ASSESSMENT OF THE BACTERIOLOGICAL, THE PHYSICOCHEMICAL CHEMICAL QUALITIES OF DRINKING WATER IN HARGEISA, SOMALILAND

BY

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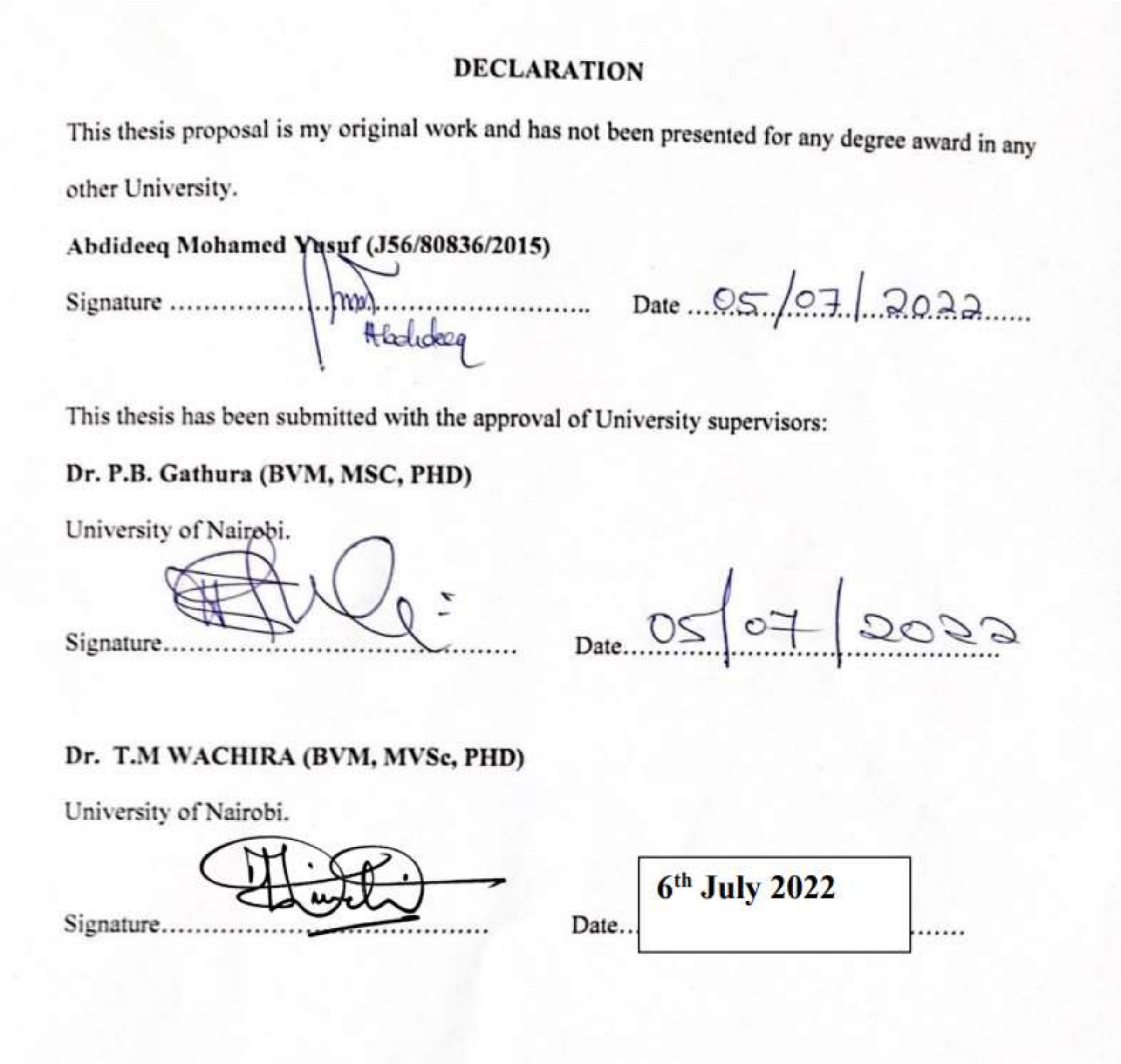
DECLARATION



DECLARATION

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

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DEDICATION

I would like to dedicate this thesis to my mother, Xaliimo Aw Jama, my lovely wife Awo, and my children for their unwavering support, unconditional love, endless inspiration, and support that has enabled me to get this far.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
E.coli	Escherichia coli
EC	Electric conductivity
F-	Fluoride
FAO	Food and Agriculture organization
HUWSUP	Hargeisa Urban Water Supply Upgrading Project
HWA	Hargeisa Water Agency
IMVIC	Indole, Methyl red, Voges Proskauer, and Citrate
Mg/l	Milligrams per liter
MoLFD	Ministry of Livestock and Fishery Development
MPN	Most Probable Number
MSC	Master of Science
ND	Not Detected
NO3	Nitrate
pH	Potential of hydrogen
PHD	Doctor of Philosophy
$SO4^{2-}$	Sulphate
SQQC	Somaliland Quality Control Commission
SWALIM	Somali Water and Land Information Management
TDS	Total Dissolved Solids
UN	United Nations
UN Habitat	United Nations Human Settlement Programme
UNEP	United Nation Environmental Programme
UNICEF	The United Nations International Children's Emergency Fund
WHO	World Health Organization

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ABSTRACT

This study was conducted to evaluate the quality and safety of drinking water in Hargeisa city, Somaliland. Hargeisa water agency serves only 30% of the population, and the majority of Hargeisa's population gets their water from unsupervised sources. Furthermore, there was a limited information available about the safety of drinking water in Hargeisa. The objectives of this study was to assess the bacteriological, physical and chemical quality of drinking water from different sources.

A total of 85 samples were collected from three main sources of drinking water (Pipped, wells and bottled) and their bacteriological quality evaluated based on the most probable number (MPN) of coliforms, *feacal coliform* counts and for *E. coli* and *streptococcus fecalis*. In addition, 30 samples were processed for physical and chemical parameters. UV-visible spectrophotometer, titration and atomic absorption spectrophotometer (AAS) were the employed analytical techniques.

This study found, about 16% (n=55) of bottled, 87 % (n=15) of pipe, and 93 % (n= 15) of wells water were positive, indicating the presence of lactose fermenting coliform. The mean value for bottled water was 7.8, while piped and well water had 58.9 and 106 cfu/100ml respectively for total coliforms, reflecting unsafe water based on WHO 0 MPN index/ 100ml. The water source and coliform units was found to be statistically significant F (2, 32) = 3.1, $p < 0.001$. The overall prevalence of *E. coli* contamination in water samples was 13 % (n= 55) of the bottled, 47% (n= 15) of the piped, and 73 % ((n= 15) of the well's water. This study revealed that 15 % of the bottled, 53 % of piped water, and 67 % of the well waters at the household level have at least two colonies / 100ml of *Streptococus fecalis*.

The mean values for pH (expect for well water), total dissolved solids (TDS), Sulphate (SO4^{2-}), Nitrate (NO^{3} -), Fluoride (F^{-}), Magnesium (bottled and Well), Calcium, Potassium, Sodium, Iron, Zinc, and Lead were within the permissible limits recommended by the World Health Organization (WHO) standards for drinking water. However, Electric conductivity (EC) level for piped and wells, Magnesium for pipe water, and pH level for wells were all above WHO recommended levels. In the majority of parameters there was no significant different between pipped and well water sources. However, there was a significant difference in the means of bottled from the other sources. The study discovered a discrepancy between the label information and the actual content in the bottles sampled, particularly in pH, TDS, and Chlorides.

The research discovered poor bacteriological quality drinking water in Hargeisa, mainly due to water shortages, poor water handling, lack of centralized drinking water sources, inadequate community awareness, and inadequate water safety guidelines. It is recommended, storage practices should be improved, water should be boiled before drinking, and the government should establish and enforce drinking water quality guidelines and standards.

CHAPTER ONE

INTRODUCTION

1.1 Background

Access to safe and quality drinking water is a essential human right necessary for human health (Hall *et al.,* 2013; Oliveira, 2017; Desye *at el.*, 2021). As a result, the Global Sustainable Development Goals recognize the need for all people on the planet to have equitable access to quality and affordable drinking water by 2030 (United nation,2018; Yu *et al.,* 2019). In many developing countries, ensuring a sufficient supply of safe and quality drinking water is one of the most puzzling tasks (Ouf *et al.*, 2018). The global burden of disease associated with the consumption of contaminated water is estimated to result in over 1.2 million deaths per year, with the most significant impact felt in low-income countries such as Somaliland (Gibney *et al.*, 2017).

The microbial contamination of water is major public health and nutrition concern (Keferstein, 1999 and Sobsey, 2016). Immunocompromised people, children and women more particularly those from rural areas are considered as the most vulnerable to waterborne pathogenic microorganisms (Obi *et al.,* 2007). Waterborne bacteriological agents can infect people if water that is contaminated with bacteria directly or when is used in food preparation, processing, or production (Kirby, 2003). Contaminated water has been associated with diseases such as diarrhea, cholera, dysentery, typhoid, and polio, and some 829 000 people are estimated to die each year from diarrhea as resulted of unsafe drinking water, sanitation and hygiene (WHO, 2022). Based on UN estimates (2018), more than 55% of the global population lives in urban area. With the snowballing urban population and growth of urban areas, many city administrators face the problem of providing sufficient quantity and quality of water (McDonald *et al.,* 2011).

In Somalia, only 52% of population has access to a primary water supply (UNICEF AND WHO, 2019). Water for domestic use in Somaliland is largely accessed from underground water sources with high levels of total dissolved solids (TDS), which frequently exceed the allowable recommended levels for human consumption (Heen , and Madar, 2020). A hydrogeological survey conducted in Somaliland discovered that samples from over 500 natural domestic use water sources had dangerous concentrations (mg/l) of chloride (601), Sulphate (1653), sodium (353), manganese (0.89), fluoride (1.8), and iodine (270) (FAO SWALIM, 2012).

In low and middle income countries, the biggest proportion population has access to water from springs and streams that may be hazardous for domestic use due contamination through natural and anthropogenic reasons (Amanial, 2015). The situation is further complex in cities in developing countries such as Hargeisa city in Somaliland, which has old and dilapidated water infrastructure systems with a rapidly growing population that needs clean, potable water for both domestic, agricultural and industrial use (UN Habitat, 2014). According to the Hargeisa municipality, the estimated population is one million people, with an annual growth rate of 5 - 7 percent (UNICEF/WHO, 2019). Water distribution in Hargeisa consist of a setup of thirteen water boreholes at Geed-Deeble water field where water is pumped over two twin underground 300mm width pipelines over a 20 km and elevated to in-ground storage tanks 260m high above the Hargeisa (UNHABITAT, 2014). Hargeisa Water Agency (HWA) currently incapable of wholly meeting a projected demand of approximately 20,000 m^3 per day; only thirty-five percent of Hargeisa inhabitants having some sort of access to piped water. The 35% includes of the population who depend on water from kiosks that access water from HWA. The demand for water has increased immensely, and water shortages have become a norm in Hargeisa (UNICEF, 2012A). The remainder of the population receives water from unmonitored private wells located nearby villages and is delivered by tankers. Private water providers frequently face lax regulation, resulting in exorbitant water prices (UNICEF/WHO, 2019). Research on the bacteriological and physicochemical quality of water in Somaliland are limited. This study aimed to determine the bacteriological, physical, and chemical quality of drinking water in Hargeisa city.

1.2 Problem statement

The majority of Somaliland's population is dependent on underground water sources, and studies conducted in other parts of Somaliland revealed that the electric conductivity (3539 (S/cm), total dissolved solids (TDS), fluoride (1.82), chloride (601 mg/l), Sulphate (1653 mg/l), sodium (353 mg/l), magnesium (180.2 mg/l), manganese (0.89 mg/l), and iodine (0.27 g/l were all above the WHO safety limit (FAO SWALIM, 2012). Drinking water with microbes and excess chemicals may lead to a variety of short and long term health effects, including diarrhea, cholera, dysentery, skin discolorations, nervous system problems and long term conditions such as cancer (WHO, 2008).

Hargeisa city (the study area) is experiencing an increase in water demand as its population grows exponentially, and HWA supplying only about 35% of the Hargeisa population and continues not being able to fully meet an approximated water demand of 16,000 – 20,000 m^3 per day (Farah and Yonis., 2015). As a result, the rest of the population obtain domestic use water from a number of unmonitored sources including the water trucks from wells in neighboring villages. Furthermore, packaged (bottled) water is widely available and widely consumed because it is perceived to be safer and tastes better. There is limited information available about the bacteriological, physical and chemical quality of Hargeisa's drinking water. As a result, assessing drinking water quality would provide basic data to facilitate the implementation of appropriate mitigation measures to safeguard the public's health.

1.3 Objectives

1.3.1 General Objectives

To determine the bacteriological, physical, and chemical qualities of drinking water in Hargeisa city.

1.3.2 Specific Objectives

1. To assess bacteriological quality of bottled, stand piped and wells water in Hargeisa city
2. To assess the physiochemical quality of bottled, stand pipe and wells water in Hargeisa city.
3. To assess the sensitivity profile of pathogenic isolates to commonly used antibiotics.

1.4 Hypothesis

1. Drinking water from piped, bottled and wells water sources are safe for human consumption

1.5. Justification

The majority of Hargeisa's population gets their water from unmonitored sources, therefore, this study will provide baseline information on drinking water quality and safety and will assist agencies responsible for public health, food safety, and nutrition, such as the Somaliland Quality Control Commission (SQCC), the Hargeisa Water Agency (HWA), the Ministry of Health, the World Health Organization (WHO), and the United Nations Environmental Programme (UNEP), in developing strategies to provide quality water to the community and advising the government and water producers on the importance of following the recommended guidelines for drinking water.

CHAPTER TWO

LITERATURE REVIEW

2.1. Waterborne infections.

Among the major problems of the 21st century, water access in terms of quantity and quality is a pressing need ((Devipriya, 2012; Cosgrove and Loucks., 2015). Access to safe water supply to households may be the norm in developed countries but in developing countries such as Somaliland, access to both safe water and efficient sanitation systems is not assured leading to the likelihood of occurrence of waterborne infections (Alavian *et al.,* 2009; Cosgrove and Loucks., 2015; Hutton, G. and Chase., 2017). Over 41% of the world's population, do not have access to clean and safe drinking water and efficient sanitation systems (Ashbolt., 2005; Hutton, G. and Chase., 2017; Oki and Kanae., 2006). Availability of water is going to be even a bigger problem in the future with the current underlying issues such as climate change which is resulting in the intensification of the water cycle (Alavian *et al.*, 2009; Oki and Kanae., 2006). Fresh water supply and accessibility is limiting resource in world over; this is more so in developing nations where potable water accessibility has remained problematic resulting to the bigger proportion of the population consuming from water sources contaminated by sewers, over-flows and animal dropping (Hutton, and Chase., 2017.). The key disease risk linked to drinking water in developing countries is bacteria that spread via consumption of water contaminated with fecal waste (Ashbolt., 2005; Cabral., 2010). Bacteria such as, *E. coli, Streptococus, Campylobacter, Vibrio cholerae* among other multidrug-resistant have been associated with waterborne diseases and outbreaks have been isolated from water (Ashbolt., 2005; Cabral., 2010). These bacteria are more common in areas with poor and or inexistent sanitation infrastructure and with rampant water scarcity (Cabral, 2010).

Waterborne diseases are illnesses caused by pathogenic microorganisms that are transmitted in water and can be spread while bathing, washing, drinking water, or eating food that has been exposed to contaminated water. (Petel & Pharm, 2018). Such disease outbursts can be huge, particularly in urban municipalities that receive water from a centralized water supply chain (Ashbolt., 2005; Cabral., 2010). Despite there being a public awareness on issues pertaining water safety since the cholera outbreak in London, fewer countries have been able to contain and control waterborne diseases (Dinka., 2018). Waterborne diseases account for an estimated 3.6% of the total global burden of disease. In addition, 58% of that burden, which is equivalent to 842,000 deaths per year, is attributable to a lack of safe drinking water supply, sanitation and hygiene (WHO, 2014)

2.2. Indicators for Bacteriological water quality

Water that physically looks suitable for domestic consumption may be contaminated with bacteria and other pathogens that are likely to cause life threatening health hazards (Ashbolt., 2005; Cabral., 2010; Dinka., 2018). Bacteriological examination of water for domestic consumption for the presence bacteria and other pathogens is imperative in ensuring that domestic water is safe and clean hence ensuring public safety (Ashbolt., 2005; Cabral., 2010; Dinka., 2018).

To address the issue of unsafe water, techniques are desired to assess what institutes good quality water versus polluted drinking water (Dinka., 2018). Rather than directly evaluating water for the presence of all pathogens in water, indicator organisms that are a typical of fecal pollution are used as a representation measure of a water contamination (Ashbolt., 2005; Cabral., 2010). Bacteriological evaluation of the quality and safety of water for domestic use is based on the relationship between indicator organisms and other microorganism. At present, the most common indicators that are used to check for water safety are total coliforms including *E coli, streptococcus* and *enterococcus* (Ashbolt, 2005; Cabral, 2010). They are widespread and inexpensive to detect and estimate (Ashbolt, 2005; Cabral, 2010). However, waterborne outbreaks have been reported in instances where indicator bacteria have been detected and are absent mostly due to imperfect treatment processes that fail to exhaustively eliminate the microorganisms or fresh water getting contaminated with untreated water through the distribution process (Ashbolt, 2005; Cabral., 2010; Alonso *et al.*, 2011).

2.3. Antimicrobial resistance and water

Human and animal pathogenic microorganism are continuously released into water sources and the environment; most of these microorganism harbor antimicrobial -resistance genes (Alonso *et al,* 2011). Over 90% of consumed antimicrobials by livestock and human beings and excreted in feces and urine end up in waste-water treatment plants but most often directly into water bodies that are for domestic water use (Alonso *et al,* 2011; Baquero *et al.,* 2011). Due to inefficient water distribution and treatment systems in most countries this water can be additional source of antibiotic exposure to microorganisms and domestic water users (Cabral., 2010; Alonso *et al,* 2011; Baquero *et al.*, 2011).

Water especially those in developing countries acts as not only a medium of spreading antibiotic-resistant bacteria among populations, but also as one of the main routes by which resistance genes get in contact with natural bacterial ecosystems (Baquero *et al.*, 2011). This is further amplified by the accumulation of antimicrobial agents among other chemical agents that promote the evolution, growth and dispersion of these resistant organisms in the water ecosystems (Alonso *et al*, 2011; Chamosa *et al.*, 201; Baquero *et al.*, 2011).

Unscrupulous use of antibiotics is a current global concern. This is the biggest driver of antimicrobial resistance. By 2050, it is projected that antibiotic resistance will be responsible for over 10 million deaths in the world with an associated global economic burden of nearly US$100 trillion (Sanganyado and Gwenzi, 2019; Chamosa *et al.,* 2017). Antimicrobial resistance can be spread from the environment to domestic use water sources; likely aiding a threat to human health and sustainable development (Chamosa *et al.*, 2017; Review on Antimicrobial Resistance, 2016; Sanganyado and Gwenzi, 2019). Numerous studies have documented antimicrobial resistance bacteria and genes in a diverse range of water sources including in untreated domestic use water sources such as wells and more surprisingly treated tap and bottled water (Alonso, *et al.*, 2001; Wang *et al.*, 2016).

2.4. Indicators of antimicrobial resistance

To test for antimicrobial resistance, one has to use and indicator bacteria. Indicator, *Escherichia coli* is the most frequently relied on as a proxy to test for Antimicrobial resistance in biological and environmental samples. It is used because it is common in animal feces and offers information on resistance in a population (European Food Safety Authority 2012; Sanganyado and Gwenzi., 2019).

Resistance to multiple groups of antibiotics is not unheard of in bacteria isolated from animals and humans (Harwood *et al.*, 2000). The indiscriminate pressure enacted on the normal flora in the digestive by antimicrobial use lead to patterns of antimicrobial resistance that imitate to some degree the micro-flora's contact to antibiotics (Harwood *et al.*, 2000; Sørum and Sunde., 2001). Numerous literature has recorded that antimicrobial resistance displays observed in *Streptococci* and *Escherichia coli* can be used as phenotypic indicators to conclude the source of contamination in the environment (Harwood *et al.*, 2000; Sørum and Sunde. 2001).

2.5.Ground water

Groundwater is one of the crucial sources for domestic, industrial and agricultural water in the world; over 2 billion people around the world depend on this water for their domestic use, industrial and irrigation water needs of about (Mumma *et al.,* 2011). Ground water comprises of over 97% of readily available fresh water sources. Most of the developing world like Somaliland are dependent upon freshwater resources from ground sources (Kumar *et al.,* 2015).

Although generally considered as safe, most ground water sources are mostly vulnerable to physico-chemical and pathogen pollution due to their shallowness and low depth (Gichumbi *at el.,* 2012). If ground water has great amount of numerous ions and chemicals, it is use for domestic has a potential risk on the health of the water users (Kumar *et al.,* 2015). Overreliance of fertilizers in farming and emissions from industrial and domestic waste often infiltrate through the soil to water bearing rocks (Kumar *et al.,* 2015; Gichuki and Gichumbi, 2012; Murhekar, 2011). As water seeps through soil, it dissolves various minerals and chemicals in the rocks, collects loose particles predominantly those of organic origin and may collect pathogens that eventually contribute to ground water pollution (Ombaka *et al.,* 2013; Kumar *et al.,* 2015). The adulteration of groundwater by heavy metals such as mercury has been considered with great significance over the past few years due to their potential toxicity and due to the accumulative behavior in causing toxicity (Ombaka *et al.,* 2013; Gichuki and Gichumbi, 2012; Kumar *et al.,* 2015). The evaluation of the concentration and levels of heavy metals ground water as well as the determination of the chemical forms in which these heavy metals appear has become a research focus in recent years (Baquero *et al.,* 2011; Gichumbi *at el.,* 2012, Ombaka *et al.,* 2013; Kumar *et al.,* 2015;).

2.6.The key physio-chemical attributes of ground water

The distinctiveness of chemical properties of water is on its ability to dissolve and or suspend various compounds; water is hence often contaminated with various compound from it environment (Kumar and Kumar., 2013; Murhekar., 2011). Due anthropogenic factors that constantly raise the quantity of soluble and insoluble compounds from domestic, agricultural and industrial wastes; ground water is often contaminated (Jain and Agarwal., 2012; Onwughara *et al.,* 2013). Water contamination alters the biological, chemical and physical quality of water and this may have an impact on the suitability of water for various uses (Kumar and Kumar., 2013).

Key physical parameters water that may be affected by various contaminants may include; the waters' temperature, electrical conductivity, pH, and turbidity. Determination of total dissolved solids, dissolved oxygen, hardness and alkalinity is useful in understanding the physiochemical quality of the water (Jain and Agarwal., 2012; Obot *et al.,* 2012; Kumar and Kumar, 2013; Onwughara *et al.,* 2013). There are permitted levels under which the parameters mentioned should not permit after which water is considered unsafe for domestic use (Lemna, 2012; Onwughara *et al.,* 2013).

2.6.1. PH

Evaluates the strength of the acidity or alkalinity (Murhekar, 2011; Onwughara *et al.,* 2013) and it is an indication of water that is altering chemically (Kumar *et al.,* 2015; Gichuki and Gichumbi, 2012;Lemna, 2012). The allowable standard for the water pH 6.5-8.5; low pH readings indicate water that is acidic and this water can result in health difficulties in human beings especially in the digestive system (Buridi and Gedala, 2014; Onwughara *et al.,* 2013).

2.6.2. Electrical conductivity

The electrical conductivity of water is one of the most significant parameter to evaluate the quality of the sample of water. It is interrelated to the measure of the compounds or solids present in the water (Nirmala *et al.,* 2012; Lemna *et al.,* 2012). Conductivity of water is measured by determining the ionic elements in the water. These ionic elements in water and also dependent on movement of these elements at a certain physical condition of water such as its temperature (Kumar *et al.,* 2015; Nirmala *et al.,* 2012). Electrical conductivity determines salinity of water a parameter that critically affects the taste of water, electrical conductivity also illustrates the existence of dissolved ions in the water. A higher electrical conductivity could be due to presence of higher volume of ionizable salts in water (Nirmala *et al.,* 2012; Lemna *et al.,* 2012; Jain and Agarwal, 2012; Kumar *et al.,* 2015) and this distresses germination of seeds in crops resulting to low crop harvests (Kumar and Kumar, 2013).

2.6.3. Turbidity

Achieving low turbidities in water for domestic consumption is a proven indicator of pathogen removal assuring access to safe and quality water. Turbidity can be used to evaluate source water quality. It has an impact on the color of water and encourages microbial growth causing contamination of water (Kumar *et al.,* 2015; Olumuyiwa *et al*, 2012; Lemna *et al.,* 2012; Jain and Agarwal, 2012). Studies show that higher level of turbidity is interrelated with rainy seasons while lower turbidity correlates with seasons when it is dry (Oluyemi *et al.,* 2014). Swift changes in turbidity can suggest substantial contamination of water. Changes in turbidity should be evaluated to determine causes and to undertake appropriate corrective actions (Sanganyado and Gwenzi, 2019; Chamosa *et al.,* 2017).

2.6.4. Total dissolved solids

This is a vital parameter that measures of the portion of organic and inorganic solids passing through the same filter (Gichuki and Gichumbi, 2012). Total Dissolved Solids can be measured directly by weighing the remains remaining following evaporation of a known amount of the filtered water sample (Sanganyado and Gwenzi, 2019; Gichuki and Gichumbi., 2012, Chamosa *et al.,* 2017). Total Dissolved Solids can be determined indirectly by the addition of measured concentrations of substances in the filtrate or approximated by factoring a calculated conductivity value by an empirically designed conversion factor 0.67 that is commonly is used in most natural water systems (Sanganyado and Gwenzi. 2019; Gichuki and Gichumbi., 2012, Nirmala *et al.*, 2012; Chamosa *et al.,* 2017). Water that has Total Dissolved Solids above acceptable limits may cause health problems to end users including gastrointestinal irritation; water is often not palatable due to its hardness and corrosive attributes (Sanganyado and Gwenzi, 2019; Nirmala *et al.*, 2012; Gichuki and Gichumbi., 2012, Chamosa *et al.,* 2017).

The constituents of Total Dissolved Solids may include minerals, metals and metalloids, and in addition dissolved organic matter (Nirmala *et al.,* 201; Jain and Agarwal, 2012). A high level of high Total Dissolved solids is indicative of water with a higher mineral content most likely due to the existence of rocks components in the area which are resilient to suspension (Jain and Agarwal, 2012; Kumar and Kumar, 2013). Elevated levels of total dissolved solids may also be credited to the surface run-off of organic and inorganic compounds which may make water unfit for domestic use (Olumuyiwa *et al.,* 2012; Kumar and Kumar, 2013).

2.6.5. Dissolved oxygen

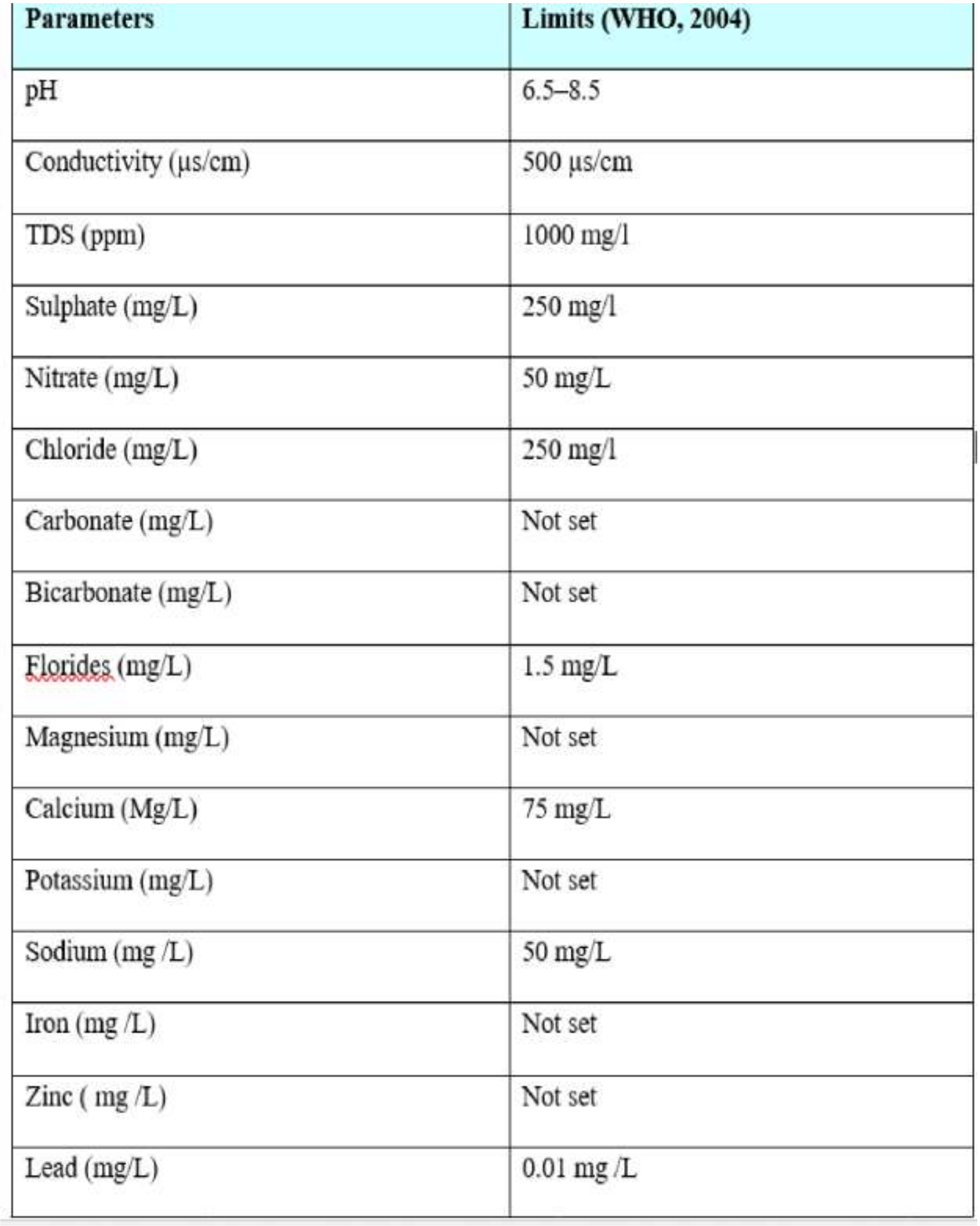
The determination of dissolved oxygen is one of the most regularly used of all chemical methods accessible for the exploration of the aquatic environment (Olumuyiwa *et al.,* 2012; Kumar and Kumar, 2013; Murhekar, 2011). Dissolved oxygen delivers valued information on the biological and biochemical activities of waters; it is a measure of one of the imperative environmental factors affecting marine life and of the capability of water to obtain organic matter devoid of causing annoyance (Murhekar, 2011; Olumuyiwa *et al*, 2012).

Oxygen dissolves easily in fresh waters. Water gains oxygen from the atmosphere or from photosynthesis by aquatic plants and is exploited by many respiratory and inorganic chemical reactions (Murhekar, 2011; Olumuyiwa *et al*, 2012). The quantity of dissolved oxygen in water is dependent on other psychochemical properties of water including its temperature and the concentrations of various ions and metals (Olumuyiwa *et al*, 2012; Buridi and Gedala, 2014).

2.6.6. Ions and Cations in water

Nearly all waters existing in nature acquire ions such as calcium and bicarbonate as water interacts with rocks and sediments in the environment. Even the unpolluted rainwater has some hydrogen- and bicarbonate ions from its interaction with carbon dioxide in the atmosphere (WHO, 2008; Ombaka *et al.,* 2013). There are a variety of dissolved polyvalent metallic ions that can be established in water. They may include, magnesium, calcium, sodium, potassium, fluoride, nitrate, chloride and phosphates. Existence of these ions and cations is often considered important for living organisms but there are set threshold that the concentration cannot go above (Nkansah and Ephraim, 2009; Murhekar, 2011).

Table 1. WHO guidelines 2004 on the maximum allowable limits



Parameters	**Limits (WHO, 2004)**
pH	6.5–8.5
Conductivity (µs/cm)	500 µs/cm
TDS (ppm)	1000 mg/l
Sulphate (mg/L)	250 mg/l
Nitrate (mg/L)	50 mg/L
Chloride (mg/L)	250 mg/l
Carbonate (mg/L)	Not set
Bicarbonate (mg/L)	Not set
Florides (mg/L)	1.5 mg/L
Magnesium (mg/L)	Not set
Calcium (Mg/L)	75 mg/L
Potassium (mg/L)	Not set
Sodium (mg /L)	50 mg/L
Iron (mg /L)	Not set
Zinc (mg /L)	Not set
Lead (mg/L)	0.01 mg /L

Anthropogenic factors such as over reliance of inorganic fertilizers and leachate from untreated sewage has been demonstrated to introduce ions and affect their natural concentration to exceed permissible volumes (Jain and Agarwal, 2012; WHO, 2011). Consumption of water with exceedingly high level of these ions and cations has been linked to cardiovascular disease, cancers, Digestive health and constipation, urogenital conditions, cerebrovascular disease and may affect bone mineral density (Murhekar., 2011; WHO, 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was carried out in Hargeisa, Somaliland's capital city. Somaliland declared independence from Somalia in 1991, but the international community still considers it to be a part of Somalia. Somaliland is located in the Horn of Africa, between northern Somalia and the southern coast of the Gulf of Aden. Hargeisa City has a population of about 1.03 million people (CIA factbook, 2022). Hargeisa Water Agency (HWA) is the government agency in charge of drinking water supply in Hargeisa, and supply piped water to approximately over 30% of Hargeisa residents (HWA, 2018). The rest of the population in Hargeisa obtain drinking water from a number of unmonitored sources including the water trucks from wells in neighboring villages. The coordinates of the sampled sites were collected and the map of Hargeisa city indicating the sampled areas were developed as indicated in Figure 1.

Figure 1. *Water Sampling points in Hargeisa city - (Map source - FAO SWALIM)*

3.2 Study design

A cross-sectional study was conducted to determine the Bacteriological, physical and chemical quality of drinking water in Hargeisa City. Laboratory investigation carried out on water samples collected from bottled, piped and wells water sources in Hargeisa City. The bacteriological research was carried out from July to August 2020 in Hargeisa and Physical and chemical analysis were carried out in January and February 2021.

3.3 Sampling

3.3.1 Bacteriological examination

Water samples were obtained from three water sources: piped, bottled and Wells. Eighty-five water samples were collected for this study, of which 55 were bottled water, 15 samples each were obtained for both well and piped water.

3.3.1.1 Bottled water

In Somaliland, 15 privately owned companies supply bottled water, and of these, eleven water brands from these companies were sampled. The 11 brands (equivalent of 73 % of total population) which are mainly available on the shelves of the shops in the study area were sampled. Five different batches of each brand were sampled.

3.3.1.2 Piped water

Hargeisa's piped water comes from about 13 boreholes in Geeddeeble village. Pipes transport water from Geed deeble reservoir to Biyo shiinaha reservoir (the central water storage of Geeddeeble). The water is then transferred to the reservoirs in the Sheedaha area (northern Hargeisa City), where it is distributed via small pipes to supply drinking water. For this water, no specific treatment procedure was observed. Since, the source of piped water is from one reservoir (Biyoshiinaha reservoir), 15 samples were collected and processed to assess their quality.

3.3.1.3 Wells water

Hargeisa's water agency serves only about 30% of the City's population; therefore, tankers collect water from wells dug in nearby villages to supply the vast majority of the town. These privately owned wells are located in Hargeisa's eastern (Aw Barkhadle and Dararwayne) and western neighboring villages (Arabsiyo). Families receive water via tanks, barrels (locally referred to as foosto) depending on their financial situation. Therefore, 15 families who receive water from 15 different Wells were sampled.

3.3.2 Physicochemical examination

Chemical analysis was subjected to 30 samples equally distributed to all three sources, 10 samples were drawn from each water source (Piped, bottled and wells) for the chemical analysis. Ten out of Fifteen packaged water companies supplied one sample. Because the pipe water from HWA is known to come from a single reservoir that supplies the entire City, ten samples were collected from ten households that receive piped water and ten samples from ten households that receive water from different wells were sampled.

3.4 Sample collection procedure

3.4.1 Piped and Wells Water

The water was pumped out and allowed to run to waste for three minutes (for pipe water) to clear the water within the pipe system. After which the outlet was sterilized using 70 % alcohol and then flamed.

Figure 2 Sterilizing pipe before collecting water samples

Figure 3 collecting water samples from households

The sample bottle was held from the bottom, opened and the mouth was flamed and filled with 500 ml of water. The sample was clearly labeled (date, number, collection site, time, and temperature) and packed in a lightproof container with an ice-cold before being transported to the Somaliland's Ministry of Livestock and Fisheries Development (MoLFD) laboratory in the same day and processed within 24 Hours. Further, water samples (250 ml) for chemical analysis were collected in plastic bottles (because they are non-reactive to chemicals), refrigerated at 4^{o}C and transported from Somaliland to the Soil Chemistry Research Laboratory at Nairobi University in January and February 2021.

3.4.2 Bottled water

Eleven (11) brands were chosen at random from a pool of fifteen (15) available on the market. Bottled water was collected at shops, and five different batches of 750 ml from each selected brand were collected. After collection, the samples were labeled with the collection date, time, and place of purchase before being transported in a lightproof cool box packed with ice to the Ministry of Livestock and Fishery Development (MoLFD) laboratory in Hargeisa, Somaliland. 250 ml of water samples for chemical analysis were collected in plastic bottles and transported from Somaliland to the Soil chemistry research laboratory at Nairobi University.

3.5 Exclusion criteria

Bottled water samples with damaged packaging or expired dates were rejected and were therefore excluded from this study. Households that use well water but store it in containers other than tanks (minimum five barrels) were excluded from this study.

3.6 Laboratory Sample Analysis

3.6.1. Bacteriological analysis

The bacteriological analysis was carried out using the enumeration of indicator organisms. Total coliforms, *Escherichia coli*, and Faecal S*treptococcus* counts were performed. In addition, the isolated organism was subjected to a drug sensitivity test.

3.6.1.1 Presumptive coliform test

The most probable number (MPN) method used to enumerate the total coliforms in drinking water (McCrady’s, 1915). Fifty ml of double strength MacConkey broth (Oxoid), was put in to the bottle. In addition to that, 10 ml of the same broth was disseminated into five universal bottles. 5ml single strength Mackonkey broth were put into a set of five fermentation tubes. Inverted

Durham tubes were availed with all universal bottles and tubes. The broth was sterilized in an autoclave at 121 °C for 15 minutes and allowed to cool.

Before inoculation, water samples were rapidly mixed. Using a sterile pipette, 50 and 10 ml of the sample were put into bottles containing 50 and 10 ml of double strength broth, respectively, and 1 ml of the sample was decanted into each of the 5 fermentation tubes holding 5ml of single strength broth. The bottles and tubes were placed into an incubator at 37°C for 24 hours and the gas and acid production was monitored. The positive presumptive test was indicated by gas and acid production. Using the McCradys probability tables, the MPN of coliforms in the 100 ml well water sample was estimated (Bartram, *at el.*, 1996).

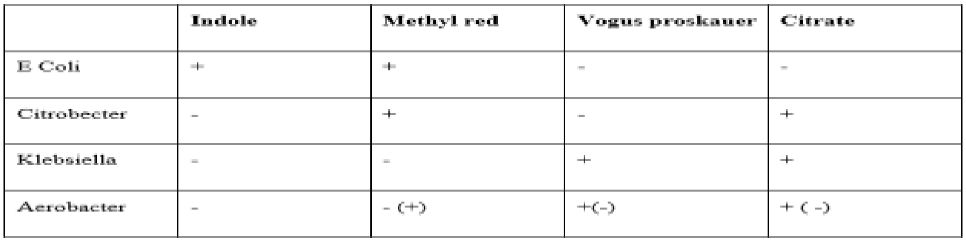
3.6.1.2 Test for *Escherichia coli*

Samples from the positive broth was streaked onto Eosin methylene blue (EMB) agar and incubated for 24 hours for 24 hours at 37 °C. A thin smear of gram staining from the green metallic seen was conducted and confirmed by biochemical test ("Standard Methods for the Examination of Water and Wastewater," 2012).

3.6.1.3 Biochemical test

The bacteria isolated were subjected to a number of biochemical test for identification of E coli known as IMViC Tests which stands for indole production, methyl red for acid production, Voges -Proskauer and citrate utilization (Baird *et al.*, 2017). The table 2 indicated the different characteristics that each coliform will show indicate IMViC test.

Table 2. Interpretation of the IMVIC test.



	Indole	Methyl red	Vogus proskauer	Citrate
E Coli	+	+	-	-
Citrobecter	-	+	-	+
Klebsiella	-	-	+	+
Aerobacter	-	- (+)	+(-)	+ (-)

3.6.1.4 Faecal *Streptococci*

The water samples were shaken well, and their stopper was flamed and open. A 100 mL sample of water was filtered using sartorius membrane filters with a pore size diameter of 0.45 µm, and the filter was aseptically transferred onto the Slanetz and Bartley agar (Oxoid) plate by means of a sterile forceps. Following that, the plates were placed at 37°C for 24 hours, and the plates were examined for characteristic maroon colonies, which were enumerated and recorded as fecal *streptococci* per 100 ml of the water sample.

3.7 Antibiotic sensitivity test of *E. coli* serotypes

Antimicrobial disk diffusion tests were performed to assess the susceptibility of microorganisms isolated from water to a variety of antimicrobial drugs (Jain and Agarwal, 2012; WHO, 2011; Bauer *et al.,* 1966). The Kirby Bauer disc diffusion method was used to test antimicrobial sensitivity using Mueller Hinton agar. Approximately 0.1ml of *E.coli* water samples were spread-plated onto Mueller Hinton agar and then overlaid with an antibiotic diffusion disk containing an array of antibiotics including but not limited to Tetracycline, Chloramphenicol, Streptomycin (S 10 mcg), Penicillin G, Amoxicillin, Vancomycin, Ceflaxine, Gentamycine, Ampicillin, Ceftraixone, and Doxycycline mcg, The plates were then be incubated overnight at 37°C. Zones of inhibition were measured and the results were compared with zone size interpretation chart of the manufacturer and the results were organized in to three category, Sensitive, intermediate and resistant (Jones, 1986).

3.8 Physicochemical parameters

Physical and chemical parameters from piped, bottled and Well water sources are conducted at NEMA accredited Soil Chemistry Research Laboratory at University of Nairobi. The parameters were determined according to the standard procedures for the examination of water and wastewater (APHA, 1998). The determination of pH, EC and TDS was measured by using with multi parameter

HI98194**.** The determination of metal (Na, Mg, K, Ca, Zn, and Pb) values in water was used through Atomic Absorption Spectrophotometer (ASS), fluorides and Nitrites were measured through selective electrodes ion concentration methods. Chlorides carbonate and Bi carbonate was measured through titration. UV/Vis spectrophotometer was used to determine the Sulphate quantities in water samples.

3.9 Label information

The label information on the bottled water brand was collected and recorded in an excel spreadsheet, to compare this data to the laboratory findings of the same brand's samples.

3.10 Data management and analysis

Data on physical, chemical and bacteriological qualities of water were entered into a database developed in Microsoft excel. The data were exported to a SPSS statistical software for further analysis to assess variation and central tendency, descriptive statistics such as mean, range, median and standard deviation were used. The one-way ANOVA test was used to assess if there was a significant difference in the physical, chemical and bacteriological quality of the various water sources. T-test was used to determine the difference between the label information and findings from the bottled water.The prevalence of *E. coli* and *Streptococcus fecalis* contamination in water samples was determined by dividing the number of samples with counts greater than zero CFU/100 mL by the total number of samples analyzed. The mean levels were compared to WHO and SQCC standards to determine the water's suitability for drinking.

CHAPTER FOUR

RESULTS

4.1. Bacteriological results

The results of feacal and total coliforms of water samples tested from 55 bottled water 15 wells and 15-piped water in Hargeisa City are presented in Table. The sampling of water was conducted at end consumer level for bottled and household level for pipe and well water.

Table 3 Summary Bacteriological Results

Source of water	**Sample size**	***Coliform* (%)**	***E. coli* (%)**	**Streptococus fecalis (%)**
Bottled	55	16%	13%	15%
Piped	15	87%	47%	53%
Wells	15	93%	73%	67%

4.1.1. Total coliform count

16 % (n=55) of bottled, 87 % (n=15) of pipe, and 93 % (n= 15) of Wells water demonstrated evidence of lactose fermenting coliform in the water samples (Table 3). The MPN index for coliform ranged from 0- > 161 CFU/ 100ml. Wells water had the highest average Cfu/100 at 106.1 colonies per 100ml of water, while bottled water had the least Cfu at 7.8 per 100ml.

The mean value for bottled water was 7.8, while piped and well water had 58.9 and 106 cfu/100ml respectively for total coliforms, reflecting unsafe water based on WHO and SQCC guidelines recommends 0 MPN index/ 100ml. There is high variability (338 %) recorded in samples from bottled, compared to well (65%), and piped water had the least variability at 11 %. The source of drinking water had statistically significant impact to the level of coliforms in the water F (2, 32) = 3.1, $p < 0.001$.

4.1.2. *Escherichia coli*

Thirteen percent (13 %) of the bottled, 47% of the piped, and 73 % of the well's water showed evidence of *E.coli* contamination (Table3). The highest prevalence (73%) of E. coli is recorded from the samples collected from the households consuming water from wells. Therefore, the study found that 13 % of the bottled water sampled, 47 % of the pipe water, and 73 % of the wells sampled are not compliant with WHO and SQCC guidelines of 0 Ecoli / 100ml of drinking water.

4.1.3. *Streptococcus fecalis*

This study revealed that 15 % of the bottled, 53 % of piped water, and 67 % of the well waters at the household level have at least two colonies / 100ml of *Streptococus fecalis* (Table3). Therefore, they are not safe for drinking since they are not compliant with WHO and SQCC drinking water guidelines for *Streptococcus Fecalis* of 0 colonies / 100ml for drinking water.

4.2 Antibiotic sensitivity test for E.coli isolates

The E. coli isolates (15) were subjected to sensitivity tests to eleven antibiotics namely; Tetracycline, Chloramphenicol, Streptomycin (S 10 mcg), Penicillin G, Amoxicillin, Vancomycin, Ceflaxine, Gentamycine, Ampicillin, Ceftraixone, and Doxycycline mcg). Results of antibiotics sensitivity to E. coli are shown in Table 3.

Table **4.** Antimicrobial susceptibility test (%) results for the seven antimicrobials against *E coli*

Type of antibiotics	**Specification**	***E coli*** **n = 15**		
		S	**I**	**R**
Tetracycline	30 mcg	60	10	30
Chloramphenicol	30 mcg	80	10	10
Streptomycin	10 mcg	70	30	0
Penicillin G	10 mcg	0	0	100
Amoxicillin	10 mcg	0	20	80
Vancomycin	30 mcg	0	0	100
Ceflaxine	30 mcg	60	0	40
Gentamycine	120 mcg	100	0	0
Ampicillin	10 mcg	10	0	90
Ceftraixone	30 mcg	80	10	10
Doxycycline	30 mg	20	40	40

Legend: n= number of Samples S = Susceptible I = Intermediate R = Resistant

For quality control, the ATTCC 29522 was used as the standard quality control organism for *E. coli.* The test organism in (table 3) was highly sensitive to Gentamycine (100 %), Chloramphenicol

(80%), Ceftraixone (80 %), Streptomycin (70 %) and moderately responsive to Tetracycline (60%), and Ceflaxine (60 %) . The *E. coli* found to be resistance to Penicillin G (100%), Vancomycin (100 %), Ampicillin (90 %), and Amoxicillin (80 %). Percentage of resistance was noted in all the antibiotics drugs tested against *E. coli* except Gentamycin (Table 4).

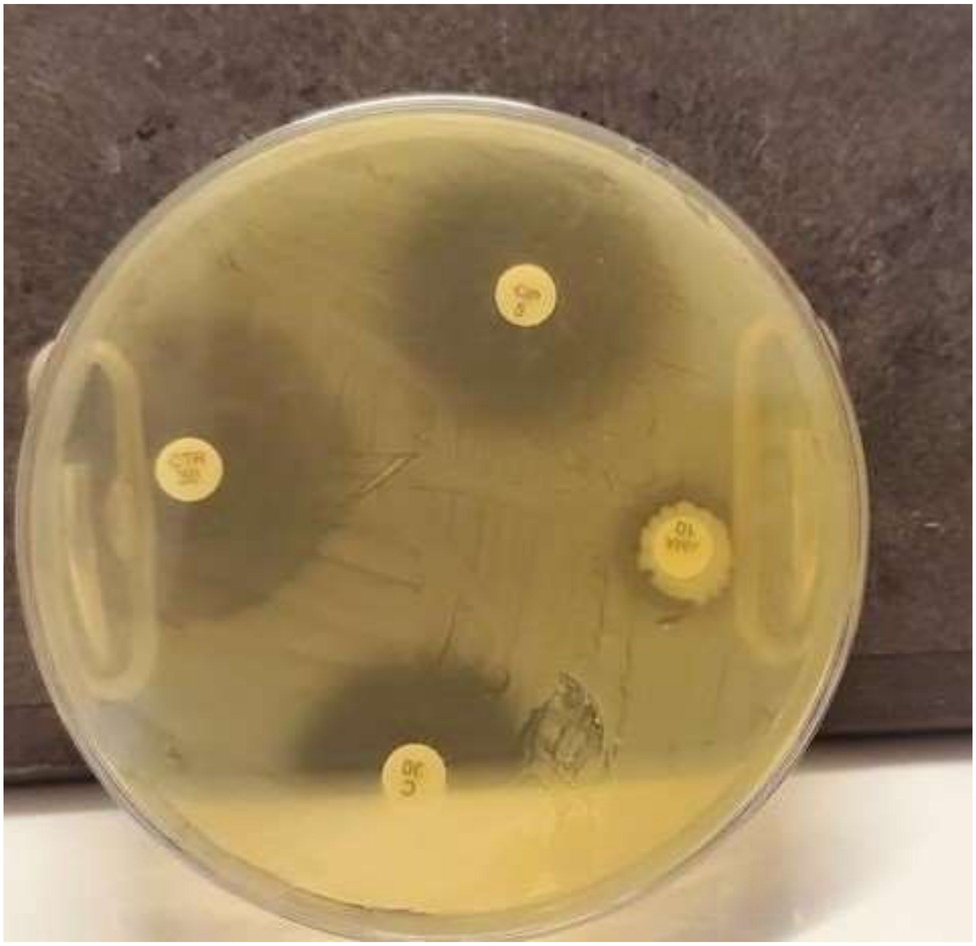


Figure 4 the zones of inhibition indicated against E. Coli isolates

4.2. Physiochemical results

4.2.1. General physiochemical results

Thirty (30) samples collected from three different drinking water sources in Hargeisa City were analyzed. The summary of the means and WHO standards limit are presented in the below table.

Table 5 Physicochemical Analysis of Drinking Water in Hargeisa City

Parameters	Samples			Limits	Limits
	Bottled	Piped water	Well	WHO, 2004	SQCC, 2021
pH	7.7	8.5	8.6	6.5–8.5	6.5–8.5
Conductivity (µS/cm)	84.4	1399.8	1014.0	500 µS/cm	1500 µS/cm
TDS (ppm)	22.5	559.4	363.8	1000 mg/L	700 mg/L
Sulphate (mg/L)	11.1	47.7	63.0	250 mg/L	400 mg/L
Nitrate (mg/L)	0.3	7.2	4.2	50 mg/L	45 mg /L
Chloride (mg/L)	2.3	40.5	36.2	250 mg/l	250 mg/L
Carbonate (mg/L)	0.0	9.0	1.0		
Bicarbonate (mg/L)	41.1	266.3	263.0		
Florides (mg/L)	0.1	1.1	1.0	1.5 mg/L	1.5 mg /L
Magnesium (mg/L)	6.0	62.5	46.4		100 mg /L
Calcium (Mg/L)	10.8	74.5	58.8	75 mg/L	150 mg/L
Potassium (mg/L)	0.8	2.8	2.8		
Sodium (mg /L)	7.5	20.7	15.9	50 mg/L	200 mg/L
Iron (mg /L)	ND	ND	ND		0.3 mg/L
Zinc (mg /L)	ND	ND	ND		5 mg/L
Lead (mg/L)	ND	ND	ND	0.01 mg /L	0.01 mg/L

ND = Not detected
N.B = SQCC standards for drinking water are still in draft and has not yet adopted

4.2.2. pH

The pH of the water samples collected ranged between 7.3 and 8.9. Water samples from wells had the highest mean pH value at 8.6, while bottled water had the lowest mean value of 7.7 (Figure 5). The mean from Well water was above the WHO recommended pH level 6.5 – 8.5 (Table 5) but bottled, and piped water sources were within WHO recommended guidelines.

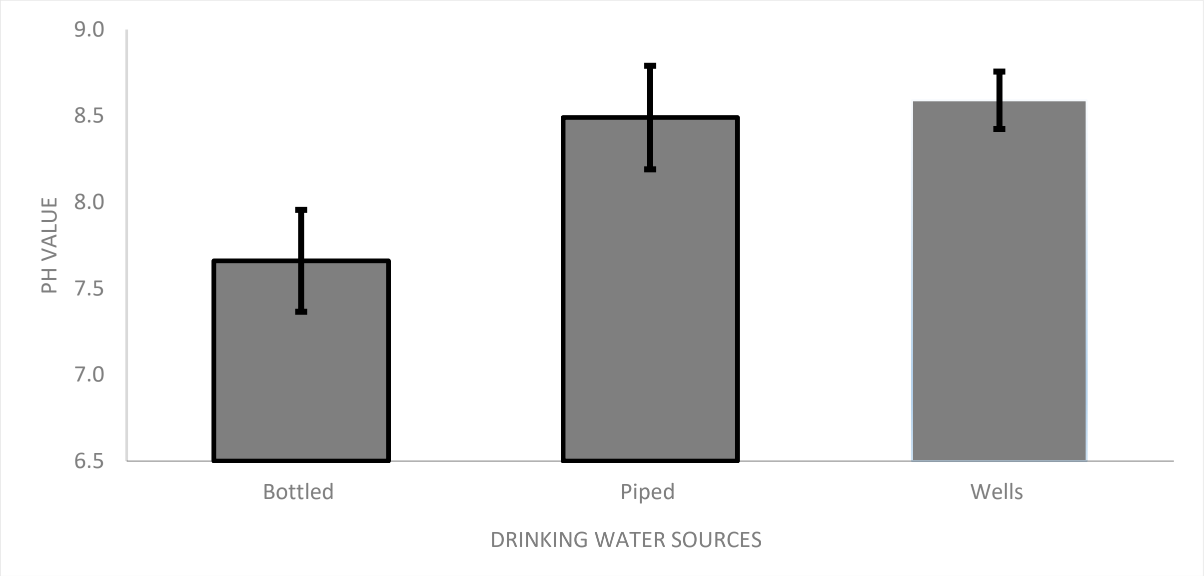


Figure 5. The pH values recorded from different source of drinking water in Hargeisa City.

The source of drinking water had statistically significant impact to pH level in the water F (2, 38.2) = 3.6, *p* < 0.001, which indicated that at least one of the means is different.

4.2.3. Total Dissolved Solids

The TDS value of all sampled drinking water has ranged between 1036 mg/L to 46 mg/L. However, the piped water samples had the highest mean value at 552.9 mg/L, followed by Well water (363.8 mg/L) and bottled water at just 24.3mg/L (Table 5). The TDS mean findings in this study have are within the WHO and SQCC recommended limit of 1000mg/L. However, there was individual sample from Well water, which was slightly above (1036 mg/L) the WHO limit for TDS(Table 5).Variation of water samples within the same source were observed at 45% for bottled water, 2 % for piped and 70% for Well water sources. The source of drinking water had statistically significant impact to TDS level in the water F (2, 72.5) = 3.4, *p* < 0.0001.

4.3.4. Electric Conductivity

The Electric Conductivity of water samples was found to be in the range 300 - 2587.5 µs/cm. The piped water sources had the highest mean value (1399.8 µs/cm), followed by Well water at 1014 µs/cm (Graph 6). The bottled water electric conductivity was found to be the least 84.4 µs/cm. The mean value of water samples from pipes and well were above the WHO recommended limit of 400 µs/cm (Table 5).

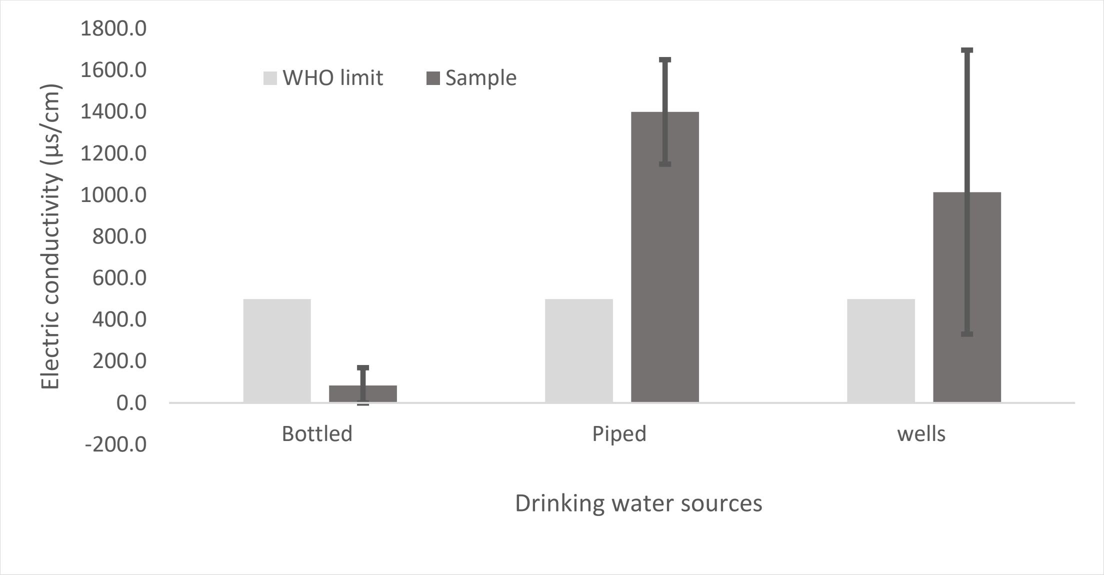


Figure 6. Average Electric conductivity against WHO recommended limit

The Electric Conductivity has a direct relationship with TDS and this trend has been observed in all the samples analyzed in this research with a positive correlation of 0.947 (Table 6).

The range of water samples varied considerably from 25 µs/cm to 2587.5 µs/cm; the Coefficient of variation of the results indicated high sample variability Bottled at 101% followed by Well at 67 %, and piped water at 17 %.

The pipped water value (M = 1 1399.8 µs/cm, SD = 251.3), well water value (M = 1014.0 µs/cm, SD = 683.1) and Bottled water values (M = 84.4 µs/cm, SD = 85) was analyzed and found they had statistically significant impact to EC level in the water F (2, 23) = 3.4, *p* < 0.0001.

4.3.5. Fluorides

The mean fluoride concentration was 1.14 mg/L in the piped, 0.07 mg/l in bottled, and 1.02 mg/l in water from Wells. All sampled water sources were within the WHO limit (1.4 mg/l.) (Table 5).

The fluorides concentration of sampled water from different sources ranged from 0.03 to 1.35 mg/l. Samples from bottled water had the highest coefficient of variation hence the highest variability of data at 71 %, followed by wells water at 36%. Piped water has the lowest data variability at 5 %. The study revealed a significant statistical difference between the fluorides mean value and water sources F (2, 70.7) = 3.4 $p < 0.0001$. Hence, the source of drinking water had significant impact to fluoride level in the water**.**

4.3.6. Nitrates

The Nitrate value in this research varied from 2.5 to 5.6 mg/L. The mean value of Nitrate in Piped water was highest at 7.2 mg/L, followed by Well (4.2 mg/L), while Bottled water had the least mean value of Nitrate at 0.3 mg/L(Table 5).. The study found this value to be below the WHO recommended limit of 50 mg/L. The samples range varied from 0.1 mg /L in bottled to 8.4 mg/L in pipe water. The source of drinking water had significant impact to Nitrate level in the water F (2, 72.5) = 3.4, $p < 0.0001$.

4.3.7. Sulphates

According to WHO the highest desirable Sulphate limit in drinking water is 250 mg/L and study found that all water sources were within WHO and SQCC limit for drinking water safety.

The sample ranged between 2.8 to 159.9 mg/l. High sample variability was recorded in both well and bottled water at 211% and 141 %, respectively. The water samples from pipe sources had the least variability at 37%. The mean value for Sulphates were 47.5 mg/g, 11.1 mg/l, and 62.97) for pipped, bottled and well water respectively and were all within the WHO safety limit. The source of drinking water had significant impact to Sulphate level in the water F (2, 9.7) = 3.4, $p < 0.0001$.

4.3.8. Calcium

The concentration value of calcium in drinking water was 74.5 mg/l in Piped water, 10.8mg/l in bottled water, and 58.8 mg/l in well water, which were within the WHO (100 mg/L) and SQCC (100 mg/L) desired limit for drinking water (Table 5).

The sample range varied from 4.3 mg/L to 117.5 mg/L. Bottled and well water sources had the highest variability at 63 % and 55 %, respectively, while data variability of piped water was 17%. The study revealed a significant statistical difference between the calcium mean value and water sources; hence, the source of drinking water had significant impact to Calcium level in the water F (2, 26.1) = 3.6 $p < 0.0001$.

4.3.9. Magnesium

Magnesium's mean value in sampled water sources was 62.5 mg/l for the piped water, 6 mg/l in the bottled water, and 46.4 mg/l in well water sources (Graph 7). According to WHO the permissible range of magnesium in drinking water should be 50 mg/l. The mean value of bottled and Well sources were within the WHO guidelines; however, piped water (62.5 mg/l**)** was beyond WHO guidelines (Table 5).

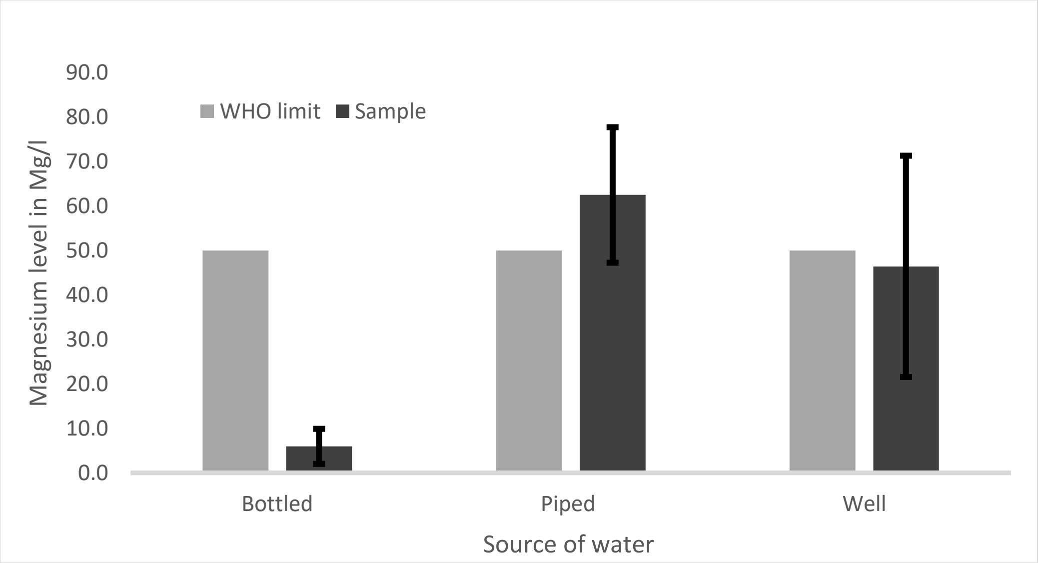


Figure 7. Mean Magnesium level against WHO recommended limit

The value of Magnesium from different sampling sites irrespective of the sources varied from 2.5 mg/l to 102.7mg/l. Samples from wells sources had the highest coefficient of 315 %, followed by bottled water at 65%. Pipe water has the lowest data variability at 24 %. The study revealed the source of drinking water had significant impact to Magnesium level in the water F (2, 29.4) = 3.6 $p < 0.0001$.

4.3.10. Sodium and Potassium

The acceptable level of concentration of sodium and potassium water used for drinking is 200 mg/L and 12 mg/L, correspondingly. The range of sodium level in study area vary from 4 mg/l to 14 mg/l, and bottled water had the highest data variability of 38 %, and both piped and well water had less variability of 5 % and 31 % respectively . The mean value of sodium for piped were 21 mg/l, wells at 16 mg/l and 8mg/l at bottled water. The sodium level of the drinking water from all sources were within the WHO recommended guideline (200mg/l) (Table 5).

The potassium mean value for both Well, Pipe water was same at 2.8 mg /l, and bottled water was 0.8 mg/l. Those values were within the recommended WHO guidelines (Table 5). The data variability of Potassium level in bottled water was highest at 150 % and both Well and piped water had the same variability level of 25 %. The interaction effect between source of water and sodium and potassium were both statistically significant at F (2, 35.9) = 3.6, $p < 0.0001$ and F (2, 16.4) = 3.6, $p < 0.0001$. This indicated that the source of drinking water had significant impact to Sodium and Potassium level in the water

4.3.11. Chlorides (Cl)

The Chloride mean value of piped water (40.5 mg/L), Wells (36.2 mg/L), and 2.3 mg/L for bottled water were found. The findings were within the WHO (250 mg/L) and Somaliland quality control commission (SQCC) (250 mg/L) chloride limit of drinking water (Table 5).

Bottled water showed a highest variability of 82%, followed by well and piped sources at 37 % and 6% respectively. The source of drinking water had significant impact to Chloride level in the water F (2, 70.7) = 3.4, $p < 0.001$.4.4.

4.4 Physico-chemical correlation

The correlation coefficient was used to assess the degree of connection between various water variables assessed in this study at alpha value for the confidence interval (5%). Significant correlation coefficient values among the physicochemical water quality parameters was observed.

*T*able **6**. Correlation Among all Water Quality Parameters

	pH	EC	TDS	NO_3	F	Cl	CO3	HCO3	K	Na	Mg	SO4	Ca
pH	1												
EC	.714**	1											
TDS	.701**	.947**	1										
NO_3	.714**	.835**	.860**	1									
F	.774**	.637**	.747**	.817**	1								
Cl	.774**	.637**	.747**	.817**	1.000**	1							
CO3	.399*	.436*	.481**	.587**	.436*	.436*	1						
HCO3	.749**	.763**	.756**	.739**	.802**	.802**	.306	1					
K	.568**	.585**	.630**	.679**	.724**	.724**	.378*	.649**	1				
Na	.737**	.795**	.859**	.885**	.850**	.850**	.540**	.751**	.578**	1			
Mg	.734**	.864**	.928**	.871**	.811**	.811**	.559**	.779**	.686**	.875**	1		
SO4	.592**	.757**	.767**	.598**	.585**	.585**	.232	.661**	.579**	.660**	.786**	1	
Ca	.689**	.795**	.874**	.843**	.833**	.833**	.529**	.780**	.682**	.873**	.974**	.747**	1

All elements are positively correlated, and no negative correlation is observed. The TDS showed a high significant positive correlation with Electric conductivity, Magnesium, Calcium, nitrate (0.95, 0.92, 0.87, and 0.86). Calcium revealed high level of correlation with magnesium, Sodium, Nitrates, fluorides, and chlorides (0,97, 0.87, 0.84, 0.83, and 0.83) (Table 6).. Chlorides showed maximum correlation with fluorides (1) but also had a significant correlation with Sodium (0.85), Calcium (0.833), and Bi carbonates (0.80). Nitrates showed a significant correlation with Sodium (0.88) Magnesium (0.87), TDS (0.86) and fluorides (0.81) (Table 6).

4.5. Comparison of bottled label information to lab results

The label information of the bottled sample collected were recorded and the result of the chemical analysis obtained from the same sample were compered. The comparison between the mean of the ten parameters (pH, TDS, Sulphate, Nitrate, Chloride, Bicarbonate, Magnesium, Calcium Potassium, and Sodium found in the majority of the label information is documented.

4.5.1. pH

The pH value of the mean in the label information (M= 7.66, SD= 0.30, n=10) was compared to laboratory results of the bottled samples (M = 7.22, SD = 0.36, n = 10) and found a statistically significant difference. The label information and pH of bottled water had significant difference, t (18) = 2.10, *p* = 0.001 (two tail).

4.5.2. Total Dissolved Solids

The TDS mean value in the label information (M= 81, SD= 42.2, n = 9) was compared to laboratory results of the bottled samples (M = 22.5, SD = 11.7, n = 8) (Graph 8). The label information and actual amount of the TDS in bottled water were statistically significant, t (15) = 2.13, *p* = 0.002 (Two tail). The graph 7 below illustrates the TDS mean value and standard deviation of the bottled water and label information

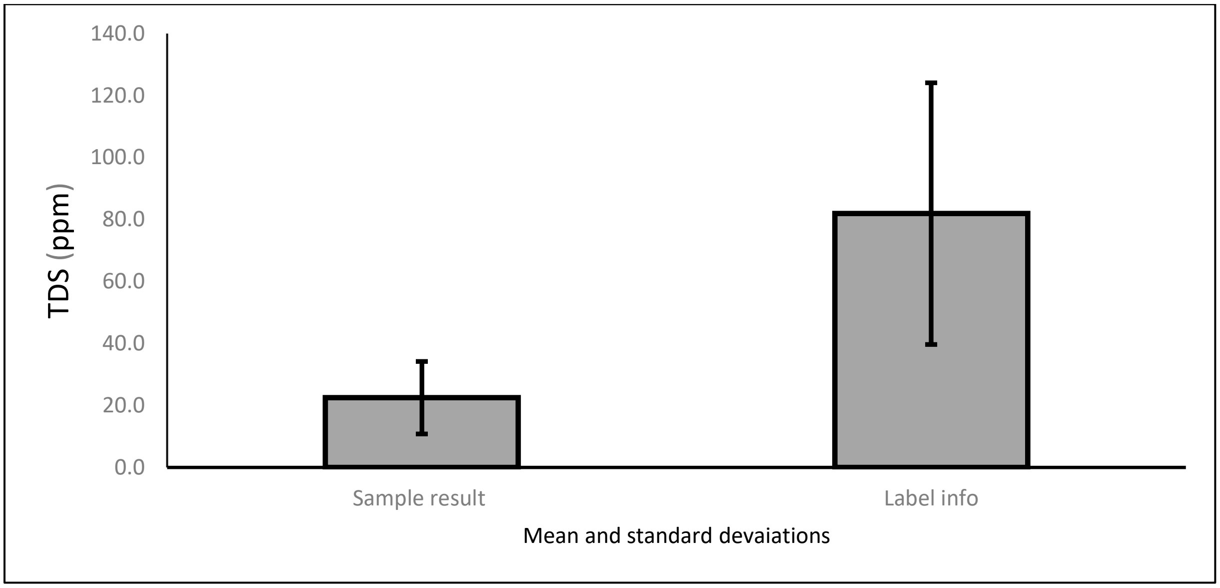


Figure 8. The TDS values from bottled water samples and their label information

4.5.3. Sulphate

The Sulphate mean value in the label information (M= 11, SD= 11.61, n=8) was compared to laboratory results of the bottled samples (M = 11.1, SD = 15.68, n = 10). The label information and actual amount of the Sulphate in bottled water had no statistically significant difference, t (16) = 2.11, *p* = 0.89 (two tail).

4.5.4. Chlorides

The Chloride mean value in the label information (M= 15.57, SD= 13.4, n=10) was compared to laboratory results of the bottled samples (M = 2.3, SD = 1.79, n = 10) (Graph 9). The difference was statistically significant, t (18) = 2.10, *p* = 0.01 (two tail). Indicating that the label information regarding Chloride and actual amount of the Chloride in bottled water were not statistically the same. The graph 9 is indicating the mean and standard deviations of the chloride values

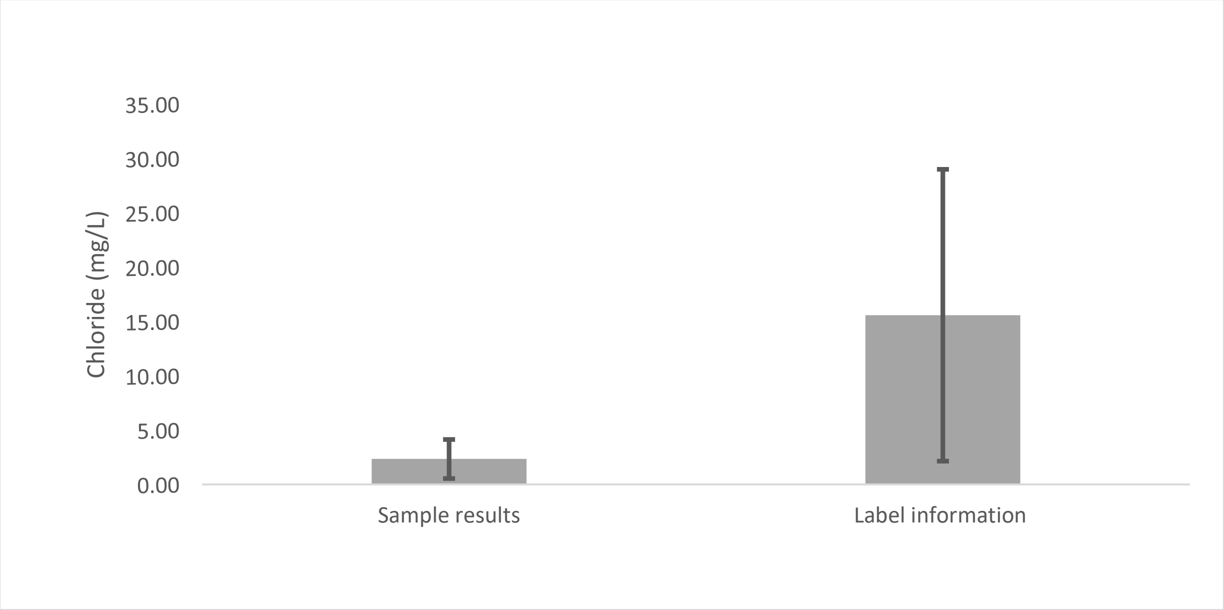


Figure 9. The Chloride values from bottled water samples and their label information

4.5.5. Nitrate

The Nitrate mean value in the label information (M= 2.30, SD= 1.65, n=6) was compared to laboratory results of the bottled samples (M = 0.18, SD = 1.65, n = 10). The difference was statistically significant, t (14) = 2.14, *p* = 0.001 (two tail). Hence, label information regarding Nitrate and actual amount of the Nitrate in bottled water were not statistically the same.

4.5.6. Bi carbonate

The Bicarbonate mean value in the label information (M= 25.3, SD= 12.3, n=7) was compared to laboratory results of the bottled samples (M = 41.1, SD = 12.3, n = 10). The difference was not statistically significant, t (15) = 2.13, *p* = 0.1 (two tail). Therefore, label information regarding Bicarbonate and actual amount of the Bicarbonate in bottled water were statistically the same

4.5.7. Magnesium

The Magnesium mean value in the label information (M= 4.74, SD= 5.54, n=10) was compared to laboratory results of the bottled samples (M = 6, SD = 3.94, n = 10). The label information regarding Magnesium and actual amount of the Magnesium in bottled water were statistically the same, t (18) = 2.10, *p* = 0.6 (two tail).

4.5.8. Calcium

The Calcium mean value in the label information (M= 5, SD =4.66, n=9) was compared to laboratory results of the bottled samples (M = 10.8, SD = 6.9, n = 10). The label information regarding Calcium and actual amount of the Calcium in bottled water were statistically found to be the same, t (17) = 2.10, *p* = 0.052 (two tail).

4.5.9. Sodium and Potassium

The sodium mean value in the label information (M= 7.84, SD = 5.37, n=9) was compared to laboratory results of the bottled samples (M = 7.52, SD = 3.38, n = 10) . The difference was not statistically significant, t (17) = 2.11, P = 0.88 (two tail). Meanwhile, the Potassium mean value in the label information (M= 1.71, SD = 1.17, n = 10) was compared to laboratory results of the bottled samples (M = 0.80, SD = 1.17, n = 10). The difference was not statistically significant, t (18) = 2.10, *p* = 0.09 (two tail) indicating that both the label information regarding to Sodium and Potassium and the actual Sodium and Potassium level in the water were the same.

CHAPTER FIVE

DISCUSSION

This study was conducted in Somaliland to assess the bacterial, physical, and chemical quality of drinking water in Hargeisa City. A high prevalence of *Coliforms* in piped water (87 %) and in Well water (93 %) was noted (Table 3). a significant number of samples tested positive for *E. coli* contamination, 13 % of the bottled, 47% of the piped, and 73 % of the Well's water (Table 3). Therefore, drinking water in the study area were not compliant with WHO and SQCC acceptable limit for coliforms (0 MPN/ index/100ML), *E coli* (0 colonies / 100ml) and streptococcus fecalis (0 colonies / 100ml). The presence of these indicator bacteria in drinking water signify fecal contamination of the water sources (Griffin *at el.,* 1991; Olsen, *at el*., 2002). Presence of these organisms in treated and processed water is often an indication of treatment ineffectiveness and or introduction of contaminated water into already treated water systems (Griffin *at el.,* 1991; Olsen, *at el.*, 2002). Studies conducted in Somaliland revealed half of the bottles had significant growth of total coliforms (Heen, and Madar, 2020). The current study is in agreement with other reports of Well and piped water samples contamination with coliform bacteria (Jessen *at el;* 2021; Mohammed Yassin, *at el*; 2015).

The detection of *E. coli* in water suggests the possible existence of hazardous pathogens, such as *Vibrio cholerae*, *Salmonella* Typhi, *Salmonella* Paratyphi and *Campylobacter* spp. (Ashbolt, 2004). Some strains of *E. coli* (e.g. *E. coli* O157:H7) are causing waterborne or foodborne diseases that can be life threatening (Griffin *at el.,* 1991; Olsen, *at el.,* 2002).

The bacteriological quality of water at the end user stage is affected by numerous factors, such as the original state of pollution of water at sources, the storage situations, fetching and handling attitudes and practices as well as the methods used to treat to improve quality (Griffin *at el.*, 1991; Wright *at el*., 2004; Olsen, *at el.,* 2002; Trevett *at el,* 2005). Water is delivered by tankers to the majority of Hargeisa's population, and there was no quality assurance mechanism in place to ensure water quality throughout the value chain. Furthermore, the high amount of bacteriological presence in the water may have been caused by inappropriate water handling due to inadequate cleaning of water containers.

Drinking Water collected in Hargeisa showed presence of resistance pathogens. The *E. coli* found to be resistance to Penicillin G (100%), Vancomycin (100 %) and Ampicillin (100 %) (Table 4). Varying Resistance was noted in all the antibiotics (Tetracycline, Chloramphenicol, Penicillin, Amoxicillin, Vancomycin, Ceflaxine, Ampicillin, Cetfriazone and doxicyline) (Table 4). Streptomycin and Gentamycin did not show any resistance. High levels of resistance to the above listed have been detected in other study areas arguing that domestic water is a potential route of exposure to antimicrobial resistance (Christopher *et al*.,2013; Dolejska *et al*.,2009; Lyimo *et al.*, 2016).

The pH average value of 7.7, 8.5, 8.6 for bottled, pipped and well water sources (Graph 2) were found. The pH concentration from Well water were not within harmless limit (8.6). A more acidic pH (5.6) has been documented in another research focusing bottled water in Somaliland (Heen., and Madar 2020). Which is not consistent with result of this research of 7.7. The Alkalinity results found in Well water matches alkaline results (pH 8.1-8.9) documents in Muqdisho boreholes (Abdolahi, 2015). The dissolved ions concentration is usually measured as TDS. The TDS value of all sampled drinking water has ranged between 1036 mg/L to 46 mg/L. These values from both bottled and Well water were within the recommended limits of 500 mg/L for drinking water quality set by the WHO. While piped water was slightly above the recommended limit (Table 5). TDS value found in similar study for bottled water in Somaliland found mean value of 34mg/l (Heen, and Madar, 2020). Werkneh *et al*. 2015) also reports similar result (647 and 537 mg/l) of drinking water in Jigjiga city. High values of TDS in ground water are do not generally cause serious health problems, but high concentration of these may have negative impacts including urogenital and heart diseases. Drinking water with high solids may cause gastrointestinal issues including cathartic or constipation effects (Sasikaran *et al.*, 2012).

Electric Conductivity is the measure of liquid capacity to conduct an electric charge (Marandi. *at el*., and Kumar *at el*., 2015). Its capability is dependent on dissolved ion concentrations and strength, and temperature of measurements (Hem, 1985). In this study, the mean value of water samples from pipes and Wells were above the WHO recommended limit of 500 µs/cm (Table 5).A comparable value was documented by (Moenga, 2020) in drinking water of Naivasha sub county. These results evidently show that bottled water in the Hargeisa was not significantly ionized and has the lesser level of ionic concentration activity due to lower levels of dissolve solids but piped and well water sources are ionized. Similar study also found low mean level of EC (48 µS/cm) and TDS (34mg/l) in the bottled water (Heen, and Madar, 2020), compared to other sources of water.

In this study, fluoride concentration registered ranges from 0.03 mg/l (bottled water) to 1.35 mg/l (well water). Fluoride concentrations did not go above the 1.4 mg/L standard set by the WHO. present investigation was similar with reports made by other researchers' study (Kassegne *at el*., 2020; and Abdolahi *et al*. 2015).

Metal ions such as Na^+, K^+, Mg^{2+}, Ca^{2+} and Fe^{2+} are often present in groundwater, extraordinarily high concentrations of these metal ions in water as a result of pollution of water by natural and anthropogenic inputs (Griffin *at el*., 1991; Barbieri *et al.*, 2019; Olonga *et al.*, 2015). In the present study, the mean concentration of major ions in

Sodium mean value for piped water (21 mg/l), wells (16 mg/l), and bottled (8mg/l) were all within the WHO recommended limit for drinking water (Table 5). Similar researches in Muqdisho wells and Somaliland bottled water reported sodium level within WHO limit (Heen, and Madar, 2020;

and Abdolahi *et al.,* 2015; Meride, *at el*., 2016)**.** The potassium mean value was within the recommended WHO guidelines.

The magnesium's mean value was 62.5 mg/l for the piped, 6 mg/l for the bottled, and 46.4 mg/l for wells (Graph 7). The mean value of bottle and wells were within the WHO guidelines; however, magnesium level of piped water (62.5 mg/l**)** was beyond WHO guidelines. Similar studies for bottled and well water also found the mean values within the recommended level (Heen, and Madar. 2020; and Abdolahi *et al.,* 2015). Magnesium is significant a cofactor in the body and its deficiency are associated with many conditions including Hypertension, Cardiac arrhythmias, Pre-eclampsia etc. however, increased intake of Magnesium leads Gastrointestinal problems like diarrhea (WHO, 2009).

The concentration value of calcium in drinking water were within the WHO (100 mg/L) and SQCC (100 mg/L) desired limit for drinking water (Table 5). This study disagrees with high (601 mg/l) chloride level reported elsewhere in Somaliland (Stauder *at el***,** 2012) but similar studies of bottled water in Somaliland revealed safe levels of calcium (Heen, and Madar, 2020). The mean value for Sulphates were 47.5 mg/g, 11.1 mg/l, and 62.97 for pipped, bottled and well water respectively and were all within the WHO safety limit. This result disagrees with high level of Sulphate mean reported (Stauder. *at el.,* 2012) in several places in Somaliland. Similar study conducted with bottled water and well water reported safe levels of Sulphates (Heen, and Madar, 2020; Abdolahi *et al.* 2015; and Yirdaw *at el.,* 2016).

The Nitrate mean values of 7.2 mg/L for pipped, 4.2 mg/L for wells and 0.3 mg/L for bottled in this study were all below the WHO recommended limit of 50 mg/L (Table 5). this indicated safe quantity of Nitrate in drinking water. Similar studies conducted also reported the similar findings (Abdolahi *et al.*, 2015; Alamnew *at el.*, 2020, and Nikaeen *at el.*, 2015).

This study found flaws with respect to labeling practices of the bottling companies. There are discrepancies in concentrations of the laboratory values and values written on the label of brands sampled. This discrepancy was evident in TDS, pH, Chlorides and Nitrates mean values. Other studies have found out discrepancies between label information and actual amounts of elements in water (Amogne, 2016; Khan and Chohan., 2010; Baba *et al*., 2008).

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion.

The significance of having access to safe drinking water cannot be overstated. The increased population in Hargeisa city, combined with a lack of centralized water distribution, forces many people to drink water from unsupervised wells, putting more pressure on the provision of safe drinking water.

In terms of bacteriological findings, the majority of the households (90 percent) sampled had coliforms in their drinking water. As a result, it was determined that the quality of drinking water in Hargeisa had poor bacteriological quality, posing a probable public health and food safety risk to inhabitants of Hargeisa.

The physicochemical properties of water in most samples meet the recommended standards. The pH (expect for well water), Total Dissolved Solids (TDS), Sulphate ($SO4^{2-}$), Nitrate (NO^{3}-), fluoride (F^{-}), Magnesium (bottled and wells), Calcium, Potassium, Sodium, Iron, Zinc, and Lead were all within WHO recommended limits permissible for drinking water. However, the levels of Electric Conductivity (EC) in pipe and Well sources, magnesium in piped water, and pH in wells were all above WHO recommended levels.

The was statically significant difference between the water sources and parameters assessed which indicated that source of water has direct impact of the value of parameters in drinking water. The bottled water had a low mineral content compared with the rest of the sources, however, the majority water sources were within WHO's recommended limit.

This study found flaws with respect to labeling practices of the bottling companies. The study reveal discrepancies in concentrations of the laboratory values and values written on the label of brands sampled. This discrepancy was evident in TDS, pH, Chlorides and Nitrates mean values.

Because this study found a high number of coliforms, there is an urgent need to raise awareness about the current drinking situation in Hargeisa. Resistance to most of the commonly used antibiotics was noted necessitating the need for more studies to understand the causal pathways of their existence and spread in water sources.

6.2 Recommendation

1. Investment to increase drinking water availability to enable the Hargeisa Water Agency to produce more water to meet the city's water demand.
2. The government to implement a quality control mechanism to monitor all drinking water sources and their value chain.
3. Establishment of drinking water quality standards and synchronizing the treatment methods applied to bottled water companies.
4. Frequent drinking water quality assessment should be conducted by Somaliland quality control commission (SQCC) or other regularly bodies to ensure water safety.
5. Water companies should write actual values of elements connationtained in their water to allow the public to make informed decisions.
6. The public should be educated on the importance of further treatment (such as boiling), proper storage and handling practices of water before it consumed.
7. Further studies to be conducted to determine the temporal and spatial variation of the bacteriological and physicochemical quality of drinking water in Hargeisa city.
8. More AMR research needs to be conducted to understand the causal pathways of their existence and spread in water sources.

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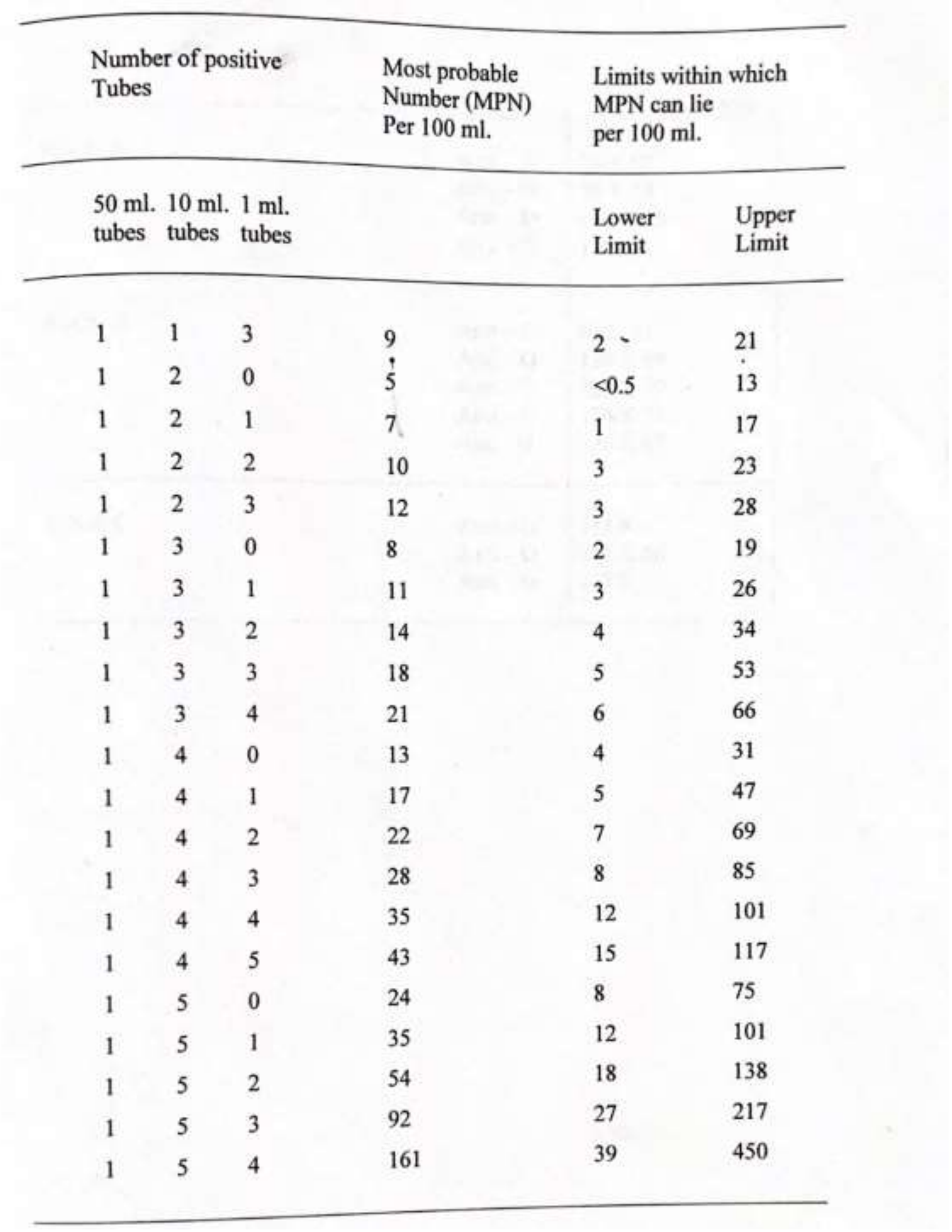
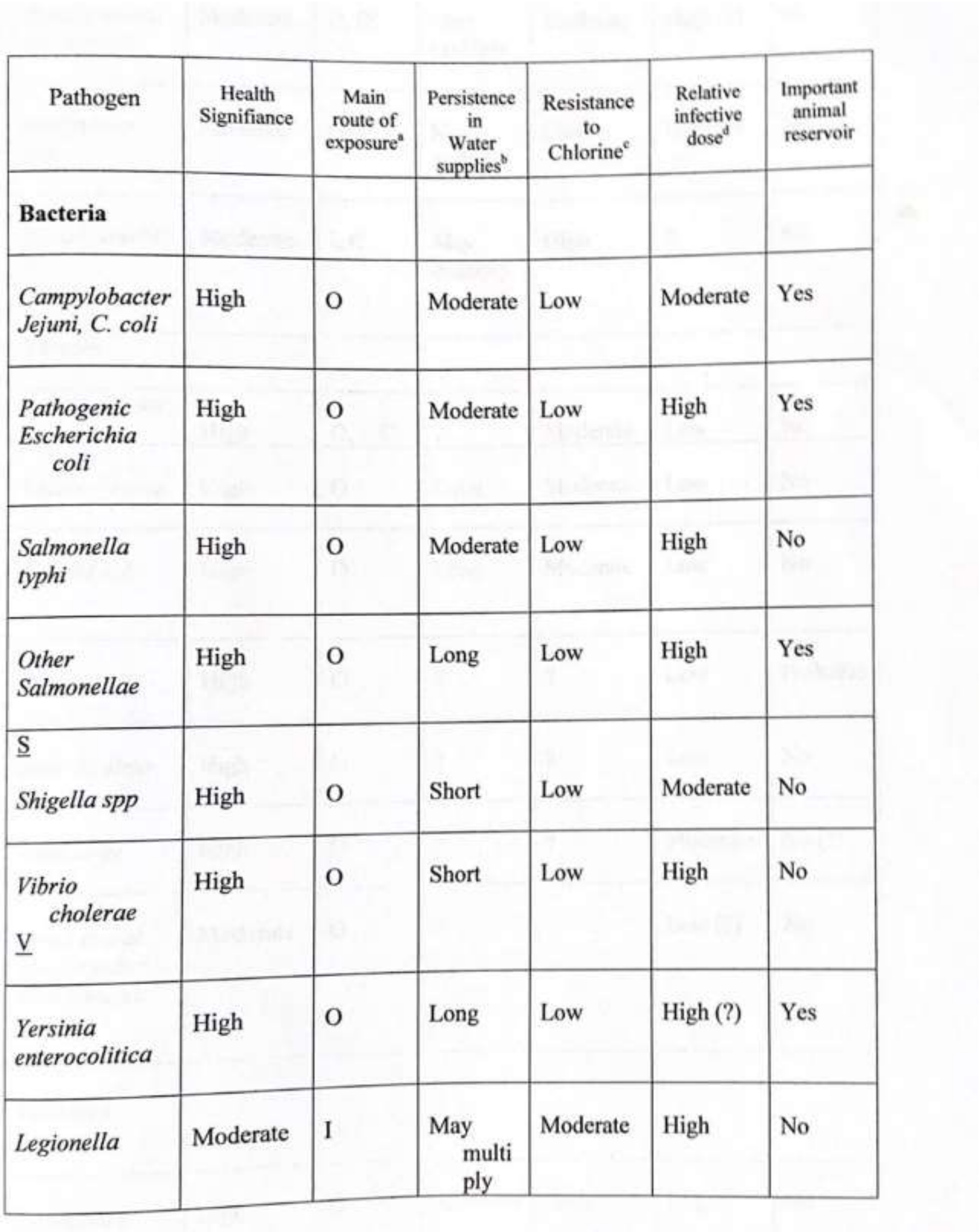
APPENDICES

Appendix # 1. McCardy's Statistical Table



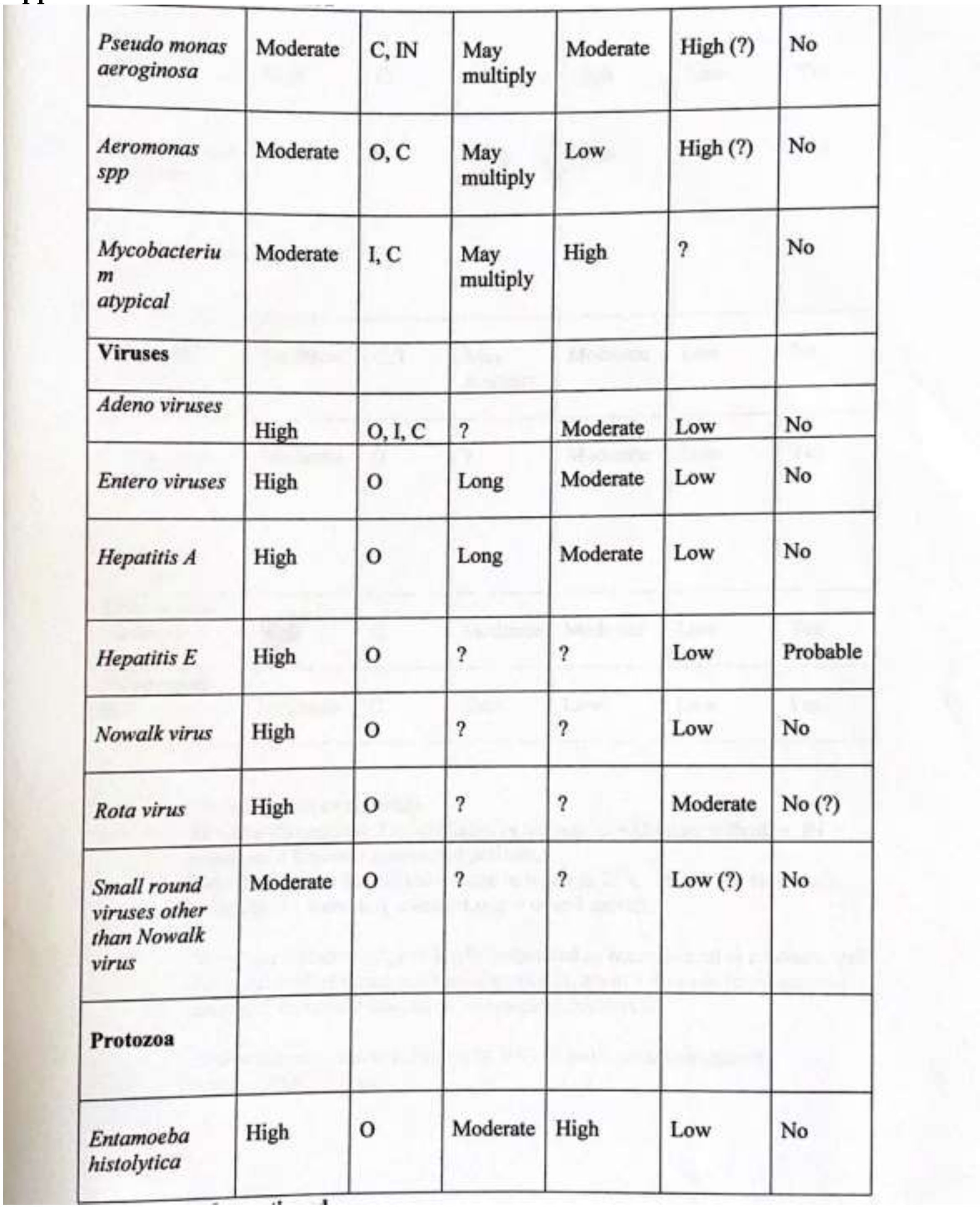
Number of positive Tubes			Most probable Number (MPN) Per 100 ml.	Limits within which MPN can lie per 100 ml.	
50 ml. tubes	10 ml. tubes	1 ml. tubes		Lower Limit	Upper Limit
1	1	3	9	2	21
1	2	0	5	<0.5	13
1	2	1	7	1	17
1	2	2	10	3	23
1	2	3	12	3	28
1	3	0	8	2	19
1	3	1	11	3	26
1	3	2	14	4	34
1	3	3	18	5	53
1	3	4	21	6	66
1	4	0	13	4	31
1	4	1	17	5	47
1	4	2	22	7	69
1	4	3	28	8	85
1	4	4	35	12	101
1	4	5	43	15	117
1	5	0	24	8	75
1	5	1	35	12	101
1	5	2	54	18	138
1	5	3	92	27	217
1	5	4	161	39	450

Appendix 2: Waterborn pathogens and their significance in water supplies



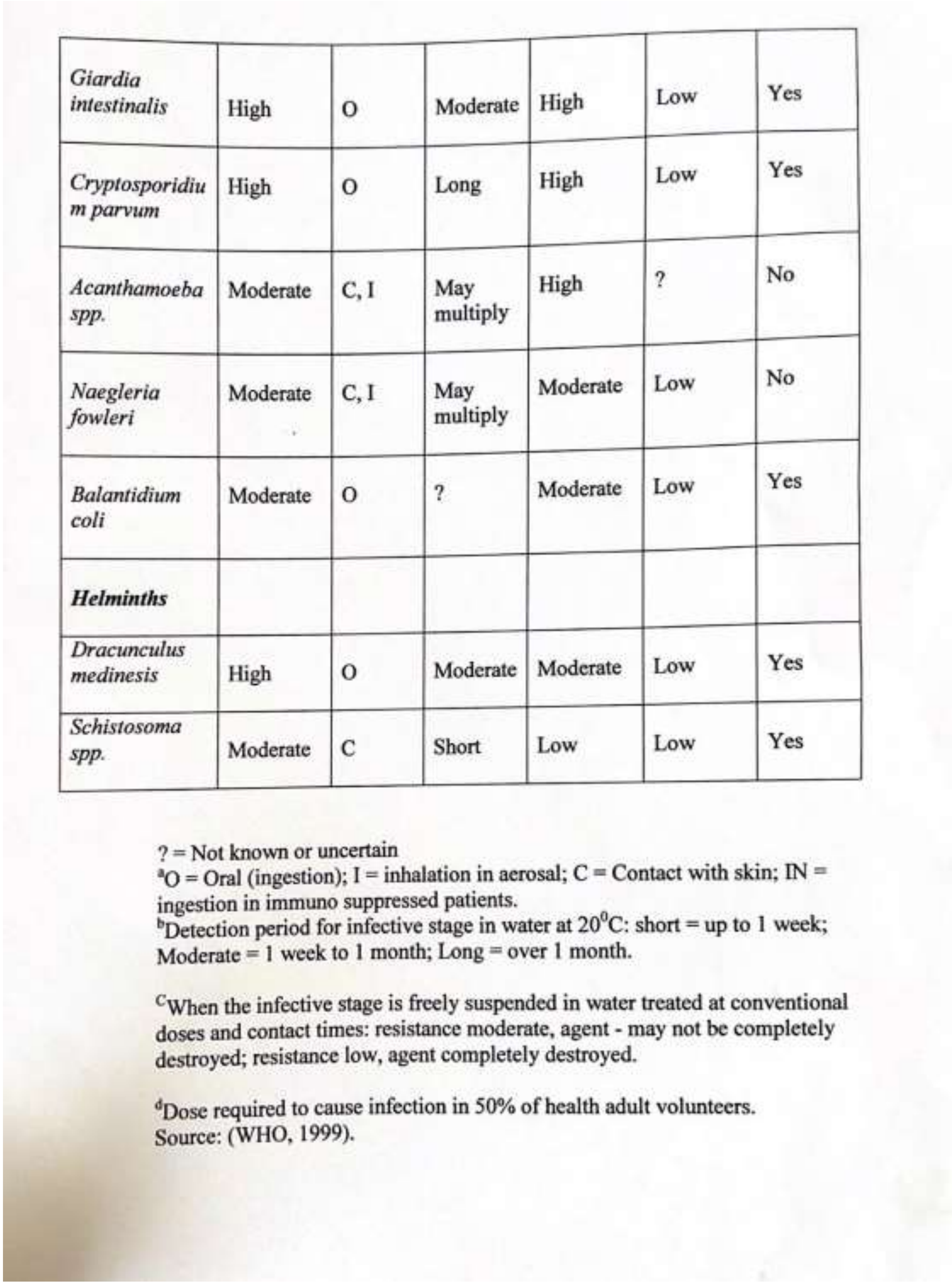
Pathogen	Health Signifiance	Main route of exposure[a]	Persistence in Water supplies[b]	Resistance to Chlorine[c]	Relative infective dose[d]	Important animal reservoir
Bacteria						
Campylobacter Jejuni, C. coli	High	O	Moderate	Low	Moderate	Yes
Pathogenic Escherichia coli	High	O	Moderate	Low	High	Yes
Salmonella typhi	High	O	Moderate	Low	High	No
Other Salmonellae	High	O	Long	Low	High	Yes
S *Shigella spp*	High	O	Short	Low	Moderate	No
Vibrio cholerae V	High	O	Short	Low	High	No
Yersinia enterocolitica	High	O	Long	Low	High (?)	Yes
Legionella	Moderate	I	May multiply	Moderate	High	No

Appendix # 2. Continued



Pseudo monas aeroginosa	Moderate	C, IN	May multiply	Moderate	High (?)	No
Aeromonas spp	Moderate	O, C	May multiply	Low	High (?)	No
Mycobacterium atypical	Moderate	I, C	May multiply	High	?	No
Viruses						
Adeno viruses	High	O, I, C	?	Moderate	Low	No
Entero viruses	High	O	Long	Moderate	Low	No
Hepatitis A	High	O	Long	Moderate	Low	No
Hepatitis E	High	O	?	?	Low	Probable
Nowalk virus	High	O	?	?	Low	No
Rota virus	High	O	?	?	Moderate	No (?)
Small round viruses other than Nowalk virus	Moderate	O	?	?	Low (?)	No
Protozoa						
Entamoeba histolytica	High	O	Moderate	High	Low	No

Appendix # 2. Continued



Giardia intestinalis	High	O	Moderate	High	Low	Yes
Cryptosporidium parvum	High	O	Long	High	Low	Yes
Acanthamoeba spp.	Moderate	C, I	May multiply	High	?	No
Naegleria fowleri	Moderate	C, I	May multiply	Moderate	Low	No
Balantidium coli	Moderate	O	?	Moderate	Low	Yes
Helminths						
Dracunculus medinesis	High	O	Moderate	Moderate	Low	Yes
Schistosoma spp.	Moderate	C	Short	Low	Low	Yes

? = Not known or uncertain
[a] O = Oral (ingestion); I = inhalation in aerosal; C = Contact with skin; IN = ingestion in immuno suppressed patients.
[b] Detection period for infective stage in water at 20^0C: short = up to 1 week; Moderate = 1 week to 1 month; Long = over 1 month.

[C] When the infective stage is freely suspended in water treated at conventional doses and contact times: resistance moderate, agent - may not be completely destroyed; resistance low, agent completely destroyed.

[d] Dose required to cause infection in 50% of health adult volunteers.
Source: (WHO, 1999).