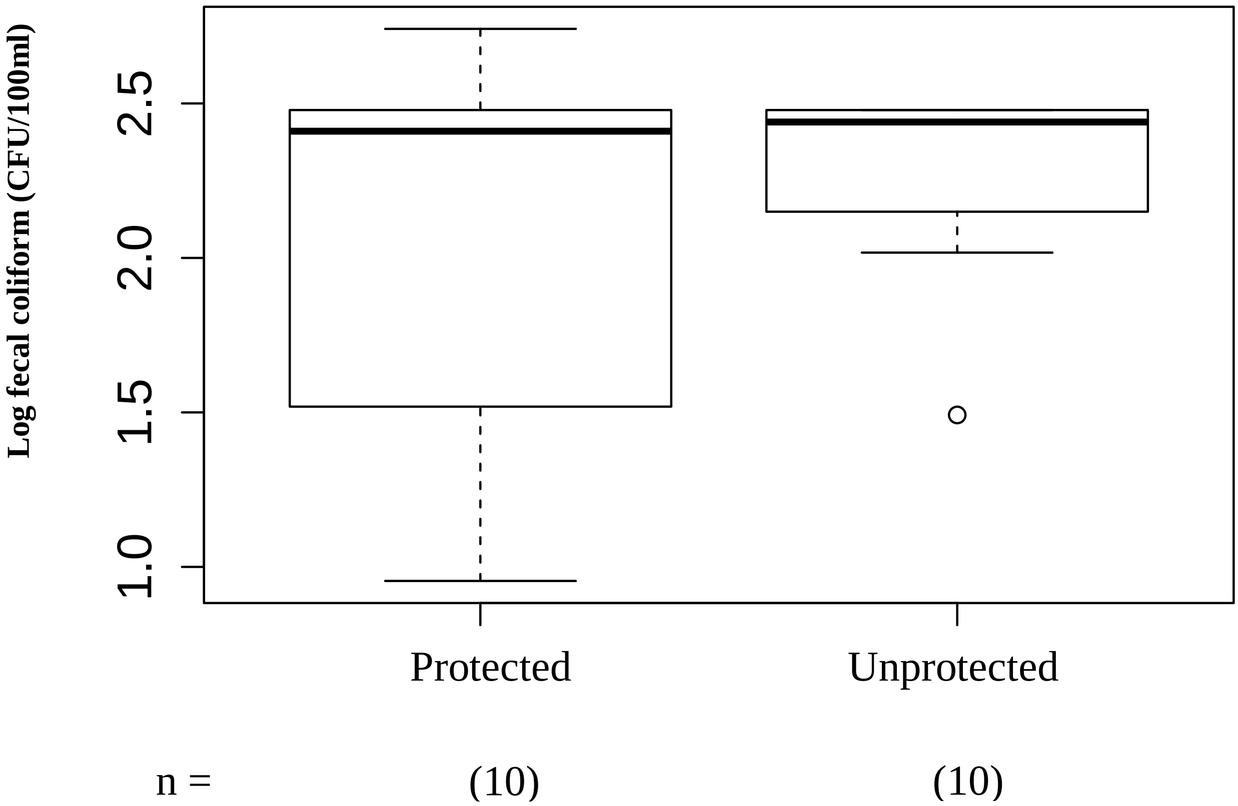

Figure 7: Variation between protected and unprotected wells in Kisii County

4.4 Frequency of occurrences of the sanitary hazards and the relation of the risk factor to a positive outcome for fecal coliform.

4.4.1 Springs

The sanitary survey inspections revealed 44% of the springs (n=25) were not protected.

Table 8: Frequency of risk factors and contamination by spring risk factor

Springs (n=25)					
Risk factors	**Frequency of risk factor %**	**Risk factor present and positive for fecal coliform**	**Risk factor absent and positive for fecal coliform**	**Exact odds ratio 95% CI**	***p***
Q1	11 (44)				
Q3	22 (88)	95 (21/22)	100 (3/3)	0 (0,284.73)	1
Q4	12 (48)	92 (11/12)	100 (13/13)	0 (0,36.00)	0.48
Q5	24 (96)	96 (23/24)	100 (1/1)	0 (0,922.52)	1
Q6	10 (40)	100 (10/10)	93 (14/15)	Inf (0.02,inf)	1
Q7	7 (28)	100 (7/7)	94 (17/18)	Inf (0.01,inf)	1
Q8	6 (24)	83 (5/6)	100 (19/19)	0 (0,12.32)	0.24
Q9	2 (8)	100 (2/2)	96 (22/23)	Inf (0.002,inf)	1
Q10	9 (36)	89 (8/9)	100 (16/16)	0 (0,21.94)	0.36
Q11	1 (4)	100 (1/1)	92 (23/25)	Inf (0.002,inf)	1
Q12	21 (84)	95 (20/21)	100 (4/4)	0 (0,204.10)	1
Q13	8 (32)	88 (7/8)	65 (11/17)	3.6 (0.32,200.05)	0.36
Q14	14 (56)	100 (14/14)	82 (9/11)	Inf (0.24,inf)	0.18

*Q Springs sanitary survey questions 1-14 in the appendix

4.4.2 Wells

For wells the sanitary survey inspections revealed 50% of the wells (n=20) were not protected.

Table 9: Frequency of risk factors and contamination by well risk factor

Wells (n=20)					
Risk factors	**Frequency of risk factor %**	**Risk factor present and positive for fecal coliform**	**Risk factor absent and positive for fecal coliform**	**Exact odds ratio 95% CI**	***P***
Q1	10 (50)	90 (9/10)	90 (9/10)	1 (0.01,87.05)	1
Q2	16 (80)	100 (16/16)	50 (2/4)	Inf (0.87,inf)	0.03
Q3	12 (60)	92 (11/12)	88 (7/8)	1.5 (0.02,134.24)	1
Q4	12 (60)	100 (12/12)	75 (6/8)	Inf (0.29,inf)	0.15
Q5	14 (70)	86 (12/14)	100 (6/6)	0 (0,12.84)	1
Q6	12 (60)	83 (10/12)	100 (8/8)	0 (0,8.03)	0.49
Q7	14 (70)	100 (12/12)	100 (6/6)	0(0,inf)	1
Q8	0 (0)	0	90 (9/20)	0(0,inf)	1
Q9	19 (95)	89 (17/19)	100 (1/1)	0 (0,349.09)	1
Q10	1 (10)	100 (1/1)	89 (8/9)	Inf(0.003,Inf)	1
Q11	16 (80)	94 (15/16)	50 (2/4)	12 (0.45,932.5)	0.09
Q12	20 (100)	90 (18/20)	0	0 (0, inf)	1
Q13	8 (40)	100 (8/8)	83 (10/12)	Inf (0.12,inf)	0.49
Q14	1 (10)	100 (1/1)	89 (17/19)	Inf (0.002,inf)	1
Q15	1 (10)	100 (1/1)	89 (17/19)	Inf (0.002,inf)	1
Q16	12 (60)	92 (11/12)	88 (7/8)	1.5 (0.02,134.24)	1
Q17	15 (75)	93 (14/15)	80 (4/5)	1 (0.01,83.98)	0.45

*Q Wells sanitary survey questions 1-17 in the appendix

4.4.3 Rainwater tanks

Table 10: Frequency of risk factors and contamination by rainwater tank risk factor

Rainwater tank (n=16)					
Risk factors	**Frequency of risk factor %**	**Risk factor present and positive for fecal coliform**	**Risk factor absent and positive for fecal coliform**	**Exact odds ratio 95% CI**	***P***
Q1	1 (6)	100 (1/1)	73 (11/15)	Inf (0.01,inf)	1
Q2	12 (75)	67 (8/12)	100 (4/4)	0 (0,4.81)	0.52
Q3	3 (19)	67 (2/3)	77 (10/13)	0.6 (0.02,47.07)	1
Q4	6 (4)	83 (5/6)	70 (7/10)	2.0 (0.12,134.5)	1
Q6	0 (0)	0	75 (12/16)	0 (0, inf)	1
Q7	0 (0)	0	75 (12/16)	0 (0, inf)	1
Q8	9 (56)	78 (7/9)	71 (5/7)	1.4 (0.07,25.31)	1
Q9	9 (56)	78 (7/9)	71 (5/7)	1.4 (0.07,25.31)	1
Q5	10 (62)	60 (6/10)	100 (6/6)	0 (0,2.314183)	0.23

*Q Rainwater tanks sanitary survey questions 1-5 in the appendix

4.5 Variations in sanitary risk score

The sanitary risk score ranged from low to high for rainwater tanks and low to very high risk score for springs while for wells the range was from medium to very high. Only rainwater tanks never attained the very high sanitary risk score category with 45% of the wells and 8% of the springs being under this category. Majority of the water sources (rainwater 44%, springs 44%, and wells 50%) presented a medium risk score ranking (31 – 50%). Wells were generally very risky for apart from many of them falling in the very high risk category; no single well fell under the low risk category. A huge percentage of rainwater tanks (38%) fell under the low risk category while only 20% of the springs fell under this category (Figure 7).

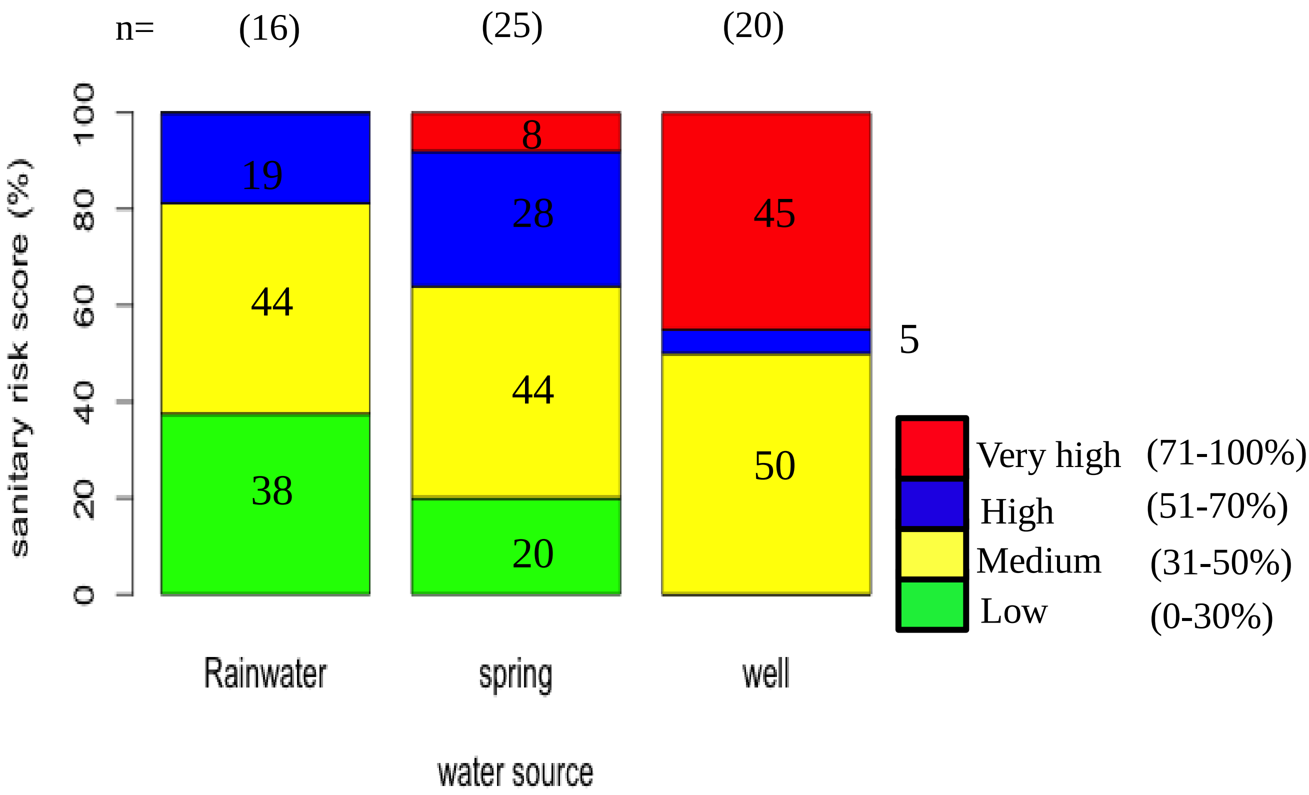

Figure 8: Sanitary risk score categories for drinking water sources in Kisii County.

4.6 Fecal coliform count vs. sanitary risk score prediction

To ascertain whether sanitary surveys can be used in prediction of water quality, the log fecal coliform was plotted against the risk score. This showed whether increase in the sanitary score correlated with increasing fecal coliform counts. The base ten logarithmic Fecal coliform counts ($Log_{10}FC$) was used in order to accommodate the wide range of FC counts from zero/100ml to Too Numerous to Count (TNTC) which consisted of counts more than 300CFUs/100ml. To avoid log0 problems 1 was added to each FC count. There was no definite relationship between the increase of fecal contamination with increasing risk of contamination score (Figure 8). Therefore there may be other contributory factors such as rainfall and hydrogeological conditions which may influence the correlations between the log FC counts and the sanitary survey hazards.

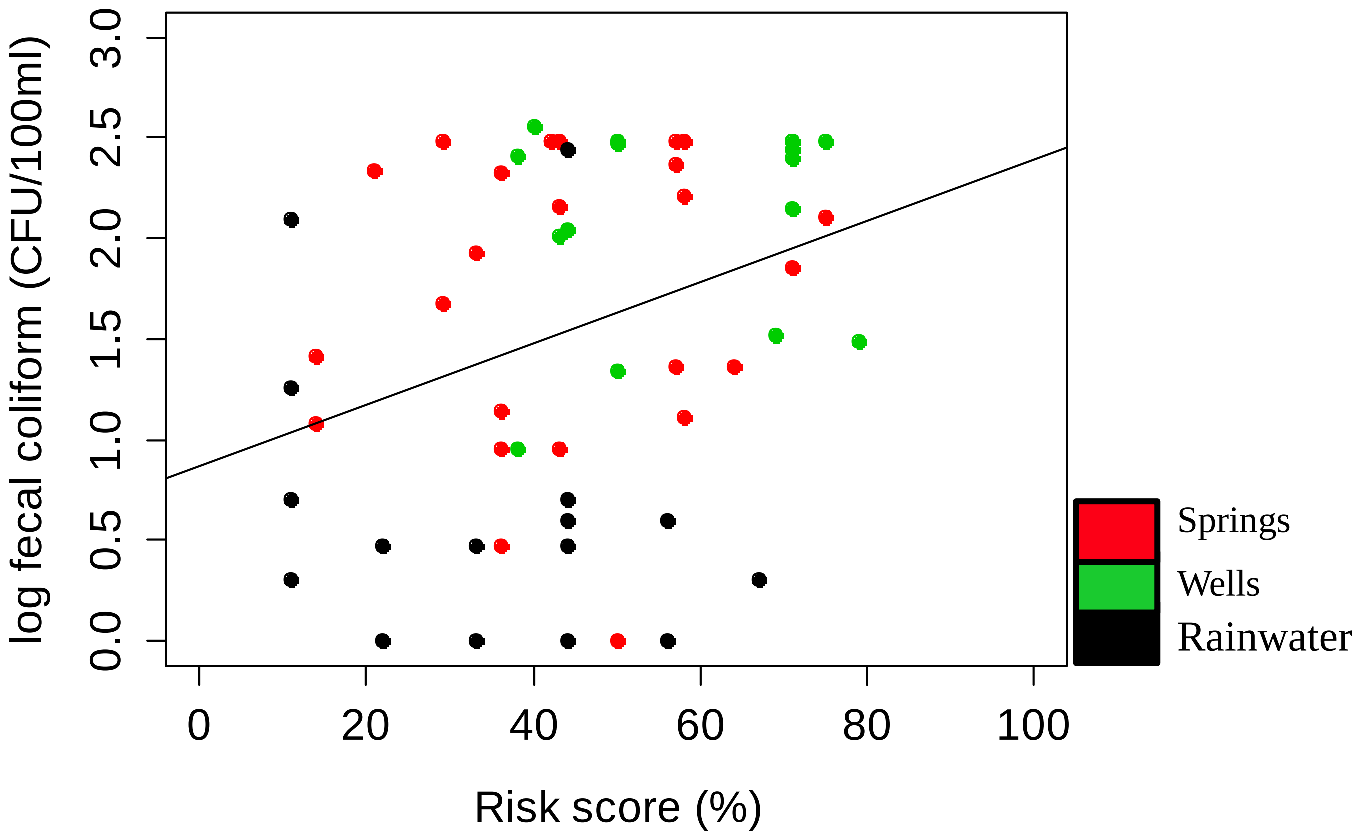

Figure 9: Relationship between the Log fecal coliform concentration and the Risk score for the different water source type.

4.7 Comparison of the physico-chemical quality of the three sources of water (springs wells and rainwater tanks).

4.7.1 Average Conductivity for sample 1 and sample 2

Electrical conductivity is a good indicator for evaluating nature of the purity of water. Wells had the highest mean conductivity of 151µS/cm followed by springs with 94µS/cm and then rainwater tanks having the least conductivity at 13µS/cm (Figure 9).

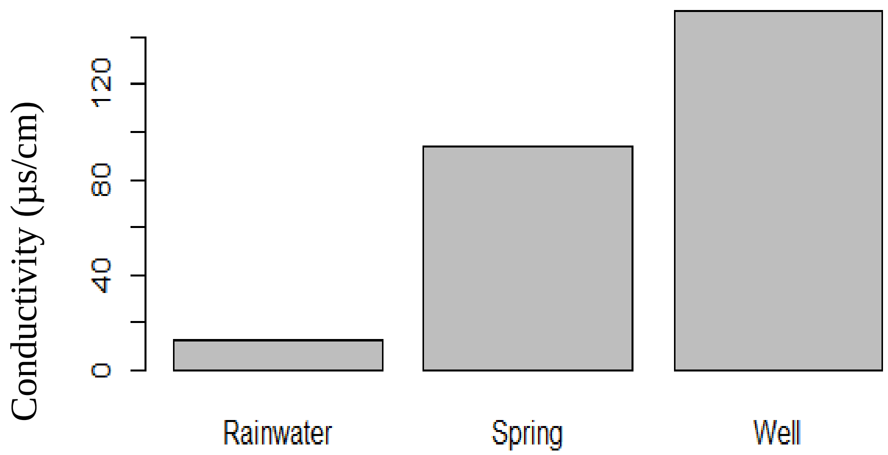

Figure 10: Mean conductivity for the different water sources

4.7.2 Average Temperature for the first and second sample

All the water sources had a mean average temperature of approximately 23° C with negligible variations from one source type to the other (Figure 10).

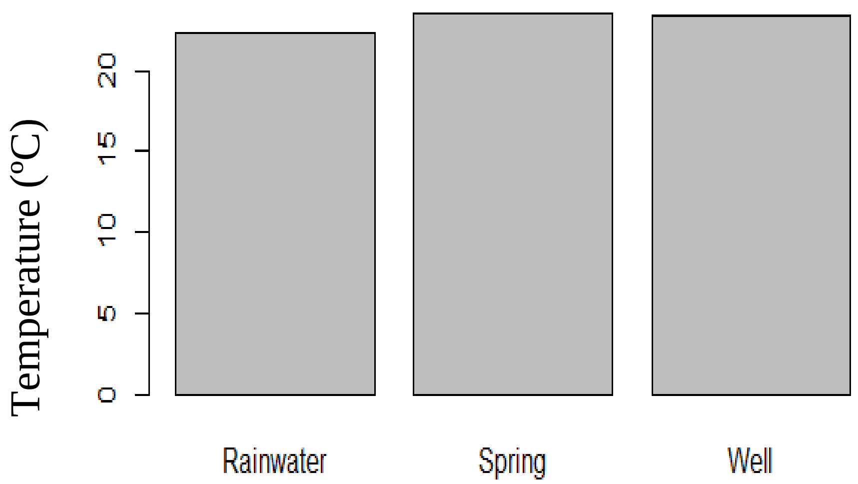

Figure 11: Mean temperatures for the different water source types

4.7.3 Average turbidity for the first and second sample

Turbidity varied greatly depending on the water source type. Wells had the highest mean turbidity of 20 NTUs followed by springs with 12 NTUs and rainwater tanks which had the lowest mean turbidity of only 4 NTUs (Figure 11). Only rainwater tanks met the WHO guidelines of less than 5 NTUs.

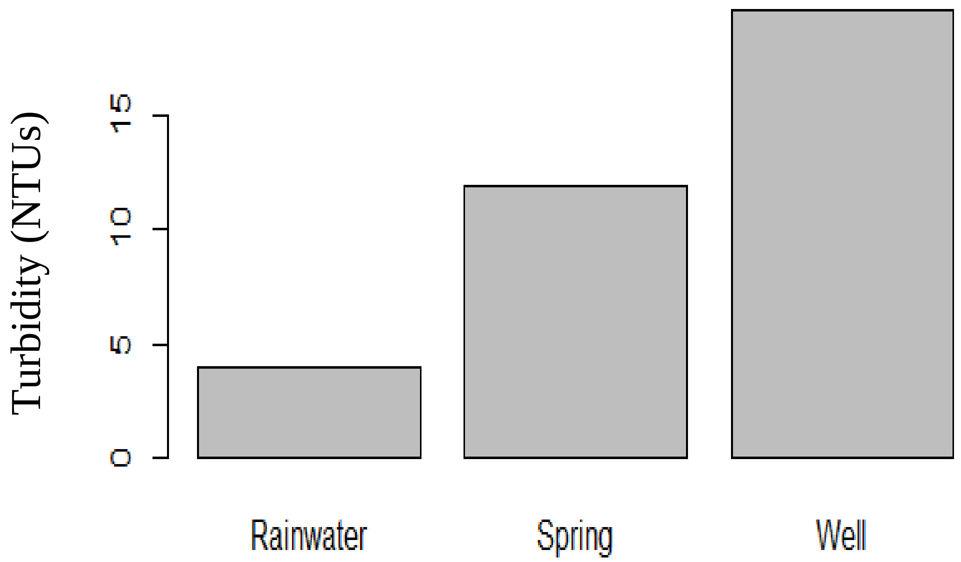

Figure 12: Mean turbidity for each water source type

4.7.4 Average pH for both the first and second sample

Just like temperature, the mean pH variations were negligible between the different water source types. The mean pH for the different source type was 6 (Figure 12). There is no health based guideline value proposed for pH by WHO.

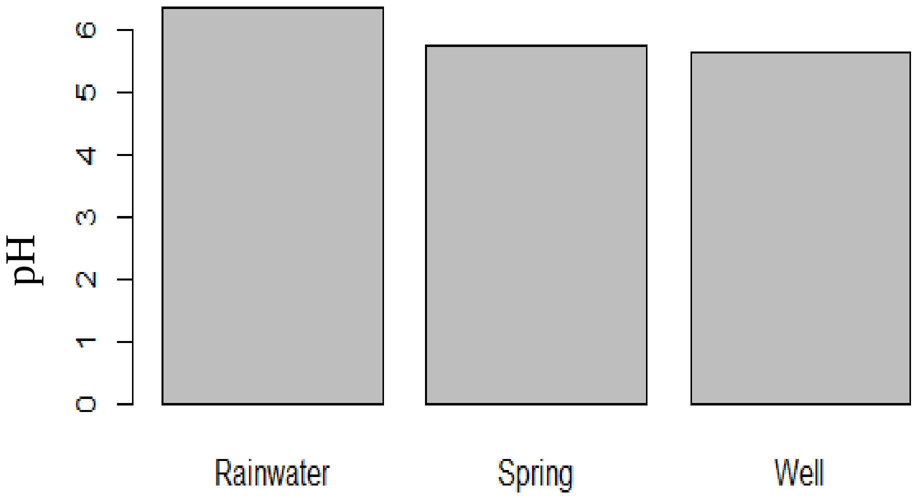

Figure 13: Mean pH for each water source type

4.7.5 Comparison of the physico-chemical parameters between the first and second sampling sessions.

There was no temporal variation of the physico-chemical parameters between the first sampling period and the second sampling period.

Table 11: Comparison of physico-chemical parameters

Parameter	Springs		wells		Rainwater tanks	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Temperature (°C)	24	23	24	23	22	22
Conductivity (µs/cm)	92	99	146	163	13	12
pH	6	6	6	6	6	6
Turbidity (NTUs)	9	14	24	14	4	4

4.8 Household safe water management in Kisii County

4.8.1 Demographic data

Majority of the respondents (68%) were wives who are mostly involved with the management of water in the household. The highest level of education recorded was tertiary level which involves colleges and universities with the majority of the respondents (62%) having attained primary level of education.

4.8.2 Water management in the household

Springs were predominantly used as the main source of water with 97% of the households using them. Majority of the water sources (92%) were less than a kilometre and mothers predominantly at 65% were the ones responsible for fetching water.

Approximately over half (58%) of the sampled households never treated their drinking water to ensure that it was safe for drinking. Mostly (56%) the households used jerricans for the storage of water with a majority of the households (95%) covering their containers which were elevated from the reach of children in 52% of the households. All the households ensured that their containers were clean with a majority (62%) cleaning them twice weekly (Table 10).

Table 12: Household water management practices

Household elements	Percentage of households
1. Water source (n=346)	
Rainwater	4(1%)
Springs	336 (97%)
Wells	6 (2%)
2. Water treatment (n=345)	
Boiling	84 (24%)
Filtering	26 (8%)
Use of chemicals	34 (10%)
None	201 (58%)
3. Storage of water (n=344)	
Earthen pots	82 (24%)
Drums	70 (20%)
Jerricans	192 (56%)
4. Covered containers (n=339)	
Yes	322 (95%)
No	17 (5%)
5. Narrow necked containers (n=344)	
Yes	222 (65%)
No	122 (35%)
6. Container elevated (n=337)	
Yes	175 (52%)
No	162 (48%)
7. Cleaning of container (n=345)	
At least daily	53 (15%)
Twice in a week	215 (62%)
Once in a week	74 (21%)
Once in a month	3 (1%)

DISCUSSION

4.9 Fecal coli form concentrations of drinking water sources in Kisii County

The study revealed that the bacterial density was relatively high in wells compared to the other drinking water sources. Only 39% of rainwater tanks and 5% of springs met the WHO guideline of 0 CFU/100ml while no wells met this guideline. These results give a clear picture of the potential health risks found in water in Kisii County as a result of the presence of fecal coliform in water, which is an indicator of fecal pollution and enteric pathogens which have been reported to cause diarrhoea urinary tract infection, haemorrhagic colitis and other intestinal diseases. These fecal coliform bacteria in water can be attributed to several origins some of which could be improper sanitary conditions within the water sources and poor siting of latrines leading to contamination.

There was a high variation of fecal coliform concentration for the different water source types. The median value was highest in wells at log 2.4CFU/100ml followed by springs at 1.9CFU/100ml and lowest in rainwater at 0.5CFU/100ml. These results are in harmony with those of Parker *et al*., (2010) study which rated rainwater as better than that of wells. The median was used because of its property as the most resistant statistic and also it reduces the importance to be attached to outliers since they may be measurement errors. Good water quality of rainwater tank compared to the other source type may be attributed to the reduced contamination pathways a fact also cited by Parker *et al*., (2010).

Rainwater being assumed to be of the best quality because of the reduced pathways of contamination, only 39% of rainwater tanks met the WHO guideline. Mosley, (2005) stated that although rainwater tanks are isolated from many of the usual contamination, leaves from trees, birds and animals defecate can lead to some level of contamination. The fecal coliform counts found in rainwater tanks may have also resulted from the mixing of rainwater with spring water in the storage tanks which compromised the quality of rainwater. This practice was carried out to ensure availability of water throughout even if there was no rain. This concurred with a study by Macharia *et al*., (2015) which stated mixing of harvested rain water and groundwater as a common practice.

The median fecal coliform count was higher when sampling was done after a previous episode of rain for all the water source types. Further analysis confirmed a significant statistical difference in the median fecal coliform count based on whether there was previous rain before sampling or no previous rain for only the springs. (p=0.0023). The higher level of fecal coliform count after an episode of rain could be attributed to recharge of underground water sources such as the wells and springs. This finding concurred with a study by Kilonzi *et al*., (2014) that stated elevated levels of fecal contamination in springs during wet season was as a result of storm-water rich in organics and other pollutants ingress into the spring water. Al-Bayati *et al*., (2012) also confirmed contamination of water sources during rainy seasons which carried environmental contamination resulting from different human and animal activities.

4.10 Protected verses unprotected

Protection of underground water sources such as wells and springs is very important in preventing or reducing possible contamination pathways. The study focused at both the springs and the wells.

4.10.1 Springs

Unprotected springs were highly contaminated than protected springs and there was a significant statistical difference between the median fecal coliform for protected springs and unprotected springs (Wilcox. Test, p=0.03924). This concurs with a study by Tsega *et al*., (2003) that stated there was a higher total coliform and thermotolerant counts in unprotected water sources relative to protected ones. This highlights the importance of protection in ensuring good water quality. The protection was done by enclosing the eye of the spring in a covered concrete box with an outlet near the bottom to allow flow of water away from the original site of the spring which ensured minimal spring disturbance.

Though protected some of the springs were found to be contaminated. Among other factors, this may be attributed to the lack of the following precautionary measures that ensure consistency of high quality spring water: Provision of a surface diversion ditch which ensured interception of surface water runoff carrying possible contaminants and carrying it away from the drinking water source and Construction of a fence to exclude livestock uphill of the string. Only one spring met this condition.

4.10.2 Wells

Observations between protected wells and unprotected wells never gave a significant difference in fecal coliform counts. This corresponded with Amenu *et al*., (2013) finding that stated there was no significance difference between unprotected and protected wells for TC and TTC/FC. This doesn't mean that protection is not important for wells but it highlights the standards of protection. This observation may be attributed to what people at Kisii County consider as protected wells. The wells that were protected were poorly done so and they lacked some important features of protection like lining and lack of a windlass which made the fetching container to be stored in unsanitary way. This loopholes may have increased contamination of the well water despite of it being considered protected by the availability of cement covering.

4.11 Correlation

In this study, there was no correlation between fecal coliform counts and sanitary scores. This agrees with a study by Parker *et al*., (2010) which found out that the sanitary survey scores did not correlate well with water quality. Bacci and Chapman, (2011) also found no correlation between sanitary survey identified hazards and thermotolerant coliforms in Cork County, England. However it contradicts the findings of other studies (for example Howard *et al*., 2003) who stated that there was a correlation between sanitary survey scores and water quality and Mushi *et al*., (2012) that found there was a strong correlation between the sanitary risk score and water quality for shallow protected springs in Kampala, Uganda. From the study, water quality prediction cannot be entirely based on sanitary surveys. However, a sanitary survey is an important tool in determining the risk of future contamination which might be further accelerated by heavy rainfall.

4.12 Specific risk factors influencing microbiological water quality

4.12.1 Wells

For the wells, the study revealed that exposure to the following four risk factors; pollution within 10m of the water source, stagnant water within 2m of the water source, walls inadequately sealed and lack of fencing have a negative association to the number of wells testing positive for fecal coliform (OR=0). Two of the risk factors which are protection and dirty environment had no association to the number of wells testing positive for fecal coliform (OR<1). This may be attributed to the poorly protected wells and the difficulty of ascertaining whether the environment is dirty or clean. The other eight risk factors had a positive association to the number of positive tests for fecal coliform (OR>1). There was a significant difference between fecal coliform contamination and only one risk factor of the location of a latrine within 10m of the well. This can be attributed to the fact that wells are privately owned and they are more proximal to pit latrines especially for homesteads with limited land space.

This corresponds to a study by Siyum and Woyessa, (2013) that identified relative position of wells with latrines and short distance of wells from the latrines among the major risk factors of water contamination.

4.12.2 Springs

The study revealed that only five of the risk factors had a positive association to the number of springs testing positive for fecal coliform (OR>1) while the remaining six showed a negative association. Being underground water sources, the hydrogeological conditions may act as a confounding factor in many of the springs. There was no significant relationship between fecal coliform contamination and any individual question on the spring sanitary survey form. This contrasted a study by Howard *et al*., (2003) which found a significant difference between risk factors such as erosion of the backfilled area, absence of a fence and waste within 20m and presence of thermotolerant coliforms at 99% level. Surface water uphill, other pollution sources uphill and waste within 10m were significant at 95% level. This can be attributed to broader sources of groundwater contamination rather than nearby point sources of contamination identified through sanitary surveys (Luby *et al*., 2008)

4.12.3 Rainwater tanks

The four risk factors that showed a positive association to the number of rainwater tank testing positive for fecal coliform include:

- Visible roof contamination
- Defective or leaking taps
- Tank opening not covered
- Access hatch not sealed

The other five risk factors showed a negative association. They include; dirty guttering channels, point not properly covered, source of pollution around, thatched or tarred roof and poor drainage. There was no significant relationship between fecal coliform contamination and any individual question on the rainwater tanks sanitary survey form.

4.13 Household safe water management

Most of the households lacked tap water; hence drinking water is usually collected at source and transported to the household where it is stored for consumption. This brings out the importance of understanding the safe water management practices because this will also determine the quality of water apart from the source characteristic. Water may be of good quality at source but contaminated further or recontaminated at the household. Focusing on community supplies by ensuring they are well protected and making other improvements, may be reversed by in-house contamination.

The household questionnaire results showed that there existed several risks at the household. The risk of not treating water for consumption was in 58% of the households. This may contributed to the fact that spring water which is a major source of drinking water is viewed as clean and free from any pathogens. Other risks noted included not covering the water container, risk of permitting dipping for those containers lacking narrow neck and the risk of container being accessible to children. The 48% of the households where the containers were accessible to children are at risk of contamination since unsupervised children could be pathogen entry route a fact also observed by Elala *et al*., (2011).

Water that was safe in storage may be contaminated as a result of these risks or unsafe practices a fact also cited by John *et al*., (2014). This reinforces the need for safe handling practices at the household level which can be effected by health education on safe water management practices. Macharia *et al*., (2015) stated that decline in the microbial quality of water after collection occurred through increased bacterial growth or regrowth in already contaminated water and therefore proper water management at the household level is tied to determination of fecal contamination at the source whereby amplification of bacteria occurs especially where no treatment method is used.

Majority of the households (62%) cleaned their containers twice in a week which was also observed in a study by John *et al*., (2014) whereby the frequency of cleaning varied from once a day to once every 2-3 days. This is a good practice of ensuring that there is no growth of bacteria in the container. Simple, acceptable, low-cost interventions at the household level can lead to improvement of water quality stored at the household which eventually leads to reduction in diarrheal diseases. (Sosbey 2002; Clasen and Sandy 2004)

CHAPTER 5

5.1 CONCLUSIONS

The research study presents an up to date evidence based dataset testing microbiological water quality against source type and risk management of water sources. Through measuring the fecal coliform concentrations, it was established that rainwater ranked first in water quality followed by springs and lastly wells. The study also established potential risk factors which are very important in any water safety plans. When determining the variations in sanitary risk score it was established that the different types of water sources presented a medium risk score ranking (31-50%) highlighting the importance of putting in place water safety plans. For the household water management practices, they were good except for one major problem whereby most of the households never treated their spring water before consumption. It was proven that sanitary surveys as conducted in the study cannot be used to predict water quality as there was no correlation. However, some questions in the sanitary survey form presented the specific risk factors influencing the microbiological quality of the different water source types. This set of questions can therefore be useful in giving an idea of the water quality of particular water sources

5.2 RECOMMENDATIONS

- Water treatment should be encouraged for springs and wells based on the fact that fecal coliform concentrations were high in these sources and majority of the people never treated their drinking water especially from springs.
- Strategies should be put in place by the County public health department to remove the established risk factors influencing microbiological water quality and use sanitary surveys in further identifying new risk factors.
- The county government should base their decisions on sanitary risk scores of water sources to prioritize the urgent action areas.
- Kisii County government under the relevant department should ensure that those contracted to protect springs are specially trained for the constructions to meet all the precautionary measures required in protecting a spring.
- Since most of the wells are privately owned, the County government through the relevant department can equip the community with knowledge and skills on well protection to ensure that adequate protection of wells is done.
- The public should be made aware and educated on the importance of proper latrine location and siting in relation to water sources.
- The public should be made aware and educated on importance of household water management especially treatment of water to change the attitude that spring water doesn't need any form of treatment since it is clean.

FURTHER RESEARCH

1. The study was not able to analyze water quality at the point of use. This can be done to establish whether a correlation exists between the household water management practices and the drinking water quality at the point of use.
2. The prevalence of water borne diseases once established can be correlated with the water quality and the risk factors findings to be able to analyze the impact on the population.

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APPENDICES

APPENDIX 1: SANITARY SURVEY FORMS

I. Type of facility WELLS

General information:

1. Village ....
2. Code no. — Address ....
3. Water authority/community representative signature ....
4. Date of visit ....
5. Water sample taken? .... Sample no. .... Thermotolerant coliform grade ....

II. Specific diagnostic information for assessment — Risk

1. Is the well unprotected by masonry or concrete wall? Y/N
2. Is there a latrine within 10 m of the well? Y/N
3. Does the well have a cover? Y/N
4. Is the nearest latrine on higher ground than the well? Y/N
5. Are there any other sources of pollution (e.g. animal excreta, rubbish) within 10 m of the well? Y/N
6. Is there stagnant water within 2m of the well? Y/N
7. Is the wall (parapet) around the well inadequate, allowing surface water to enter the well? Y/N
8. Is the concrete floor less than 1m wide around the well? Y/N
9. Are the walls of the well inadequately sealed at any point for 3m below ground? Y/N
10. Are there any cracks in the concrete floor around the well which could permit water to enter the well? Y/N
11. Are the rope and bucket left in such a position that they may become contaminated? Y/N
12. Does the installation lack fencing? Y/N
13. Were animals grazing arround the well within 2m at the time of visit? Y/N
14. Were people washing clothes within 2m arround the well at the time of visit? Y/N
15. Is there open defecation uphill the site within 2m? Y/N
16. Is the site protected against flooding (located in a depression or along storm water pathway)? Y/N
17. Is the environment around the well dirty? Y/N

Total score of risks .... /17

III. Results and recommendations

The following important points of risk were noted: .... (List no's 1–17) and the authority advised on remedial action.

Signature of sanitarian ....

I. Type of facility RAINWATER COLLECTION AND STORAGE

General information:

1. Village ....
2. Code no.— Address ....
3. Water authority/community representative signature ....
4. Date of visit ....
5. Water sample taken? .... Sample no. .... Thermotolerant coliform grade ....

II. Specific diagnostic information for assessment **Risk**

1. Is there any visible contamination of the roof catchment area (plants, dirt, or excreta)? Y/N
2. Are the guttering channels that collect water dirty? Y/N
3. Is there any other point of entry to the tank that is not properly covered? Y/N
4. Is the tap leaking or otherwise defective? Y/N
5. Is the water collection area inadequately drained? Y/N
6. Is there any source of pollution around the tank or water collection area (e.g. excreta)? Y/N
7. Is the type of roof thatched or tarred? Y/N
8. Is the opening to the tank not covered? Y/N
9. Is the access hatch not sealed to prevent entry of contaminants? Y/N

Total score of risks .... /9

III. Results and recommendations

The following important points of risk were noted: .... (List no's 1–9) and the authority advised on remedial action.

Signature of sanitarian ....

I. Type of facility SPRING SOURCE

General information:

1. Village ....
2. Code no.—Address ....
3. Water authority/community representative signature ....
4. Date of visit ....
5. Water sample taken? .... Sample no. .... Thermotolerant coliform grade ....

II. Specific diagnostic information for assessment

	Risk
1. Is the spring source unprotected by masonry or concrete wall or spring box and therefore open to surface contamination?	Y/N
2. Is the masonry protecting the spring source faulty?	Y/N
3. Is the area around the spring unfenced?	Y/N
4. Can animals have access to within 10 m of the spring source?	Y/N
5. Does the spring lack a surface water diversion ditch above it, or (if present) is it nonfunctional?	Y/N
6. Are there any immediate latrines uphill of the spring?	Y/N
7. Is the nearest visible latrine on higher ground than the Spring?	Y/N
8. Are there any other source of pollution (e.g. animal excreta, rubbish) within 10 m of the well?	Y/N
9. Are animals grazing within 2m arround the spring?	Y/N
10. Are people washing clothes within 2m uphill the spring?	Y/N
11. Is there open defecation uphill the site?	Y/N
12. Is human activity not restricted (chidren playing arround the spring)?	Y/N
13. Is the spring collection area not developed to minimize ponding of surface water?	Y/N
14. Is the spring collection area with deep rooted vegetation?	Y/N

Total score of risks .... /14

III. Results and recommendations

The following important points of risk were noted: .... (List no's 1–10) and the authority advised on remedial action.

Signature of sanitarian ....

APPENDIX 2: SAFE DRINKING WATER MANAGEMENT IN HOUSEHOLDS

WATER MANAGEMENT PRACTICES IN HOUSEHOLDS QUESTIONNAIRE

SECTION A: DEMOGRAPHIC DATA			
1. Subject: ……………………………………………………… ………		Age/YOB: ………………………………………… ……	
2. Relationship to head of household	Husband ❑ Wife ❑ Son ❑ Daughter ❑ Relative ❑	5. Marital status	Married ❑ Single ❑ Widowed ❑
3. Education level	Primary ❑ Secondary ❑ Tertiary ❑ Uneducated ❑	6. Occupation	Farmer ❑ Business ❑ Employed ❑ Unemployed ❑ Casual laborer ❑ Housewife ❑
4. Religion	Christian❑ Muslim❑ Hindu❑		
SECTION B: WATER MANAGEMENT IN HOUSEHOLDS			
1. What is the main source of your domestic water?	Rain ❑ Springs ❑ Wells❑	7. How do you ensure your water is safe for	Boiling❑ Filtering❑ Use of

		drinking?	chemicals❑ None❑ Others (specify)
2. Who fetches water in the household?	Father❑ Mother❑ Daughter❑ Son ❑	8. How do you store your drinking water?	Earthen pots❑ Drums❑ Jerricans❑ Sufurias❑ Others (specify)
3. How far is the water source from the homestead?	< 1 km❑ 1km❑ > 1 km❑	9. Is the container covered?	Yes❑ No❑
4. How many minutes does it take to fetch water?	<20 min❑ 20 – 30 min❑ >30 min❑	10. Does the storage container have a narrow-neck?	Yes❑ No❑
5. Is your water source protected?	Yes❑ No❑	11. Is the container elevated so that children cannot reach it?	Yes❑ No❑
6. Is water available from the source every day?	Yes❑ No❑	12. How many times is the container cleaned?	At least daily ❑ Twice in a week❑ Once in a week❑ Once in a month❑ No ❑ Other (specify)