WATER QUALITY ASSESSMENT AND EVALUATION OF HUMAN HEALTH RISK OF DRINKING WATER AT THULAMELA MUNICIPLAITY, LIMPOPO PROVINCE

By

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DECLARATION

I, Ndivhudzannyi Luvhimbi declare that, the mini-dissertation titled: **WATER QUALITY ASSESSMENT AND EVALUATION OF HUMAN HEALTH RISK OF DRINKING WATER AT THULAMELA MUNICIPLAITY, LIMPOPO PROVINCE** is my own work and that all sources that I have used or quoted have been indicated and acknowledged by means of complete references, and that it was never submitted to any other institution.

Signature

Date: 29/06/2020

DEDICATION

This mini-dissertation is dedicated to my creator the Almighty God. He is the pillar that holds my life through it all. Oh, how great He is.

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But with God everything is possible – Matthew 19:26 (NLT)”. I would like to express my profound gratitude to Almighty God, the author and finisher of my faith for this MPH mini-dissertation to you alone be all the glory.

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ABSTRACT

Water quality of drinking water has been linked to good health outcomes across the world. The aim of this study was to assess physico-chemical, bacteriological, community practices regarding collection and storage of water and evaluation of human health risk characteristics of drinking water supplied by the government to Lufule village in Thulamela municipality, Limpopo Province, South Africa

A cross-sectional study was conducted using questionnaires and interviews to determine drinking water handling practices and levels of contamination between the source and point-of-use at household. Assessment of water quality was carried out on 114 samples from selected sampling points using scientifically approved protocols. Total coliform was determined in 62.5% and 87.5% of the samples during the dry and wet seasons respectively. Similarly, E. coli was determined in 10.4 % and 13.2% in the dry and wet seasons, respectively.

Trace metals levels in the drinking water samples were analysed and were within permissible range of both SANS and WHO. The calculated non-carcinogenic effects using hazard quotient toxicity potential, cumulative hazard index and chronic daily intake of drinking water through ingestion pathways were less than one unity, which showed that consumption of the water could pose little or no significant health risk.

The results of this research suggest that lead has the potential of cancer risk to the residents through the cumulative ingestion in the drinking water samples of the studied area. Therefore, precaution needs to be taken to avoid potential risk of people in Lufule area especially, children.

Keywords: Assessment, drinking water evaluation, human health risk, water quality.

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LIST OF ACRONYMS AND ABBREVIATION

ADWG:	Australian Drinking water guideline
BDCP:	Blue Drop Certification Programme
BDL	Below Detected Limit
BDS:	Blue Drop System
CDI:	Chronic Daily Intake
CR_{ing}:	Carcinogenic Risk Assessment
DWAF:	Department of Water Affairs and Forestry
E.coli:	Escherichia Coli
EC:	Electrical Conductivity
EPA:	Environmental Protection Agency
HI:	Hazard Indices
HQ:	Hazard Quotient
HWTS:	Hold Water Treatment and Safe Storage
ICP-MS:	Inductively Coupled Plasma Mass Spectrometry
MCL:	Maximum Contaminant Level
MPH:	Masters in Public Health
ND:	Analyzed but Not Detected.
SANS:	South African National Standard
SDG:	Sustainable Development Goal
TDS:	Total Dissolved Solids
TM:	Thulamela Municipality
TTC:	Thermo Tolerant Coliform (TTC)
UHDC:	University Higher Degree Committee
UNEP:	United Nations Environment Programme

UNICEF	United Nation International Children Emergency Fund
USEPA	United States Environmental Protection Agency
VDM	Vhembe District Municipality
WHO	World Health Organization
WSP:	Water Safety Plans

CHAPTER 1
INTRODUCTION

1.1 Background of the study

Water is among the major essential resources that nature provides to sustain the lives of plants, animals and humans. It is undoubtedly the most precious natural resource that exist on earth. Social and economic progress are based and sustained upon this pre-eminent resource (Taiwo et al., 2012). Without water, life on earth would be non-existent (Apeh & Ekenta, 2012). Taiwo et al. (2012) postulate that water is a defined resource of most importance for the existence of human, agriculture and industry. The aim of the public health and international development policy is to make drinking water safe and accessible (Bain et al., 2014).
Although the world's multitudes have access to water, in numerous places the availability of water is seldom safe for human drinking and not affordable or obtainable in plenty quantities to meet basic health needs (Shaheed et al., 2014). According to the World Health Organisation, 4.9 billion people globally use an enhanced sanitation facility as compared to 2.4 billion who do not (WHO, 2014). Among those lacking enough sanitation are 946 million people who do not have any facilities at all, who went on to employ open defecation. In 2015, 68% of the global population was using advanced sanitation facilities compared to 59% in 2000.

Nevertheless, the unsafe management of fecal waste and wastewater continues to present a major risk to public health and the environment. WHO (2011) recently estimates that about 1.1 billion people globally drink unsafe water and the vast majority of diarrheal disease in the world (88%) is attributed to unsafe water, sanitation and hygiene. In addition to this, supply of water sector is facing enormous challenges due to climate change, global warming and urbanization. With no doubt, insufficient quantity and quality of water have serious impact on sustainable development. In advanced countries, environmental monitoring agencies are more effective and environmental laws are strictly followed (Al-Bayatti et al., 2012).

According to sustainable development goals (SDG) water security is one of the major concepts, which is the basic element of the Global Goal on Water. Water security is the capacity of a population to safeguard sustainable access to adequate quantities and acceptable quality of water for sustaining livelihoods of human well-being, and socioeconomic growth ensuring protection against pollution and water related disasters; and for conserving ecosystems in a climate of peace and political balance (Lu et al., 2015).

The Guidelines for Drinking-Water Quality recommend that faecal indicator bacteria (FIB), preferably *Escherishia coli* (*E. coli*) or alternatively thermo tolerant coliform (TTC), should not be found in any 100 ml of drinking water sample (WHO, 2011). Yet numerous reports document faecal contamination of drinking water sources especially in low-income countries by WHO and United Nations International Children Emergency Fund (UNICEF) (Bain *et al*., 2014). Solid evidence has been found to demonstrate that enhanced sources of drinking water can carry faecal contamination. In a systematic review of microbial drinking water quality, many improved sources including piped water were found to be contaminated with *E. coli* or TTC (Bain *et al*., 2014).

Water quality guidelines for potable water supplies has been established by a lot of international organisations, according to makarigakis et al., (2019) 90% sewage in developing countries is discharged directly into water bodies, this increases lack of sanitation which is one of the most significant form of water pollution and as a results treatment process has not yet meet the defined standards. Unfortunately portable water for all is a goal that is not yet fully acquired. Water-related diseases remain the primary cause of a high mortality rate for children under the age of five worldwide. These problems are specifically seen in rural areas of developing countries. In addition, emerging contaminants and disinfection by-products have been associated with chronic health problems for people in both developed and developing countries (Younos et al., 2014).

The presence of heavy metals in natural water as major cause of pollution has received considerable attention in recent years due to its potential risk to human health and ecology (WHO and UNICEF, 2011; UNICEF and WHO 2012; Olukanni et al., 2014). Mining activities has destroyed natural habitats, polluted the air, soil and water, as well as long term environmental impacts (UNEP, 1997). The toxicity of heavy metals from the mining, milling and smelting companies such as cadmium, zinc, lead, copper, manganese, magnesium, iron, arsenic, silver, chromium can have harmful and even lethal effects on the human body, depending on the concentration and rate of consumption. Heavy metal can cause serious health effects with varied symptoms depending on the nature and quantity of the metal ingested (Adepoju-Bello and Alabi, 2005) the most common heavy metals that humans are exposed to be Arsenic, Cadmium, and Lead. Arsenic exposure can cause among other illness or symptoms cancer, abdominal pain and skin diseases. Cadmium exposure produces kidney damage and hypertension. Lead is a commutative poison and a possible human carcinogen.

(Bakare-Odunola, 2005). In addition, Lead may cause the development of autoimmunity in which a person's immune system attacks its own cells. This can lead to joint diseases and ailment of the kidneys, circulatory system and neurons. At higher concentrations, Lead can cause irreversible brain damage.

In Zimbabwe, there has been a remarkable decline in water service delivery since 2005 characterized by merciless water shortages which lead to the outbreak of waterborne diseases such as cholera (Hove & Tirimboi, 2011). Most of Zimbabwean rural water sources for drinking are still the traditional ones such as ponds, dams, well, rivers and streams which might harbor waterborne and vector-borne diseases such as schistosomiasis, salmonellosis, cholera, lymphatic filariasis, guinea worm, onchocerciasis, campylobacteria's, fungal, yersinosis, shigellosis viral infections and parasitic (Zvidzai et al. 2007).

The Department of Water Affairs and Forestry (DWAF) emphasises that access to safe drinking water is a basic human right and essential to people's health in South Africa (DWAF, 2005). However, Majuru et al., (2012) argues that water supply services in South Africa are generally more developed in urban than in rural areas where water services are still non-existent (no service) with basic services being established, or rudimentary services being upgraded to basic water supply services. Approximately 5% of the total population in South Africa is still without adequate water supply services of which the majority dwells in the rural areas. In these communities, the source of water is often quite far and often not available or contaminated when available (Majuru et al., 2012). The scarcity of water resources in South Africa, combined with limited health budgets, industrial pollution and lack of proper waste management, deteriorate the condition of water quality (Nekhavhambe et al, 2014).

Limpopo Province is one of poorest province in South Africa with some district having no water safety plan, process control, risk management or monitoring programme in place; and as such water quality is compromised. The Vhembe District Municipality has made numerous promises to address the shortage of water in residential areas in vain (Mukwevho, 2017). According to Mukwevho (2017), municipalities around Limpopo province lack sufficient resources to maintain the water service infrastructure. Netshifhefhe et al., (2018) reveals that only 43% of the population has access to basic water supply. Though, urban areas such as Thohoyandou, Makhado and Musina have fully reticulated water yard connections, however, they suffer frequent interruption.

Microbiological water quality can be deteriorated in the course of collection, transport, and home storage. Thus, access to a safe source alone does not ensure the quality of water that is consumed. Furthermore, a better water source does not lead to full health benefits in the absence of improved water storage and sanitation (Clasen et al., 2007). Though water supplies are improved and protected from contamination, but are not inevitably free of pathogens (Costello et al., 2009)

1.2 Problem statement

Although access to clean water is a right enshrined in the constitution of South Africa, Communities of the Vhembe district municipality depending on drinking water supplied by the plants evaluated were therefore found to face a high risk of contracting waterborne diseases (Davison et al. 2008), As a results residence of many villages in Thulamela municipality raised a concern to the municipality that the water supplied to them tastes bad; and that it is not free from bad smell. According to a report by Blue Drop Certification Programme (Mukwevho, 2017), thousands of people living in Limpopo province are consuming water, which is not suitable for human consumption. According to Mukwevho (2017) the South African Broadcasting Corporation reported that the issue became critical that it involved auditing of municipal water supply system.

Mukwevho (2017) revealed that more than half of the municipalities in the province including Thulamela are providing water, which is not suitable for human consumption. The Blue Drop report indicate that municipal drinking water quality within Limpopo has dropped from excellent to unsatisfactory. This service delivery challenge may expose residence to health risks such as schistosomiasis, salmonellosis, cholera, lymphatic filariasis, guinea worm, onchocerciasis, campylobacteria's, fungal, yersinosis, shigellosis viral infections and parasitic cholera (Drake & Stimpfl, 2007). Although the Limpopo Provincial Department of Health continues to warn rural villagers not to drink contaminated river water, residents continue to drink it because dirty water is all they have access to. The purpose of this study is to assess the quality of drinking water from sources and households of Lufule villages in Thulamela Municipality to provide the district managers with the baseline information regarding the quality of drinking water at the point of use.

1.3 Rationale of the study

Water is ultimately the origin of life and the most essential of all natural resources, without which the human beings cannot thrive (DSS, 2010). Availability and easy access to safe and quality water is a fundamental human right (Corcoran et al., 2010). In developing countries, it has been observed that drinking-water frequently becomes re-contaminated following its collection and during storage in the home.
According to Mohsin et al., (2013) the quantity of available water in developing regions of Africa is decreasing sharply while quality of water is deteriorating rapidly due to fast urbanization, deforestation and land degradation unfortunately, in less developed nations, the quality of drinking water is continuously being contaminated.

According to the United Nations/World Health Organization's 2002 report, about 1.7 million deaths is recorded per year due to unsafe water supply (WHO, 2002). A lot of these deaths are from diarrheal diseases; and 90 percent of which are children of developing countries. Typhoid fever, cholera and many other diseases still run rampant in the developing parts of the world. In rural areas of developing countries, purified water are not treated properly which leads to water borne disease. Most of these waterborne diseases aren't found in developed countries because of the sophisticated water systems that filter and chlorinate water to eliminate all disease carrying organisims (USA Water project, 2010). There is currently no information available in the scientific literature on drinking water quality and potential sources of water contamination about Lufule village and possible health risks that these water may impact human lives, therefore it is crucial to assess the drinking water quality of the municipality in order to assure safe drinking for local residents. The objective of this study is to assess community practices regarding collection and storage of water, determining physico-chemical parameters, the bacteriological level in water supply distribution network to ensure good quality, and to determine the possible health risk due to exposure of human to heavy metals.

1.4 Significance of the study

This study may serve as reference to other researchers who will be interested in carrying out similar study in the same district or other municipalities. The study is going to contribute to the general body of knowledge. The local authorities and municipalities need to be aware of this problems and associated causes. It may help in policy decision regarding waste disposal and waste management to avoid contamination or enrichment in the river.

1.5 Purpose of the study

The purpose of this study is to evaluate the quality of drinking water of Thulamela Municipality from source, main distribution system (Reservoir), and yard connections (private tap networks) and to determine the possible health risk due to exposure of human to heavy metals.

1.5.1 Objectives

1. To analyze the physico-chemical parameters and trace elements

2. To evaluate bacteriological quality of the water at source as well as the distribution system.

3. To describe community practices regarding collection and storage of water.
4. To evaluate the human health risk due to heavy metals in the water.

1.7 Definition of Terms

- **Water quality** is the condition used to measure water in comparison to the requirements of one or more biotic species, or to any human need or purpose (Omer, 2019). In this study Water quality is the degree to which water is clean, and whether it is suitable for drinking
- **Assessment** is the process of considering the amount or value of something, or the decision (Gilbert, 2012). In this study Assessment is the process of doing different analytical test of water and make conclusion thereafter.
- **Evaluation** is a process that critically observe a program. It is comprised of collection and analysis of information about a program's activities, characteristics, and outcomes. Its purpose is to make conclusions about a program, to improve its effectiveness, and to inform programming decisions (Patton, 1987). In this study evaluatoin is making a judgment about the amount, number, or value of something.

- **Human health risk** is the process of estimating the nature and probability of adverse health effects in humans who may be exposed to hazardous environmental, presently or in the future (Tepanosyan et al., 2017.) In this study human health risk is when an individual was involved in a negative health consequence due to a specific event and the situation place that individual in danger either immediately or later.
- **Drinking water** is the water which is safe for consumption purpose. (Genser, 2006). In this study drinking water is an act of ingesting water that is suitable for use.
- **Physico-chemical parameters** are factors like water temperature, pH, dissolved oxygen, oxygen saturation, conductivity, salinity, nitrate, nitrite, orto-phosphate, sulfate, chloride, total hardness, calcium and magnesium that are used in analyzing water samples (Dirican, 2015). In this study few physical and chemical parameters like (pH, dissolved oxygen, electrical conductivity, and total hardness) trace elements (mercury, lead, copper, zinc, iron, aluminium, cadmium, chromium and manganese were used to determine the quality of water.
- **Bacteriology** is a branch of microbiology that is concerned with the study of bacteria (as well as Archaea) and related aspects (Eldars, 2015). In this study is total coliforms and E. coli level were determined in water samples.

1.8 Layout of chapters

Chapter 1: Overview of the Study

Chapter 2: Literature Review

Chapter 3: Research Methodology

Chapter 4: Results

Chapter 5: Discussion

Chapter 6: Conclusion and Recommendations

1.9 Summary

This chapter provided an overview of the study and included the introduction, background of the study, and further discussed the assessment of water quality and evaluation of human health risk associated with heavy metals in drinking water. The rationale, significance and the purpose of the study were also described to acquire knowledge of the expected outcome of the study. The definition of the different terms used in this study were explained for clarification. The next chapter is about literature review.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

According to Carr (2008) water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter. Rather, it is variable in both time and space and requires routine monitoring to detect spatial patterns and changes over time. Furthermore, the conformation of surface and groundwater depend on natural factors (geological, topographical, meteorological, hydrological, and biological) in the drainage basin and varies with seasonal differences in runoff volumes, weather conditions, and water levels (Bartram & Balance, 1996). Water quality is the term used to describe the physical, chemical, biological and aesthetic properties of water in order to determine its capability for a variety of uses and for the protection of the health and reliability of aquatic ecosystem. Most of these properties are controlled or influenced by constituents that are either dissolved or suspended in water (Hubert & Wolkersdorfer 2015).

Water quality is changed and affected by both natural processes and human activities (DWA, 2009). Generally natural water quality varies from place to place, depending on seasonal changes, climatic changes and with the types of soils, rocks and surfaces through which it moves. In addition, Carr (2008) depict that large natural variations in water quality may be observed even where only a single water resource is involved. Human intervention also has significant effects on water quality and some of these effects are the result of hydrological changes, such as the building of dams, draining of wetlands, and diversion of flow. Effects of human intervention are some of the polluting activities, such as the discharge of untreated or partially treated domestic, industrial, urban, and other wastewaters into the water resource (whether intentional or accidental) and the spreading of chemicals on agricultural land in the drainage basin.

2.2 Water quality monitoring and assessment

Patil *et al*. (2012) portrays that water quality is determined by assessing three classes of attributes: biological, chemical, and physical. Further indications reveal that there are standards of water quality set for each of these three classes of attributes. Patil *et al.* (2002) also states that the national standards for drinking water are developed by the Federal Government's Environmental Protection Agency (EPA) and all municipal (public) water supplies need to be measured against these standards. Some attributes are considered of primary importance to the quality of drinking water, while others are of secondary importance. Since the drinking water supplied by municipal water systems is monitored for many contaminants. As they authorized by the 1974 Safe Drinking Water Act (SDWA) and its 1996 amendments, the U.S. Environmental Protection Agency (EPA) has established limits on the concentration of certain drinking water contaminants allowed in public water supplies. These limits, or standards, are set to protect human health and ensure that your water is of good quality (Hassinger and Watson, 2016)

Primary drinking water standards regulate organic and inorganic chemicals, microbial pathogens, and radioactive elements that may affect the safety of drinking water. These standards set a limit called the Maximum Contaminant Level (MCL) based on the highest concentrations of certain chemicals allowed in the drinking water supplied by a public water system (Patil et al., 2012). Moreover, secondary drinking water standards regulate chloride, colour, copper, corrosivity, foaming agents, iron, manganese, odour, pH, sulphates, total dissolved solids, zinc and all of which may affect qualities of drinking water such as taste, odour, colour and appearance. The concentration limit of these contaminants is referred to as the Secondary Maximum Contaminant Level (SMCL) and is used to examine the EPA’s current drinking water standards whereas the state agencies are responsible for monitoring public water supplies and enforcing the primary and secondary drinking water standards set by the EPA (Hassinger and Watson, 1998).

In the light of the above, microbial drinking-water quality testing plays an indispensable role in measures to protect public health. However, such testing remains a significant challenge where resources are limited. With a wide variety of tests available, researchers and practitioners have expressed difficulties in selecting the most appropriate test(s) for a particular budget, application and setting. To assist the selection process, it is important to identify the characteristics associated with low and medium resource settings and to specify the basic information that is needed for different forms of water quality monitoring (Bain *et al.,* 2012).

The health of any community fully depends on the accessibility of adequate and safe water. Hence, water is predominantly essential for life, health and human self-respect. Therefore, in addition to community health benefits, all people have the right to safe and adequate water retrieved in equitable manner for drinking, cooking, personal, and domestic hygiene. In this case, both adequacy and safety of drinking water are equally important to reduce the incidence of water-related and water borne health problems especially diseases like diarrhea (Bharti *et al.*, 2011).

Possible contamination sources that carry threats to drinking water quality are open field defecation, animal wastes, plants, economic activities (agricultural, industrial and businesses) and even wastes from residential areas as well as flooding situation of the area. Any water sources, especially older water supply systems, hand dug wells, pumped or gravity-fed systems (including treatment plants, reservoirs, pressure break tank, pipe networks, and delivery points) are vulnerable to such contamination. Systems with casings or caps that are not watertight are most vulnerable. This is particularly true if the water sources are located close to surface runoff that might be able to enter the source. Additional way by which pollution reaches and enters a water supply system is through overflow or infiltration by floodwaters and inundation of waters commonly contain high levels of contaminants (Oljira, 2015).

The ability of community extremely depends on the obtainability of safe and adequate water for drinking, domestic use, and personal hygiene. Adequate sanitation, together with good hygiene and safety of water, are essential to good health and to social and economic development (Mara et al., 2010). Most of the time the incidence of communicable diseases in the country is associated with water supply conditions in the locality. Infectious diseases affected by changes in the water supply condition are categorized as follows (Addisie, 2012):

- Those that spread through drinking water (i.e water borne diseases, such as typhoid, cholera, gastroenteritis etc.)
- Those transferred through aquatic vectors (water-based diseases, such as schistosomiasis)
- Those spread by insects that depend on water (water related diseases, such as malaria and yellow fever)

- Those diseases produced by the lack of adequate water for personal hygiene (water washed diseases, such as scabies and trachoma.

Based on the morbidity records, there is still a high incidence of communicable diseases which most of the time is related to water supply conditions in the in developing countries among which about 60% of the top ten diseases are relate to poor quality and scarcity of household water consumption (DeWilde et al., 2008).

2.3 Water quality analyses

Before determining on the sources of surface or groundwater, it is crucial to conduct water quality tests through representative samples. These tests ideally should be performed on site and through samples taken to the laboratory for definitive analysis (WHO, 2004).

2.4 Water quality parameters

Water quality parameters are classified into three aspects which are physical, chemical, and biological characteristics of water according to the set of standards. These parameters directly connect the safety of drinking water to human use. Water quality parameters deliver important information about the fitness of a water body. These parameters are used to find out the quality of water for drinking purpose (Gupta et al., 2009).

2.4.1 Physico-chemical parameters

2.4.1.1 PH

pH is one of the most significant parameters of water quality. It is defined as the negative logarithm of the hydrogen ion concentration (Lazar et al., 2017). Acidic water contains extra hydrogen ions (H+) and basic water contains extra hydroxyl (OH−) ions (Solomon et al., 2007). Pure water is neutral, with a pH close to 7.0 at 25°C. Safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and living organisms need (WHO, 2011) There are two methods available for the determination of pH: electrometric and colorimetric methods (Tucker & D'Abramo, 2008). The amount of oxygen in water increases as pH rises. Low-pH water will corrode or dissolve metals and other substances (Tucker, 2008).

2.4.1.2 Electrical Conductivity (EC)

Conductivity increases with the increase in mobility of ions (Lehtola *et al.,* 2004). These ions, which come from the breakdown of compounds, conduct electricity because they are negatively or positively charged when dissolved in water (Wu, et al., 2007). The World Health Organization (2003) describes total dissolved solids as "the inorganic salts and small amounts of organic matter present in solution. The EC of water depends on the water temperature, the higher the temperature, the higher the EC would be (Atekwana et al., 2004). The EC of water increases by 2-3% to an increase of 1 degree Celsius.

2.4.1.3 Total Dissolved Solids (TDS)

The materials dissolved in water and are measured as total dissolved solids in mg/l, conductivity or salinity TDS are measure of the quality of all compounds dissolved in water. Virtually all-natural waters contain varying concentration of TDS. The TDS of natural waters often depend on the characteristics of the geological formations that the water was, is, or contact with (Department of Water affairs and Forestry, 2004).

Larcern (2014) postulate that most chemicals are of concern only following long-term exposure; however, some hazardous chemicals that occur in drinking-water are of concern because of effects arising from sequences of exposures over a short period. It is further stipulated that where the concentration of the chemical of interest (e.g. nitrate/nitrite, which is associated with methane moglobinaemia in bottle-fed infants) varies widely, even a series of analytical results may fail to fully identify and describe the public health risk and as such controlling such hazards, attention must be given to both knowledge of causal factors such as fertilizer use in agriculture and trends in detected concentrations, as these will indicate whether a significant problem may arise in the future. Other hazards may arise intermittently, often associated with seasonal activity or seasonal conditions. One example is the occurrence of blooms of toxic cyanobacteria in surface water (DWAF, 2010).

According to DWAF (2010), it is important that the recommended guideline values are justified scientifically, practical and feasible to implement as well as protective of public health. In this regard, guideline values are not normally set at concentrations lower than the detection limits achievable under routine laboratory operating conditions. Moreover, some guideline values are established considering available techniques for controlling, removing or reducing the concentration of the contaminant to the desired level.

2.4.1.4 Calcium

Calcium is significant and abundant in the human body and its sufficient consumption is essential for normal growth and health (Beta, 2015). Calcium is a naturally occurring metal essential for human diet and is common in groundwater. Both Calcium and magnesium concentration are the main contributors to the hardness of water (Gray, 2008). Maximum limits have not been established for calcium. However, Dietary deficiencies of magnesium, coupled with excess calcium and stress may cause many cases of other related symptoms including agitation, anxiety, irritability, confusion, asthenia, sleeplessness, headache, delirium, hallucinations and hyper excitability (Eby & Eby 2006).

2.4.1.5 Potassium (K)

Potassium (K) is a cation in common salt found in groundwater, and it is essential in the human diet. Excessive amounts in drinking water may have a laxative effect on humans. Acceptable concentration in drinking water can range from 0 to 8 mg/L (Johnson and Scherer, 2009). Previous study by Olivier et al. (2010), showed that the concentrations of calcium are 1.40, 5.58, 1.31 and 13.73 mg/L and the concentrations of magnesium are 1.30, 0.17, 0.07 and 11.25 mg/L, respectively at Siloam, Tshipise, Sagole and Mphephu springs.

2.4.1.6 Sodium (Na)

Sodium is a cation in common salt found in groundwater, which can impart a salty taste at concentrations of over 250 mg/L (Gray, 2008). It can contribute to hypertension and high levels of sodium in drinking water should be noted by users on low sodium diets. A slight taste may be apparent above 100 mg/L (Johnson & Scherer, 2009).

2.4.1.7 Magnesium (Mg)

Magnesium is plentiful and a major nutritional requirement for humans (0.3-0.5 g/day). It is the second major component of hardness and it generally comprises 15-20 % of the total hardness expressed as $CaCo_3$ (EPA, 2001). The human body contains about 25g of magnesium (60% in bones and 40% in muscles and tissues). According to the set standards guidelines by WHO (2011) the permissible value of magnesium in water should be less than150 mg/l. The possibility that magnesium deficiency is the cause of most major depression and related mental health problems including IQ loss and addiction is enormously important to public health (Eby, 2006)

2.4.2 Microbiological quality

Microbiological contaminants in water refers to the organisms that cannot be individually seen by the naked eye, such as protozoa, bacteria and viruses present in drinking water. These microbes are mostly associated with the transmission of infectious waterborne diseases such as gastro-enteritis and cholera. The organisms which are used to measure the level of microbial contaminants are fecal indicators: organisms that indicate the presence of fecal contamination from animal or human wastes (Schreiner & Van Koppen, 2003). It is difficult to detect some of these organisms and it is therefore common practice to use microbial indicators as an indicator of recent fecal pollution and the potential risk of infectious diseases from the water (Solomon et al, 2004). Tests used to indicate the presence of pathogenic organisms include those for total coliforms, fecal coliforms, or for *E. coli* specifically (Ashbolt *et al*., 2001). Below are the microbiological water quality attributes:

2.4.2.1 Total coliforms

Total coliforms bacteria are frequently used to assess the general hygienic quality of water and to evaluate the efficiency of drinking water treatment and the integrity of the distribution system (Payment et al., 2003). The presence of total coliforms suggests inadequate treatment post-treatment contamination or after growth or an excessive concentration of nutrient. (Kassenga, 2007). In some instances, they may indicate the presence of pathogen responsible for the transmission of infectious diseases (Dallas & Day, 2004). According to Durres (2019), the highest total coliform count at bacteriological quality of household tap water was recorded from tap water at sampling site 3 of Kebele (Ethiopia) with 95 cfu/100ml, followed by 78 cfu/100ml at sampling site 1 of Kebele 08 and the lowest total coliform count was found at sampling sites 5 with ranges from 14 to 16CFU/100ml. Total coliform counts of the tap water were lower than water samples from the main distribution tank after treatment indicating that the treatment system significantly reduced microbial load of the water.

2.4.2.2 Escherichia coli (E. coli)

These are the most commonly used bacterial indicators of faecal pollution (DWAF, 2004). They are used to evaluate the quality of waste water contamination, river water, treated drinking water, raw water for drinking water supply etc. (Mwabi et al., 2012). The distribution system and proliferate in niches called biofilms can be colonized by microorganisms in drinking water (Solomon, 2004). Therefore, failure in the drinking water production and safety is increased if various obstacles like protection of water resources, proper selection and operation of a series of treatment steps and management of distribution systems are in place (piped or otherwise) to maintain and protect treated water quality. The preferred strategy is a management approach that places the primary emphasis on preventing or reducing the entry of pathogens into water sources and reducing reliance on treatment processes for removal of pathogens (WHO, 2011).

It is revealed that the greatest microbial risks are associated with ingestion of water that is contaminated with faeces from humans or animals including birds (Cabral, 2010). Faeces can be a source of pathogenic bacteria, viruses, protozoa and helminths (Huang et al., 2018). Faecally derived pathogens are the principal concerns in setting health-based targets for microbial safety. Microbial water quality often varies rapidly and over a wide range. Short-term peaks in pathogen concentration may increase disease risks considerably and may trigger outbreaks of water-borne disease (WHO, 2011).

Monitoring microbes in surface or ground waters is used to detect the presence of pathogenic organisms in order to prevent disease. There are a number of broad classes of such microbes including bacteria, protozoa, parasitic worms, fungi, and viruses Indicator micro-organisms are used to suggest the presence of pathogens (Pandey et al., 2014).

2.5 Sampling methods and location of sampling points

2.5.1 Location of sampling points

Samples must be taken from locations that are representative of the water source, treatment plant, storage facilities, distribution network, points at which water is delivered to the consumer, and points of use. In selecting sampling points, each locality should be considered individually; however, the following general criteria are usually applicable:

- Sampling points should be selected such that the samples taken are representative of the different sources from which water is obtained by the public or enters the system (Strobl et al., 2006).
- These points should include those that yield samples representative of the conditions at the most unfavourable sources or places in the supply system, particularly points of possible contamination such as unprotected sources or raw water, treatment plant, loops, reservoirs, low-pressure zones, ends of the system, etc.
- Sampling points should be uniformly distributed throughout a piped distribution system, considering population distribution; the number of sampling points should be proportional to the number of links or branches.
- There should be at least one sampling point directly after the clean-water outlet from each treatment plant (Strobl et al., 2006).

2.6 Regulation of drinking water quality limitations

Drinking water was defined as having adequate quality in relations to its physical, chemical and bacteriological parameters so that it can be safely used for drinking and cooking (Addisie, 2012). WHO describes drinking water to be safe if and only if there are no any significant of health risks after consumption (Cotruvo, 2017).

2.7 Water treatment

The Australian Drinking Water Guideline (ADWG, 2004) postulates that one of the oldest and simplest methods for treating water is to pass it through a bed of fine particles, generally sand. This indicate that sand filtration usually removes fine suspended solid matter as well as some other particles, such as larger microorganisms. Yousaf et al., (2013) postulates that drinking water must be free from microbes, toxic or harmful chemicals and comparatively free of physical compounds that affect the aesthetics of water, including turbidity, color, and taste-producing substances. While most efficient water treatment plants are able to achieve and provide these standards to their users, it is hard to meet such standards in cases where the piped supply is unavailable or where the piped network is contaminated. Household Water Treatment and Safe Storage (HWTS) systems were developed to provide a first or extra barrier of protection to ensure safe drinking water quality.

The idea of treating water at the point of use, preferably using effective but low-cost treatment technologies could be developed using locally available raw materials. Ever since, HWTS technologies such as flocculation, filtration, chlorination and solar disinfection (SODIS) have been instrumental in treating water at the point of use (Jain, 2009). There is significant evidence to suggest that these systems have been successful in improving the drinking water quality and preventing diarrheal disease (Fewtrell et al, 2005) but there also has been conflicting evidence from double-blinded studies that question HWTS efficacy (Schmidt & Craincross, 2008).

In 2008, the World Health Organization reported the percentage of rural populations within some African countries still utilising unimproved water sources. These were reported to be 72% for the Democratic Republic of Congo, 71% for Madagascar and Mozambique, 62% for Angola, 55% for Tanzania, 54% for Zambia, 28% for Zimbabwe, 23% for Malawi, 19% for Lesotho, 14% for

Swaziland, 12% for Namibia and 10% for Botswana (WHO/UNICEF, 2010). In South Africa, the safe drinking water supply to rural and urban populations has improved from 59% in 1994 to 97% in 2010. According to statistics released in 2010, about 1.65 million out of 49 million people in South Africa do not have access to a safe water supply (Pullan et al., 2014). The Department of Water Affairs is therefore seeking simple and appropriate water treatment technology options, at least 3% of the population in need of safe drinking water can treat the water sources that are available to them (Mwabi et al., 2013).

The United Nations Environment Programme (Corcoran, 2010) postulates that if the efforts to prevent pollution from entering water sources are ineffective or insufficient, mechanisms to treat the water to improve quality for drinking and other purposes should be undertaken. It is also necessary to treat the wastewater after it has been used for these purposes. Furthermore, Corcoran (2010), point out that municipality drinking water is sourced from a variety of places by utilities from groundwater, rivers, lakes, canals, reservoirs, and even from seawater. After transporting water from the source, the utility needs to treat this water to ensure that it is suitable to drink by improving the physical, chemical, and biological characteristics of the water.
Water purification can involve a series of processes depending on the source water quality. Water utilities often perform screening for large debris, pre-conditioning to treat hardness and normalize pH, then flocculation to clarify the water by binding particles, settling the particles, and filtration to remove additional suspended particles and microbiological contaminants. A final phase is disinfection, which typically at a municipal scale uses chlorine or chlorine-based disinfectants which leave a residual to the tap, or ozone. Community-scale drinking water treatment systems have also been implemented. These may include community scale filtration or disinfection plants that provide safe drinking water from existing sources. Community-scale interventions for pure drinking water are also used in emergency situations and in transition scenarios (Corcoran, 2010).

According to DWAF (2010) the amount and type of water treatment varies with the source and quality of the water. Generally, surface waters require more treatment than groundwater, as surface waters are more likely to have been polluted by man. It is believed that when a water supplier abstracts water from a river or dam, it often contains suspended materials as well as contaminants. The processes and technologies used to remove contaminants from water and to improve and protect water quality are similar all around the world. The choice of which treatments to use from the great variety available depends on the characteristics of the water, the types of water quality problems likely to be present and the costs of different treatments (DWAF,2010).

2.8 Risk assessment for water intended for human consumption

Wright et al., (2004) state that microbiological contamination of water between source and point-of-use is widespread and often significant. Increased faecal and total coli form counts in stored domestic water are especially found in urban areas with uncontaminated supplies. The results imply that samples taken from storage vessels may provide a better reflection of the quality of water consumed than source samples, particularly in urban areas with safe water sources (Wright *et al.,* 2004). In this regard, microbial water quality may also be improved at the source or other point in the distribution system by chlorination, filtration, and other means. Furthermore, these authors emphasize that improving water at the source is also frequently accompanied by improvements in quantity or access to water by increasing the volume or frequency of water delivery or reducing the time spent in collecting water and as such it significantly benefits not only in health but also in economic and social welfare (Hutton et al., 2004).

2.9 Drinking Water Quality Compliance

All drinking water quality compliance data must be submitted to the Department of Water Affairs on the Blue Drop System (BDS) at a monthly frequency. This data will be used to calculate drinking water quality compliance. The total number of samples reported and drinking water quality data submitted to the Department of Water Affairs on the Blue Drop System (BDS) must correspond (or exceed) with the requirements of the monitoring programme (which is influenced by SANS 241 and the Water Safety Planning Process). Drinking water quality data submitted must also correspond with the analysis value as captured on the laboratory data sheet and should be true to the value as determined during the analysis. Section 82 of the Water Services Act (Act 108 of 1998) makes it clear that it is a legal offence to tamper with drinking water quality data submitted to the Department of Water Affairs. Water Services Institutions must therefore submit all data (inclusive of failures) which will be used to calculate compliance.

2.10 summary

This chapter reviewed a literature relevant to the study. The content discussed were the different aspects that are should be observed to analyze the physico-chemical parameters and trace elements, to evaluate bacteriological quality, to assess community practices regarding collection and storage of water and to evaluate the human health risk due to heavy metals in the water sources. The next chapter describes the methodology of the study.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the research design, study setting, study population, sampling method, and plan for data collection, instrument, data analysis and measures to ensure trustworthiness, ethical considerations and dissemination of results.

3.2 Study Area

The study was conducted at Lufule village in Thulamela municipality Limpopo Province South Africa. The municipality is situated in the eastern subtropical region of the province. It is generally hot and humid and it receives much of its rainfall during summer (Musyoki et al., 2016). The study area includes Nandoni Dam (main reservoir) this dam acquires its raw water from Luvuvhu river that flows through Mutoti and Ha-Budeli villages just a few kilometers away from Thohoyandou town. At Nandoni dam that's where purification process is undergoing to ensure that the water meets the standard set for drinkable water. This dam is the main source of water around the municipality, and it is the one which supply water to selected areas. Lufule village is the one selected for the study area and Nandoni dam.

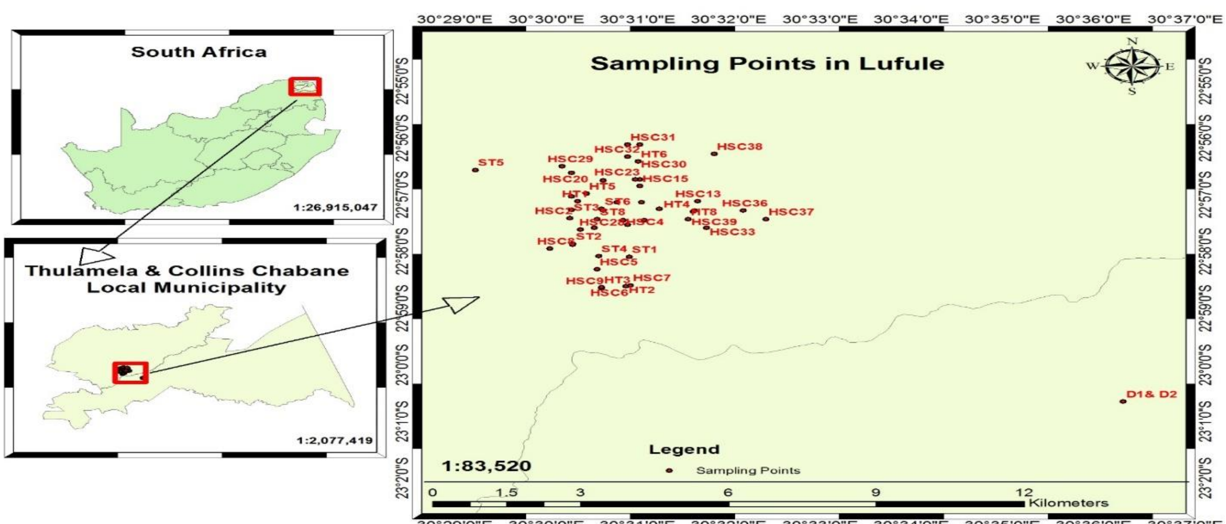

Figure 3.1: Map showing data collection areas (Nandoni dam and Lufule village)

3.3 Research Design

The research design is planned to provide an applicable framework for a study. An important decision in research design process is the choice to be made regarding research approach since it determines how relevant information for a study will be obtained (Aaker, 2005). This study addressed its objectives using quantitative design comprising of field survey and water analysis.

3.3.1 Field survey

The survey was also done to identify the selected household and their street taps. The village was visited and divided into 10 quadrants from sampling purposes. From each quadrant samples were collected from 6 households.

3.3.2 Water sampling

Drinking water samples were collected from the reservoir, tap water and household storage containers. A total of 114 samples were collected during the sampling period, 4 from the reservoir, 16 from street taps that were identified during field survey, 16 from household taps and 78 from household storage of the respondents. Water samples were collected in duplicates during dry and wet season. The samples were collected in a 500 ml sterile polyethylene bottles. After sampling containers were transported to the laboratory on ice in a cooler box. Each of the collected samples were first tested for microbial parameters then physico-chemical parameters and heavy metals to evaluate human health risk of drinking water

3.3.2.1 Microbiological water quality analysis

Analysis of microbial parameters were analysed within 6 hours of collection as recommended by American Public Health Association (APHA, 1992). The Colilert -18 became the ISO 9308-2 standard for the detection of E. coli and total coliforms. Colilert-18 is also U.S.EPA-approved, included in standard methods for examination of water and waste water and in UK's microbiology of drinking water Blue book by Rich (2017).

Viable E. coli were quantified in each sample using the IDEXX technique approved by USEPA. Colilert media was added to 100 mL sample and mixed until dissolved completely. The solution was poured into an IDEXX Quanti-Tray/2000 and sealed using the Quanti-Tray sealer. The samples were incubated at 35°C for 24 h. Trays were scanned using a fluorescent UV lamp to count fluorescent wells positive for E. coli concentration and counted with the most probable number (MPN) table provided by the manufacturer (Rich, 2017).

3.3.2.2 Analysis of physicochemical parameters

Onsite analysis of temperature, pH, EC and TDS were performed immediately after sampling using a multimeter, (model HI "HANNA, instruments), following the standards protocols and methods of American Public Health Organization (APHA, 1995). The instrument probe was calibrated with in accordance with the manufacturer guideline before taking the measurements. The value of each sample was taken after submerging the probe in the water and hold for a couple of minutes to achieve a reliable reading. After measurement of each sample, the probe was rinsed with de-ionized water to avoid cross contamination among different samples.

3.3.2.3 ICP-MS analysis of major and trace elements

An inductively coupled plasma optical atomic spectrophotometer (ICP-MS) were used to analyze both the cations and the trace metals. The instrument was standardized with eight working standard solutions multi-element calibration standard IV for ICP for Copper (Cu), Manganese (Mn), Iron (Fe), Chromium (Cr), Cadmium (Cd), Arsenic (As), Nickel(Ni), Zinc (Zn), Lead (Pb) and cobalt (Co) and analytical precession was checked by frequently analysing the standards as well as blanks. ICP multi Standard solution of (1000 ppm) for K, Ca, Mg and Na was prepared with NH_4OAC for analysis to verify the accuracy of the calibration of the instrument and quantification of selected metals before sample analysis, as well as throughout the analysis to monitor drift.

3.3.2.4 Health Risk Assessment

Risk assessment have been estimated for ingestion and dermal pathways. Exposure pathway to water for ingestion and dermal routes are calculated using Equation 1 and 2 below.

$$\text{Exp}_{\text{ing}}=\frac{IR \times C_{water} \times EF \times ED}{AT \times BW} \qquad 1.1$$

$$\text{Exp}_{\text{derm}}=\frac{C_{water} \times SA \times ET \times EF \times ED \times CF \times K_p}{AT \times BW} \qquad 1.2$$

where, Exp_{ing}: exposure dose through ingestion of water (mg/kg/day); BW: average body weight (70 kg for adults; 15 kg for children); Exp_{derm}: exposure dose through dermal absorption (mg/kg/day); C_{water}: average concentration of the estimated metals in water (µg/L); IR: ingestion rate in this study (2.2 L/day for adults; 1.8 L/day for children); ED: exposure duration (70 years for adults; and 6 years for children); AT: averaging time (365 days/year × 70 years for an adult; 365 days/year × 6 years for a child); EF: exposure frequency (365 days/year) SA: exposed skin area (18.000 cm2 for adults; 6600 cm2 for children); K_p: dermal permeability coefficient in water, (cm/h), 0.001 for Cu, Mn, Fe and Cd, while 0.0006 for Zn; 0.002 for Cr and 0.004 for Pb; ET: exposure time (0.58 h/ day for adults; 1 h/day for children) and CF: unit conversion factor (0.001 L/cm3) (Naveedullah et al., 2014 and USEPA, 1989). The hazard quotient (HQ) of non-carcinogenic risk by ingestion pathway can be determined by Equation 3

$$\text{HQ}_{\text{ing/derm}}=\frac{EXP_{ing/derm}}{RfD_{ing/derm}} \qquad 1.3$$

Where, RfD_{ing} is ingestion toxicity reference dose (mg/kg/day). An HQ under 1 is assumed to be safe and taken as significant non-carcinogenic (USEPA, 2009), but HQ value above 1 may be a major potential health concern in association with over exposure of humans to the contaminants.

The total non-carcinogenic risk is represented by hazard index (HI). HI<1 means the non-carcinogenic risk is acceptable, while HI>1 indicates the risk is beyond the acceptable level (Wu and Sun, 2016). The HI of a given pollutant through multiple pathways can be calculated by summing the hazard quotients by Equation 4 below.

$$\text{HI} = \sum_{i=1}^{n} HQ_{ing/derm} \qquad 1.4$$

Chronic daily intake (CDI) of heavy metals through ingestion are be calculated using Equation 5. Where, C_{water}, DI and BW represent the concentration of trace metal in water in (mg/kg), average daily intake of water (2.2 L/day for adults; and body weight (70 kg for adults; 15 kg for children), respectively.

$$\text{CDI}_{\text{ing}} = Cwater \times \frac{DI}{BW} \qquad 1.5$$

Carcinogenic risks for ingestion pathway are be calculated by equation 6. For the selected metals in the study, carcinogenic risk (CR_{ing}) can be defined as the incremental probability that an individual will develop cancer during his lifetime due to exposure under specific scenarios (Wu et al., 2009).

$$CR_{ing}= \frac{D_{ing}}{SF_{ing}} \quad 1.6$$

3.4 Data analysis

Results obtained from this study were presented as descriptive statistics in the form tables and graphs using Microsoft Excel. Excel was used in plotting and displaying of the obtained outcomes. The experimental data obtained was compared to SANS 241 (2015), and DWAF (1996) guidelines for domestic water use.

3.5 Ethical Consideration

3.5.1 Permission

Research that involves human subjects or participants raises unique and complex ethical, legal, social and political issues. Research ethics is specifically interested in the analysis of ethical issues that are raised when people are involved as participants in research. The main objective is to protect human participants and to ensure that research is conducted in a way that serves interests of individuals, groups and/or society as a whole.

The proposal was presented to the, School Higher Degree Committee and University Higher Degrees Committee (UHDC) at the University of Venda for recommendation and approval. Thereafter, it was registered with the university's Research Directorate and Innovation Office, where it also undergoes a scrutiny by the University's Research Ethics Committee. The ethical clearance was presented to the Department of Water affairs, Limpopo, Vhembe district Municipality and the selected clinics for permission to access the prospective participants. The basic principles of ethics were duly observed and the permission to conduct the research was sought from the department of water affairs, University of Venda, Health, Safety and Research Ethics Committee. A

3.5.2 Informed consent

The need for the study and the processes involved was explained to the participants. They were also informed that their participation in the study is voluntary, and they were free to make a choice whether to complete the questionnaire or not. Only those who agreed to participate after the explanation were given consent form to fill.

3.5.3 Confidentiality

Babbie and Mouton (2001) believe that confidentiality implies that only the researcher and possibly a few members of his staff should be aware of the identity of participants and in this study. The participants were assured that the information provided by them were treated confidentially and that only the researcher and the supervisors had access to the data; and that the questionnaires were kept in a safe place where no one can reach them.

3.5.4 Anonymity

This one means that no one, including the researcher, should be able to identify any subject afterwards (Babbie, 1990). In this study participants were advised not to include their names on the questionnaire. This will help to ensure that no subject is involved in the investigation merely because the researcher knows or does not know the person, the research reports should also preferably use averages instead of releasing information about individuals that may be identifiable by the researcher or others.

3.7 Summary

This chapter described the detailed process as to how the study was conducted in order to achieve the study objectives. The study design was quantitative in nature. Measures undertaken to ensure validity, reliability and ethical considerations were also described. Processes followed in data collection and analysis were outlined. The next chapter will focus on the results and a discussion of the analysed data.

CHAPTER 4

RESULTS

4.1 Introduction

This chapter presents the results of analysis of the questionnaires used to assess the community practices regarding collection and storage of water, bacteriological (total coliforms and E. coli) quality of the water at source as well as the distribution system and physico-chemical parameters (pH, dissolved oxygen electrical conductivity, and total hardness) as well as trace elements (mercury, lead, copper and zinc).

4.2 Questionnaire analysis

In this research, 120 questionnaires were distributed but only 115 were completed. The age of the respondents of this study show 35% of the respondents were at the age of 25 to 34 years (Figure 4.1), followed by those in the age group 65 and above while the least is in the age group of 55-64 years.

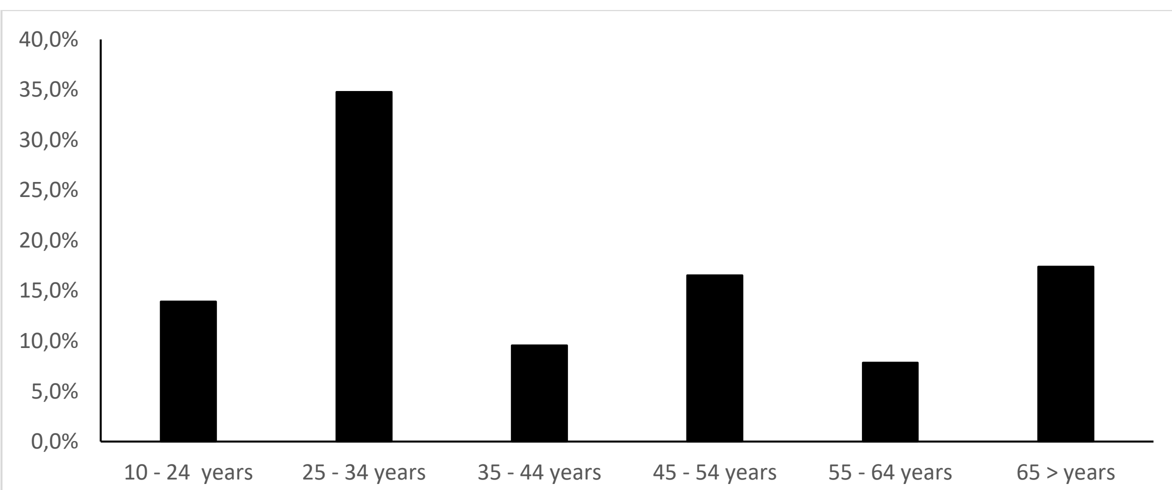

Figure 4.1: Age characteristics of study participants

The respondents for the study was more of male and slightly more than half of the respondents (50.4%) were married

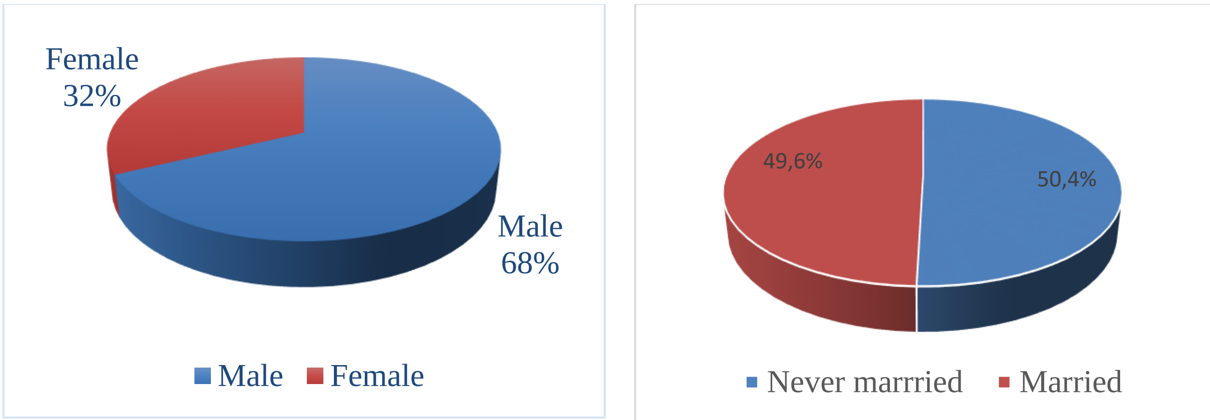

Figure 4.2: The gender (left) and marital status of the respondent.

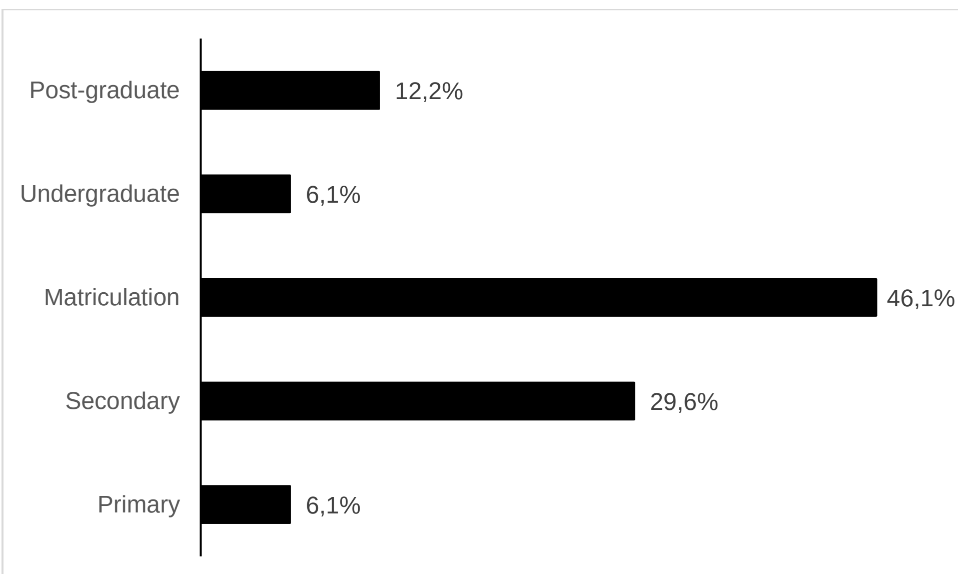

Figure 4.3. Educational level of the respondents

In terms of sources of incomes, 42.6% indicated that they are self-employed, followed by 25.2% of the participants who receive grants from the government and 21.7% who are permanently employed (Figure 4.4).

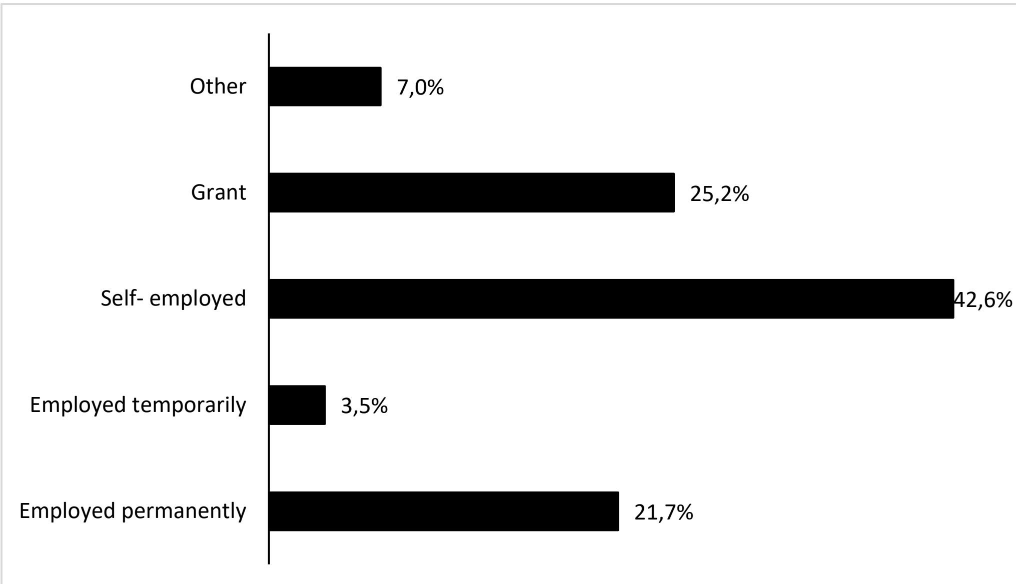

Figure 4.4: Employment status of the respondent

Households (68.7%) had their primary water source piped into their yard and 19.1% fetch water from their neighbour's yard, whereas only 5.2% used street taps (Table 4.1). Water was collected by adult women (n = 61. 53%) in most households and when there is interruption of water from the municipal taps and it took 10- 30 min to go to their secondary water source to collect water and come back in one trip. During interruption in their primary water supply 20.9% use private boreholes.

Table 4.1: Water supply in the household

Variables		Frequency	Percentage
Primary source of drinking	Piped into the house	6	5.2
	Piped into the yard	79	68.7
	Neighbour's pipe	22	19.1
	Public tap or standpipe	6	5.2
	Other	2	1.7
If sometimes interrupted the last interruption, how many days did the interruption last?	1 week	68	59.2
	2 weeks	36	31.3
	Month	2	1.7
	2 months	3	2.6
	3 months	6	5.2
During interruptions in your primary water supply, what is your secondary source of water>	Municipality treated source	4	3.5
	Communal tap	58	50.4
	Private boreholes	24	20.9
	Other	29	25.2
How long does it take to get the secondary water source, get water and come back in one trip? If water is located in the household, response is	10 - 30 mins	61	53.0
	35 mins - 1 hour	38	33.0
	1 hour 30 min - 2 hours	11	9.6
	2 hours 30 mins - 3 hours	4	3.5
	4 hours & above	1	0.9

The respondents (91.3%) reported interruptions in availability of water that last at least once a week and 8.7% interruption in one month (Table 4.2). Household water was most frequently stored in plastic buckets (n = 78, 67.8%) while few households stored water in large drums or plastic tanks (n = 2, 1.7%). Most households reported that their drinking water containers were covered (n = 111, 96.5%). 53.9% of the respondent used cup with a handle to collect water from the container whereas 37.4% used cups with no handle. Only 7.8% households reported that they treat their water before use mainly by boiling. Approximately 82.6% of respondent perceived that they cannot get sick from drinking water and only 17.4% knew the risk associated with untreated water, and cited diarrhea, schistosomiasis, cholera, fever, vomiting, ear infections, malnutrition, rash, flu and malaria as specific illnesses associated with water. Despite these perceptions, the majority were satisfied with their current water source (76.5%) and only 23.5% were not satisfied and cited reasons of cloudiness, bad odor or taste in the water.

Table 4.2: Water storage and treatment practices at the household

Variables		Frequency	Percent
How long do you have to take water from this secondary source?	At least once a week	105	91.3
	At least once a month	10	8.7
Do you usually treat water before you drink? If no skip to question 16	Yes	9	7.8
	No	106	92.2
Which method of treatment do you usually use to make water safe to drink?	Solar disinfection	2	1.7
	Use water filter (ceramic/ sand/etc.)	3	2.6
	Add bleach / chlorine	2	1.7
	Boil	2	1.7
What do you use to store your drinking water	Ceramic vessels	24	20.9
	Metal buckets	5	4.3
	Plastic buckets	78	67.8
	Jerrycan	3	2.6
	Pans	3	2.6
	Water tank	2	1.7
How long does water stay in the storage container	Less than a week	101	87.8
	Between one week and two weeks	8	7.0
	Less than a month	6	5.2
Are your storage vessels covered	No	4	3.5
	Yes	111	96.5
What do you use to get the water from the storage container?	Pour directly	10	8.7
	Use cup with handle	62	53.9
	Use cup with no handle	43	37.4
	No	95	82.6

Do you think that you can get sick from the water you use? If no skip to question 24	Yes	20	17.4
Are you satisfied with the quality of water you use? if yes skip question 25	No	27	23.5
	Yes	88	76.5

Majority of the respondents (67%) uses pit toilet whereas only 26.1% use the flush to septic tank system. Most of the toilets (93.9%) have a concrete floor, about 76.5% of households do not have designated place to wash their hands, and all respondents showed that they do wash their hands after using toilets (Table 4.3).

Table 4.3: Sanitation practices at the household level

Variables		Frequency	Percent
What kind of toilet facility do members of your household usually use?	No facility / bush / fields	3	2.6
	Pit latrine	77	67.0
	Improved pit latrine without flush	3	2.6
	Flush to piped sewer system	2	1.7
	Flush to pit (septic) tank	30	26.1
Does the toilet/latrine you use have a concrete floor	No	7	6.1
	Yes	108	93.9
How many households use this toilet facility?	0-2	53	46.1
	3-5	6	5.2
	6-8	11	9.6
	9-10	22	19.1
	12-15	22	19.1

	16-20	1	.9
Is there a designated place to wash hands by this toilet	No	88	76.5
	Yes	27	23.5
How often do you wash your hands after using the toilet?	Always	115	100.0
How often do you use toilet paper?	Always	115	100.0
How often do you wash your hands before preparing food?	Always	115	100.0
How often do you use soap when you wash your hands? (soap can include ash, sand or the use of hand sanitizer gel/ cream)	Always	115	100.0
Is there any cultivation (use of manure or fertilizer) within 30m of the main source?	No	115	100.0
Is the borehole protected?	No casing	115	100.0

4.3 Water samples analysis

The water samples analysis comprises of microbial analysis, Physico-chemical analysis and Heavy metals parameters

4.3.1 Microbial analysis

The samples from the reservoir during dry and wet season had 0 MPN/100 mL of total coliform and E. coli and were within the recommended limits of the World Health Organization (WHO) and South African National Standards (SANS) for drinking water (Table 4.4). During the dry season, the street taps samples had less total coliform contamination than during wet season. The E. coli levels of the street taps were within the recommended limits of the WHO during dry season whereas during wet season, few total coliforms was detected.

Table 4.4: Total coliform and E. coli levels in for reservoir, taps and household water samples.

Sample ID	Total coliform		E. coli	
	Dry season	**Wet season**	**Dry season**	**Wet season**
Reservoir/ Dam(D)				
D1	<1	<1	0	0
D2	<1	<1	0	0
Street taps (ST)				
ST 1	<1	>2000	0	0
ST 2	<1	144.8	0	0
ST 3	132.4	>2000	0	1.0
ST 4	<1	<1	0	0
ST 5	123.9	123.9	0	0
ST 6	770.1	770.1	0	1.0
ST 7	221.3	>2000	0	0
ST 8	146.1	62.9	0	0
SANS (2015)	0	0	0	0
WHO (2008)	0	0	0	0

Household taps showed higher levels of total coliform in the dry season than in the wet season (Table 4.5). In the wet season, the contamination was at maximum detection level of more than 2000 MPN/100 ml. There is a trend that total coliform levels are higher during the wet season than the dry season. Household taps analysis for the E. coli were not detectable in most sample except one sample which was contaminated during dry and wet season.

Table 4.5: Analysis total coliform and E. coli for Household taps

House Taps (HT)	Total coliform		E. coli	
	Dry season	**Wet season**	**Dry season**	**Wet season**
HT 1	1.0	>2000	0	0
HT 2	<1	410.6	0	0

HT 3	3.0	>2000	0	0
HT 4	78.7	200.5	1.0	1.0
HT 5	157.5	>2000	0	0
HT 6	3.0	>2000	0	0
HT 7	15.8	>2000	0	0
HT 8	>2000	307.6	0	0

Household samples from stored containers show the high level of total coliform during the wet season than during the dry season whereas the E. coli levels in both dry season and wet season were low (Table 4.6).

Table 4.6: Analysis total coliform and E. coli for Household storage containers

Household storage containers (HSC)	**Total coliform**		**E. coli**	
	Dry season	**Wet season**	**Dry season**	**Wet season**
HSC 1	>2000		0	
HSC 2	31.5	>2000	0	0
HSC 3	>2000	>2000	1.0	1.0
HSC 4	>2000	307.6	0	0
HSC 5	172.2	>2000	0	0
HSC 6	224.7	1553.1	0	0
HSC 7	>2000	579.4	0	0
HSC 8	886.4	>2000	2.0	0
HSC 9	1299.7	48.2	0	0
HSC 10	>2000	>2000	0	0
HSC 11	1553.1	39.5	0	0
HSC 12	>2000	48.2	0	0
HSC 13	47.1	62.9	0	0
HSC 14	1.0	33.6	0	0
HSC 15	38.4	*	0	
HSC 16	>2000	>2000	0	0
HSC 17	>2000	>2000	0	1.4

HSC 18	1732.9	1119.9	0	0
HSC 19	>2000	>2000	0	0
HSC 20	>2000	>2000	0	0
HSC 21	245.2	135.5	0	0
HSC 22	*	57.4	0	2.0
HSC 23	<1	*	0	
HSC 24	1.0	146.1	0	0
HSC 25	8.5	133.0	0	0
HSC 26	7.5	57.1	0	0
HSC 27	<1	146.1	0	0
HSC 28	2.0	*	0	
HSC 29	<1	>2000	0	0
HSC 30	<1	95.7	0	0
HSC 31	<1	>2000	0	0
HSC 32	<1	>2000	0	0
HSC 33	206.4	>2000	0	0
HSC 34	1119.9	>2000	0	1.0
HSC 35	261.3	>2000	0	0
HSC 36	15.8	>2000	0	0
HSC 37	229.4	>2000	0	0
HSC 38	15.8	*	1.0	
HSC 39	>2000	229.4	0	0
SANS (2015)	0	0	0	0
WHO (2008)	0	0	0	0

*= sample not detected

4.3.2 Physico-chemical analysis

In the reservoir samples the pH value ranged from 8.37-8.45, EC ranged between 183 and 259 (µS/cm) whereas TDS varied between 118 and 168 (mg/l) (Figure 4.4).

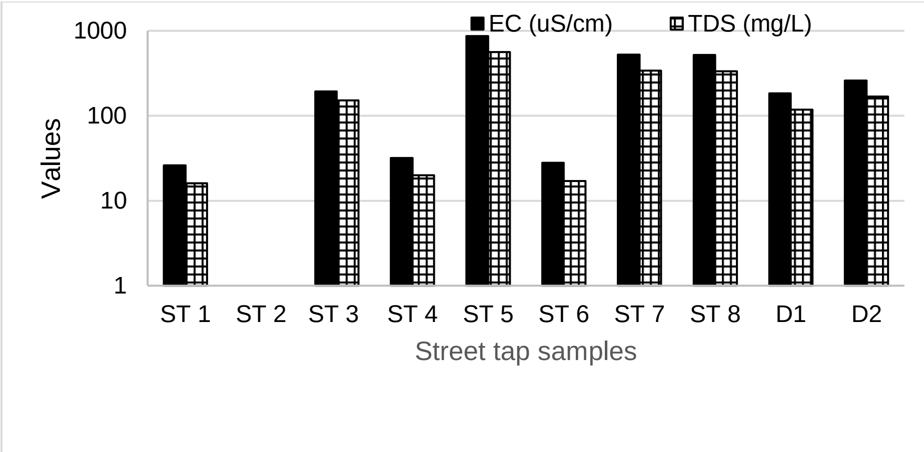

Figure 4.5: EC and TDS levels for street taps

Similarly, in the street tap samples pH value ranged from 7.28 and 9.33, EC ranged between 0 and 867 (s/cm) whereas TDS varied between 0 – 562 mg/l (figure 4.5)

In the household taps pH value ranged from 7.70 - 9.98, EC range between 28- 895 and TDS varied between 18 and 572 (Figure 4.5).

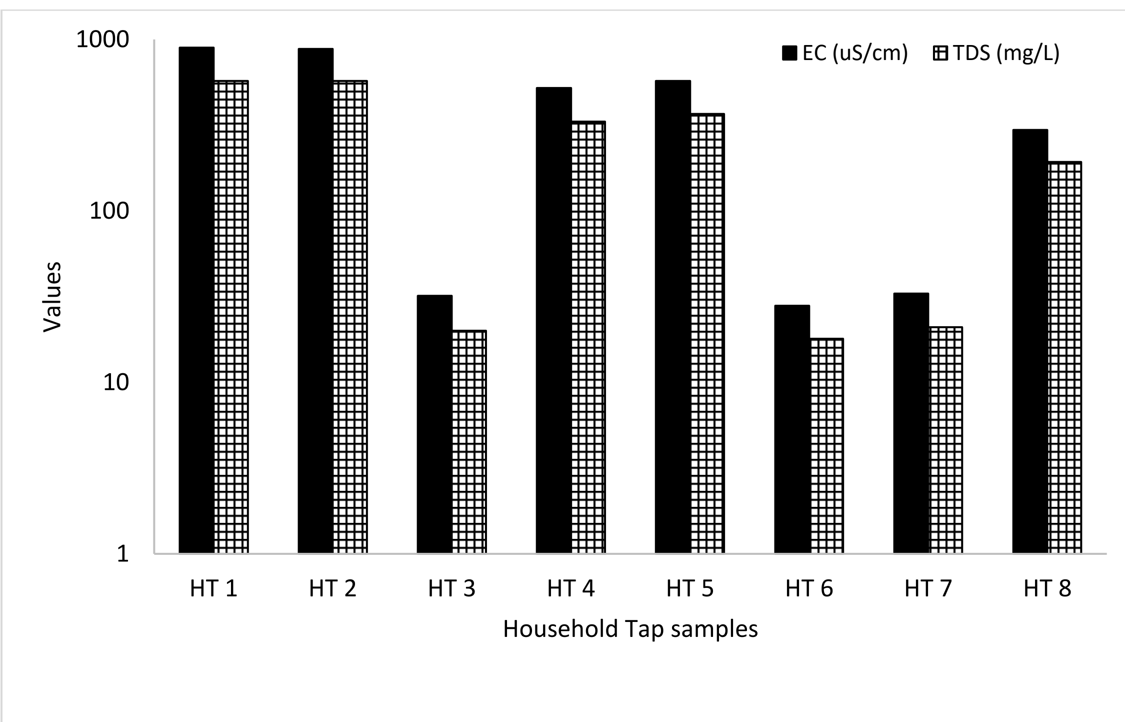

Figure 4.6: EC and TDS levels for household taps

In household storage container samples, the pH value ranges from 7.67-9.77, EC ranged between 0-903µS/cm and TDS values ranged from 0-1148mg/l (figure 4.6).

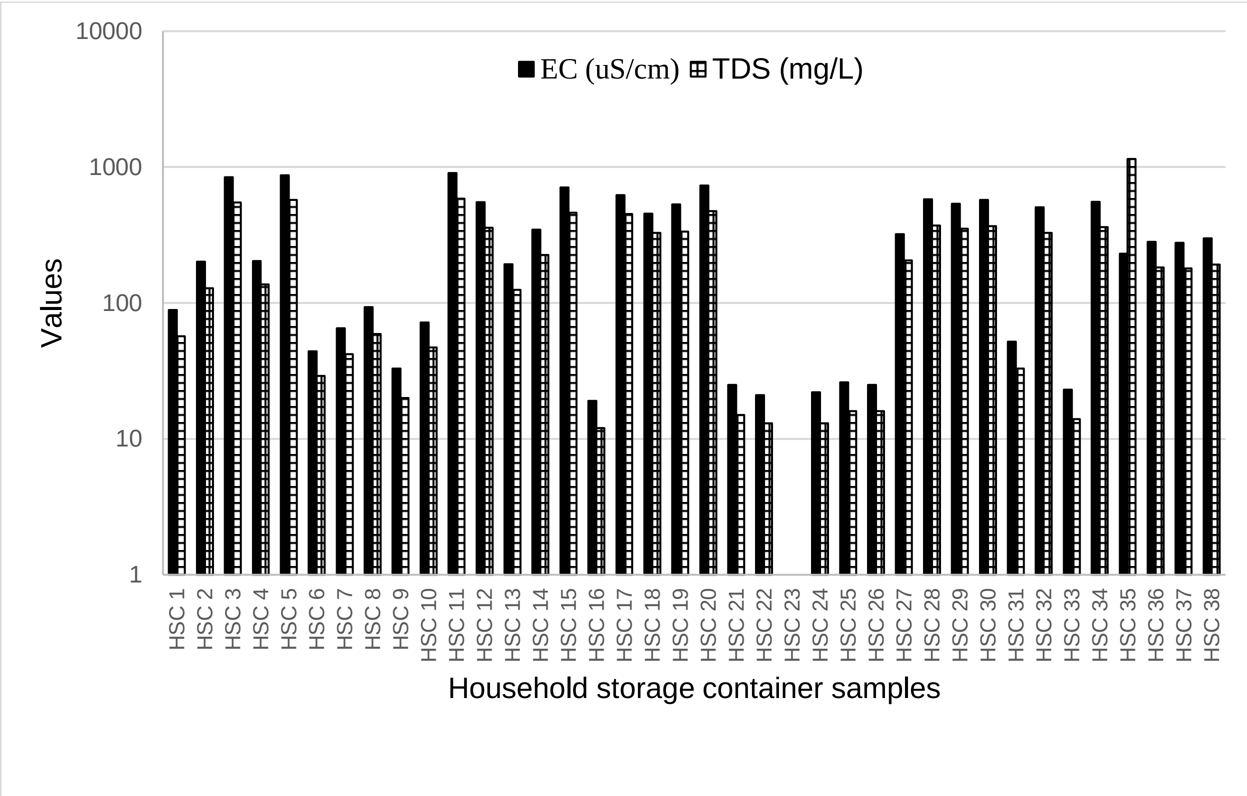

Figure 4.7: EC and TDS levels for household storage container samples

The concentration of Calcium ranged between 2.14 and 31,65mg/l (Table 4.7), Potassium concentration ranged from 0.14-1.85mg/l, Magnesium concentration varied from 1.32 to 16.59mg/l, Sodium ranged from 0.18 to 12.96 mg/l.

Table 4.7: Cations indicators in water

Metals	Ca	K	Mg	Na
Units	**mg/l**	**mg/l**	**mg/l**	**mg/l**
LOD	**0.1**	**0.1**	**0.1**	**0.1**
% Accuracy QC	**95**	**111**	**96**	**95**
D1	11.81	*BDL	6.75	7.61
D2	11.64	1.85	6.45	9.44
ST 1	20.95	*BDL	11.26	7.09
ST 3	26.99	0.31	14.22	11.12
ST 4	5.05	*BDL	2.50	0.56
ST 5	31.65	0.49	16.59	12.96
ST 6	3.41	0.15	1.59	2.57
ST 7	2.84	0.16	1.56	2.54
HT 2	30.99	0.29	16.30	12.62
HT 4	25.66	*BDL	13.57	8.83
HT 8	11.54	1.83	6.44	9.27
HSC 9	2.14	0.14	1.32	2.42
HSC 28	3.27	*BDL	1.76	0.18
HSC 30	16.24	*BDL	8.72	5.09
HSC 33	26.55	*BDL	13.85	8.95

4.4 Heavy metals parameters

Aluminium concentration ranged from 1.25-13.46 µg/L (Table 4.8), Manganese concentration varied from 0.41 to 10.91 µg/L, Iron concentration range between 0.96 and 73.53 µg/L, Cobalt ranged between 0.02 and 0.04 µg/L, Nickel concentration varied between 0.10 and 0.32 µg/L, copper concentration ranged between 1.48 and 46.20 µg/L, Zinc concentration varied from 2.54 to 194.96 µg/L, Arsenic concentration ranged between 0.02 and 0.17 µg/L, Lead concentration varied between 0.02 and 0.57 µg/L and there was no trace of chromium in any of the water samples analysed.

Table 4.8: Concentration of heavy metals in water.

Metals	**Al**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Pb**
Units	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**	**µg/L**
LOD	0.31	0.14	0.31	0.01	0.10	0.19	0.32	0.02	0.02
%Accuracy QC	**99**	**101**	**108**	**96**	**93**	**94**	**96**	**92**	**102**
D1	13.49	4.09	19.67	0.03	0.35	2.69	4.14	0.14	0.12
D2	12.65	4.44	21.45	0.04	0.38	1.51	3.49	0.13	0.11
ST 1	2.97	1.27	2.28	0.02	0.17	2.24	23.16	0.03	0.06
ST 3	2.12	1.22	1.16	*BDL	0.32	1.67	8.99	*BDL	0.04
ST 4	1.36	1.25	5.41	0.02	0.10	1.98	4.54	0.03	0.04
ST 5	1.29	2.59	0.96	0.03	0.20	1.91	6.71	*BDL	0.02
ST 6	4.83	4.10	25.94	0.02	0.04	1.73	3.71	0.02	0.08
ST 7	3.01	2.11	14.86	0.02	0.06	2.27	2.54	0.02	0.17
HT 2	1.25	0.41	*BDL	*BDL	0.12	1.24	4.07	*BDL	0.03
HT 4	1.72	8.47	5.98	0.02	0.70	46.20	194.96	0.06	0.47
HT 8	11.77	5.25	73.53	0.04	0.32	23.56	35.54	0.17	0.57
HSC 9	5.81	4.07	58.84	0.03	*BDL	4.22	7.22	0.03	0.20
HSC 28	2.46	4.10	14.37	0.02	0.11	4.21	21.38	0.04	0.12
HSC 30	5.27	3.08	8.35	0.02	0.12	3.81	10.59	0.03	0.33
HSC 33	3.00	10.91	6.85	0.02	0.32	1.48	28.59	*BDL	0.10

The minimum and maximum levels of HQ, as well as total HQ for adults and children through ingestion and dermal contact pathways, are presented in Table 4.9. The minimum and maximum levels of heavy metals (Fe, As, Mn, Co, Ni, Cu, Zn, and Pb) present in water samples from street taps household taps and household storage containers of the selected village in Thulamela municipality are presented in Table 4.10. The minimum and maximum levels of CDI, as well as total CDI for adults and children through ingestion pathways in the study area, are given in Table 4.11. The carcinogenic risk assessment for adults and children is given in Table 4.11.

Table 4.9: Human health risks associated with different heavy metals for August

Metals	RfD$_{ing}$ (µg/kg/day)	RfD$_{derm}$ (µg/kg/day)	D$_{ing}$ (Child)	D$_{ing}$ (Adult)	HQ$_{ing}$ (Child)	HQ$_{ing}$ (Adult)	D$_{derm}$ (Child)	D$_{derm}$ (Adult)	HQ$_{derm}$ (Child)	HQ$_{derm}$ (Adult)	HQ$_{ing}$/HQ$_{derm}$_Child	HQ$_{ing}$/HQ$_{derm}$_Adult
Fe	7.00E+02	1.40E+02	9.40E-04	5.59E-01	1.20E-01	2.31E+06	7.83E-03	2.42E-07	1.22E+12	3.97E+16	4.14E-11	7.99E-04
Mn	2.40E+01	9.60E-01	3.88E-01	1.02E-01	2.73E+02	1.22E+02	1.42E-03	8.31E-04	8.97E+05	1.54E+06	9.44E-03	4.23E-03
Co	2.00E-02		2.37E-03	6.22E-04	2.73E+02	1.22E+02	8.70E-06	5.09E-06	2.45E+12	4.19E+12	6.94E-02	3.11E-02
Ni	2.00E+01	5.40E+00	2.40E-02	6.29E-03	2.73E+02	1.22E+02	8.81E-05	5.15E-05	1.22E+12	2.09E+12	7.02E-04	3.15E-04
Cu	4.00E+01	8.00E+00	9.02E-01	2.36E-01	2.73E+02	1.22E+02	3.31E-03	1.93E-03	3.55E+04	6.07E+04	1.32E-02	5.91E-03
Zn	3.00E+02	6.00E+01	3.02E+00	7.92E-01	4.55E+01	2.04E+01	6.65E-02	3.89E-02	1.74E+04	2.97E+04	5.89E-03	2.64E-03
Pb	1.40E+00	4.20E-01	1.96E-02	5.13E-03	6.82E+01	3.06E+01	2.87E-04	1.68E-04	1.10E+04	1.10E+04	8.18E-03	3.66E-03
Al			5.29E-01	1.39E-01	2.73E+02	1.22E+02	1.94E-03	1.13E-03	6.33E+05	1.08E+06		
As	3.00E-01		4.82E-03	1.26E-03	2.73E+02	1.22E+02	1.77E-05	1.03E-05	4.55E+12	7.78E+12	9.39E-03	4.21E-03
										HI	1.16E-01	5.28E-02

RfD$_{ing}$ = reference dose ingestion, RfD$_{derm}$ = reference dose dermal, HQ$_{ing}$ = hazard quotient ingestion, HQ$_{derm}$ = hazard Quotient dermal

Table 4.10: The maximum and minimum average values of human health risk assessment for dry season

	Stats. Parameter	Ding (Child)	Ding (Adult)	HQ_{ing} (Child)	HQ_{ing} (Adult)	D_{derm} (Child)	D_{derm} (Adult)	HQ_{derm} (Child)	HQ_{derm} (Adult)
Fe	Min	3.88E-03	3.14E-09	1.20E-01	2.31E+06	4.40E-11	1.36E-15	2.16E+04	7.01E+08
	Max	3.88E-03	2.31E+00	1.20E-01	2.31E+06	3.24E-02	9.98E-07	1.59E+13	5.16E+17
As	Min	1.20E-08	3.14E-09	1.36E+02	6.11E+01	4.40E-11	2.57E-11	1.97E+04	3.37E+04
	Max	2.07E-02	5.43E-03	2.73E+02	1.22E+02	1.52E-04	8.89E-05	1.59E+13	2.72E+13
Mn	Min	4.89E-02	1.28E-02	2.73E+02	1.22E+02	1.79E-04	1.05E-04	1.88E+05	3.22E+05
	Max	1.02E+00	2.66E-01	2.73E+02	1.22E+02	3.73E-03	2.18E-03	3.90E+06	6.68E+06
Co	Min	1.20E-08	3.14E-09	2.73E+02	1.22E+02	4.40E-11	2.57E-11	4.28E+07	7.32E+07
	Max	4.46E-03	1.17E-03	2.73E+02	1.22E+02	1.64E-05	9.56E-06	1.59E+13	2.72E+13
Ni	Min	1.20E-08	3.14E-09	2.73E+02	1.22E+02	4.40E-11	2.57E-11	2.26E+06	3.87E+06
	Max	8.44E-02	2.21E-02	2.73E+02	1.22E+02	3.09E-04	1.81E-04	2.26E+06	2.72E+13
Cu	Min	1.49E-01	3.91E-02	2.73E+02	1.22E+02	5.48E-04	3.20E-04	1.97E+03	3.37E+03
	Max	5.54E+00	1.45E+00	2.73E+02	1.22E+02	2.03E-02	1.19E-02	1.97E+03	1.25E+05
Zn	Min	3.04E-01	7.97E-02	4.55E+01	2.04E+01	6.70E-03	3.91E-03	5.83E+02	9.97E+02
	Max	2.34E+01	6.13E+00	4.55E+01	2.04E+01	5.15E-01	3.01E-01	5.83E+02	7.66E+04
Pb	Min	2.65E-03	6.95E-04	6.82E+01	3.06E+01	3.89E-05	2.28E-05	1.40E+03	2.40E+03
	Max	6.80E-02	1.78E-02	6.82E+01	3.06E+01	9.97E-04	5.83E-04	1.40E+03	6.15E+04

Table 4.11: Chronic daily intake (CDI) and Carcinogenic risk assessment (CR_{ing}) of values in mg/kg/day of heavy metals in drinking water samples

	Stats. Parameter	CR_{ing} (child)	CR_{ing} (Adult)	CDI_{ing} (Child)	CDI_{ing} (Adult)
Fe	Min	-	-	1.20E-08	3.14E-09
	Max	-	-	8.82E+00	2.31E+00
As	Min	8.00E-12	4.15E-05	1.20E-08	3.14E-09
	Max	2.10E-12	1.09E-05	2.07E-02	5.43E-03
Mn	Min	-	-	4.89E-02	1.28E-02
	Max	-	-	1.02E+00	2.66E-01
Co	Min	-	-	1.20E-08	3.14E-09
	Max	-	-	4.46E-03	1.17E-03
Ni	Min	-	-	1.20E-08	3.14E-09
	Max	-	-	8.44E-02	2.21E-02
Cu	Min	-	-	1.49E-01	3.91E-02
	Max	-	-	5.54E+00	1.45E+00
Zn	Min	-	-	3.04E-01	7.97E-02
	Max	-	-	2.34E+01	6.13E+00
Pb	Min	3.12E-04	8.18E-05	2.65E-03	6.95E-04
	Max	8.00E-03	2.09E-03	6.80E-02	1.78E-02

4.5 Summary

Chapter four illustrate the results that were analyzed from the data collected, which is the community practices regarding collection and storage of drinking water, physico-chemical parameters, bacteriological (total coliforms and E. coli) quality of water at source as well as the distribution system and evaluation of the human health risk due to heavy metals in the water sources. Chapter five will discuss the results that were analyzed in this study.

CHAPTER 5
DISCUSSION

5.1 Introduction

This chapter focuses on the discussion of the results. Information from the respondents were acquired in form of questionnaire. In order to protect the identity of the participants. Pseudo names were used to distinguish the participants. A literature control was done to support or refute what is already known about the topic. This study aim to assess the quality of water from the water treatment plant, street and household taps as well as from storage containers and to evaluate possible human health risk associated with the consumption of the water in Lufule village.

The objectives of this study were:

1. To analyze the physico-chemical parameters (pH, dissolved oxygen, electrical conductivity, and total hardness) trace elements (mercury, lead, copper, zinc, iron, aluminium, cadmium, chromium and manganese).

2. To evaluate bacteriological (total coliforms and E. coli) quality of the water at source as well as the distribution system.

3. To assess community practices regarding collection and storage of water.

4. To evaluate the human health risk due to heavy metals in the water sources.

5.2 Community Practices

Data assessment based upon the socio-demographic, water handling and other related practices were discussed.

5.2.1 Socio-demographic characteristics

Socio-demographic variables of the study showed that 35% of respondents were of age 25-34 years. Among the total respondents, 50.4% were married and 46.1% have finished high school. Around 42.6% of the participants were self-employed.

About 98.3% of the respondents used protected water sources, (68%) water is collected by males, while females were remaining to perform other tasks in the house. Similar study was done by Sharma *et al.* (2013). In most cultures, females are mainly responsible for the collection of water, other house chores and management of water storage, health and sanitation at the household level (DESA/DSD, 2002).

5.2.2 Water handling practices

Water hygiene depends on different factors which include the cleanliness of storage containers during transportation, storage and handling practices at household level. Majority (68.7%) of the respondents had pipe in connection in their households though in most cases water was not available in their taps. Similar results were found in a study done by Mynit et al, (2015) wherein 77% of households had pipe in connection in their household whereas the remaining households carried the water from the reservoir.

Plastic buckets were used by 67.8% for the storage of drinking water followed by 20.9% which stored water in ceramic vessels. From a study done by Mynit et al (2015) observations showed that they stored their drinking-water in 44.1% plastic bottles of 20-litre capacity that had previously been filled with purified water and 23.7% in ceramic jars. Kuberan et al (year??) study done in a rural area.75% of them stored drinking water in wide mouth closed container.

Majority 96.5% of the respondents showed that their storage vessels were covered, 53.9% used cup with handle and 37.4% used a dipping method of cups with no handle to draw water from storage containers which lead to high chance of contamination. People's behavior has more significance than hardware (containers and layout) in achieving the expected benefits from water supply schemes (Dyer, 2002).

5.3 Water Analysis

Water analysis is discussed under the different tests that were done, microbiological, parameters, Physical parameters, chemical parameters and Heavy metals parameters

5.3.1 Microbiological parameter

Treated water from the dam tested negative for both total coliform and E. coli hence complied with regulatory standards of SANS (2015) and WHO (2012). The results could probably be due to the use of chlorine as a disinfectant in the treatment plant. Using disinfectants, pathogenic bacteria from the water can be killed and water made safe for the user (Abok, 2018). Similarly, findings from other studies have shown that treated water in urban water treatment plant contains no total coliforms and E. coli (Hashmi et al., 2009).

In contrast, rural treated water sources have been reported to have considerable levels of total coliform and E. coli (Onyago et al., 2018). The reason alluded to this include lack of disinfectant, no chlorine residual in the treated water, high prevalence of open defecation and unhygienic practices in proximity to water sources (Gwimbi et al., 2019).

Results of this study shows that 62.5% of water samples taken from the street taps were contaminated with total coliform while E. coli tested negative during the dry season. The street taps which is about 13 km from the reservoir recorded levels of total coliform which ranges from 1.0 -2000 MPN/100 ml which exceeds WHO (2011) guidelines of 0 MPN /100 ml and E. coli with varies from 0-1 MPN/100 ml. In the wet season, Samples (87.5%) from street taps tested positive for total coliform while all samples tested negative for E. coli (Table 4.2.1). This could probably be as a result of the decrease in residual chlorine from the treatment plant. According to Karikari and Ampofo (2013), water leaving the treatment plants often meet bacteriological standards; however, coliform bacteria were detected in the distribution lines suggesting that the water is contaminated in the distribution networks. The author attributed the results to the adherence of bacteria onto biofilms or accidental point source contamination by broken pipes, installation and repair works.

The findings of this study show that samples from household storage containers was contaminated by total coliform (73%) and E. coli (10.4%) during the dry season, whereas during wet season the contamination for total coliform was 85% and 13.2 % for E. coli based on SANS (2015) guidelines, there should be ≤10 cfu/100 ml detection of total coliform and 0 cfu/100 ml detection of E. coli in 100 ml of water intended for drinking purpose. Contamination of household water stored in containers could be due to unhygienic practices. Microbiological contamination of the water may occur between the collection point and the point-of-use in the household due to unhygienic practices causing the water to become a health risk (Sobsey, 2002; Cronin et al., (2006).

Generally, in the wet season higher level of contamination were recorded than in the dry season. The wet season in Thulamela Municipality is often characterized with increased temperature which could lead to favorable condition for microbial growth. Also, during the wet season, the treatment plant usually adds the same amount of chlorine which is unaccepted as the influent water would be of high turbidity hence reducing the levels of residual chlorine. A previous study by Edokpayi et al. (2018) has shown that low levels of residual chlorine is recorded in the treatment plant and zero level in the street taps.

5.4 Physical parameters

5.4.1 pH

pH is an important parameter in evaluating the acid-base balance of water. SANS has recommended minimum and maximum permissible limit of pH from 5 to 9.7 SANS (2015). The pH of the analyzed samples from the study area ranged from 7.15 to 9.92. The overall results indicate that the treated water is within the desirable and suitable range of SANS (2015) standard except some samples which recorded pH higher than 9.7. Basically, the pH is determined by the amount of dissolved carbon dioxide (CO_2), which forms carbonic acid in water. Present investigation results were similar with reports made by other researchers (Edimeh et al. 2011).

5.4.2 Electrical conductivity (EC)

Electrical conductivity is the ability of any medium to carrying an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence and relative concentrations, and on the temperature of the liquid (Gorde and Jadhav, 2013). The presence of dissolved solids such as calcium, chloride, and magnesium in water samples carries the electric current through water (Rahmanian et al., 2015). According to SANS (2015) the maximum acceptable level of conductivity is 1700 µS/cm. However, the results of this study show that the measured conductivity of all water samples ranged from 28 µS/cm to 903µS/cm which complied with the recommended value of SANS.

5.4.3 Total dissolved solids (TDS)

Total dissolved solids are the inorganic salts and small amounts of organic substance, which are present as solution in water (WHO, 2003). Water has the ability to dissolve a wide range of inorganic and some organic minerals or salts such as potassium, calcium, sodium, bicarbonates, chlorides, magnesium, sulphates, etc. These minerals produced unwanted taste and colour in water (Meride et al., 2016). The water with high TDS value indicates that water is highly mineralised. The recommended TDS value set for drinking water quality is ≤ 1200 mg/l for SANS, (2015). In the present study, values ranged from 18 mg/l to 572 mg/l. Hence, the TDS of all the household's storage samples complied with the above required guidelines. The results of this study were consistent with previous studies (Mapoma & Xie, 2014). Duressa et al., (2019), also found that the TDS (37–46.5 mg/l) measurements of the tap water samples did not show significant ($P<0.05$) differences from the water sources and water main distribution tanks showing that there is no external factor that could contribute to the increase or decrease of these parameters in the tap water distribution system.

5.5 Chemical parameters

5.5.1 Calcium and Magnesium (Ca and Mg)

The results show that in this study magnesium values ranged from 1.32 to 16.59 mg/l and the concentration of calcium ranged from 2.14 to 31.65 mg/l. Hence, they were all within the permissible range recommended for drinking water by SANS (2015) and WHO (2012). All living organisms depend on magnesium in all types of cells, body tissues and organs for variety of functions while calcium is very important for human cell physiology and bones. The results of this study corroborate the findings of Meride et al., (2016) who found that magnesium (10.42 to 17.05 mg/l) and calcium (2.16 to 7.31 mg/l) values were within the range after assessing the quality of drinking water in Ethiopia. Similar results were reported by Soylak et al. (2002) after assessing drinking water of Turkey.

5.5.2 Potassium and Sodium (K and Na)

In this study, low levels of potassium in the range of 0.14 to 1.85 mg/l was recorded and sodium concentration ranges from 0.18 to 12.96 mg/l. These values were within the permissible limit of WHO (2011) and SANS (2015) and may not cause health related problems. Since proper quantity of sodium in human body prevents many fatal diseases like kidney damages, hypertension and headache. While, potassium is vital for human body functions like heart protection, regulation of blood pressure, protein dissolution, muscle contraction, nerve stimulus etc. Similar results were reported by Mohsin et al. (2013) who found that potassium values meet the WHO standard although sodium quantity was reported to be quite low.

5.6 Heavy metals parameters

5.6.1 Trace elements (Mn, Co, Ni and Cu)

Trace elements are minerals that are required in small amount (Agbede, 2015). Some trace elements have several roles in living organism. For example, metals like copper (Cu), cobalt (Co) and zinc (Zn) are essentially required for normal body growth and functions of living organisms, while in high concentrations are considered highly toxic for human and aquatic life (Edokpayi et al., 2018). Elevated heavy metal(loids) concentrations could deteriorate water quality and pose significant health risks to the public due to their toxicity, persistence, and bio accumulative nature (Mohammed et al., 2011). Thus, investigation of water contamination with heavy metals is of great importance.

In this study, concentrations of Manganese varied from 0.41 to 10.91 µg/L, Cobalt ranged from 0.02 -0.04 µg/l, Nickel varied from 0.04 to 0.70 µg/l and Copper range from 1.48 µg/l to 46.20 µg/l.

All samples complied with the recommended concentration by SANS (2015) for domestic water use. In a similar study investigated by Kantoma et al., (2017), Co was found in the range between bdl to 4.80 μgl^{-1}, while Ni varied between bdl and 0.72 $\mu gl,^{-1}$ and Cu ranged between bdl and 1.72 μgl^{-1}. The author further indicated that the concentration of all the metals were considerably found to comply with WHO's drinking water guidelines.

5.6.2 Aluminium (Al) and Iron (Fe)

Aluminum concentration in drinking water samples ranged from 1.25 - 13.46 µg/L. All analysed samples complied with the recommended concentration of ≤ 300 µg/l (SANS, 2015) for domestic water use. Another study done in Selangor, Malaysia found that aluminium concentration in drinking water is in the range of 0.02 µg/L to 0.28 µg/L which is lower than the findings in this study (Dzulfakar et al., 2011). The recorded levels of Al in water from this study should not pose any health risk problem. However, at high concentration aluminium affects the nervous system, with possible connections to several diseases, such as Parkinson's, Alzheimer's and LouGehrig's disease (Inan-Eroglu and Ayaz, 2018).

Iron (Fe) is an essential element for human health that performs various function in our body, the most well-known of them is production of protein haemoglobin, which carry oxygen from our lungs to transfer it throughout the body. Insufficient or excess levels of iron can have negative effect on body functions (Milman, 2008). The recommended concentration of iron in drinking water is ≤ 2000µg/l (SANS 2015). In this study, the concentration of iron ranged from 0.96 to 73.53 µg/L and the samples were within SANS guidelines. Similar results were reported by Jamshaid et al. (2018) in Khyber Pakhtunkhwa province. Low levels of iron, are essential to human health while, high concentration can give water a metallic taste, even though it is still safe to drink (Tagliabue et al., 2014).

5.6.3 Lead, Arsenic, Zinc and Chromium (Pb, As, Zn and Cr)

The levels of Pb, As and Zn were in the range of 0.02-0.57 µg/l, 0.02-0.17 µg/l, and 2.54-194.96 µg/l, respectively whereas Cr was not detected in the samples collected. The levels recorded complied with the SANS (2015) and WHO (2012) guidelines for drinking water. Similar results were reported by Mohod and Dhote (2013). Lead is not desirable in drinking water because it is carcinogenic and can cause growth impairment on children (Edokpayi et al., 2018) but the levels of Pb recorded in this study complied with regulatory standards. Inorganic arsenic is a confirmed carcinogen and is the most significant chemical contaminant in drinking-water globally (WHO, 2018). Zinc deficiency can cause loss of appetite, decreased sense of taste and smell, slow wound healing and skin sores (Bhowmik et al., 2010). Cr in the other hand is desirable at low concentration but can be harmful if present in elevated levels. All the trace metals complied to the SANS (2015) recommended guideline.

5.6.4 Non-carcinogenic analysis

The hazard quotient (HQ) takes into consideration the oral toxicity reference dose for a heavy metal that humans can be exposed to (Mahmud, et al., 2017). Health risk assessment model by the US. EPA were used to evaluate the health risks that heavy metals could pose on human through direct ingestion and dermal absorption of drinking water in Lufule village. Health related risk associated with the exposure through ingestion depends on the weight, age and volume of groundwater consumed by an individual this was determined using the measured minimum and maximum concentration of Fe, Mn, Cu, Ni, Zn, Pb, Co, Al and As. HQ due to heavy metal was calculated separately for children and adults. HQ_{ing} and HQ_{derm} for all analyzed heavy metals in both children and adults were less than one unit (Table 4.9). Results from this study indicated no potential risk associated with the consumption of this water either by children or adult. Similar results were reported by Edokpayi et al. (2018) where HQ_{in} or HQ_{derm} for heavy metal concentration in groundwater water for both children and adults were lower than one unit.

The calculated cumulative hazard quotients (HQ) for children and adult was 1.16E-01 and 5.28E-02, respectively. Cumulative hazard quotients (HQ) across metal served as a conservative assessment tool to estimate high-end risk rather than low end-risk in order to protect the public (Table 4.9). This served as a screen value to determine whether there is major significant health risk. The results in this study signifies that the population of the investigated area are not susceptible to non-cancer risk due to exposure to heavy metals in drinking water. Similar observation has been reported by Bamuwamye et al. (2017), after investigating human health risk assessment of heavy metals in Kampala (Uganda) drinking water. It should be noted that the HItotal elements (HQingestion + HQdermal contact) values for children were higher than that of an adult, suggesting that children were more susceptible to non-carcinogenic risk from the heavy metals.

Chronic daily intake (CDI) values for the selected metals ranged between 3.14E−09 to 6.13E+00, for adults and 120E−08 to 2.34E+01 for children, respectively. The CDI indices for heavy metals during the study period for both ages were found to be in an order of Zn > Fe > Cu > Al > Mn > Pb > As and Ni (Table 4.11). In the drinking water of Lufule village, high CDI values of Zn, Fe and Cu were estimated for both adults and children. Moreover, high estimated values for children ingesting Zn were observed throughout the study. In this study, CDI for both children and adults for the selected heavy metals were less than 1 unity. This suggests that the drinking water of Lufule village poses less significant health threats to both adults and children.

5.6.5 Carcinogenic risk analysis

Carcinogenic risk (CR_{ing}) of drinking water with heavy metals such as Pb, As, Cr and Cd could potentially enhance the risk of cancer in human beings (Saleh et al., 2019). Heavy metals (Pb, Cr As, Cd, and N) can potentially enhance the risk of cancer in humans (Tani et al, 2005). Long term exposure to low amounts of toxic metals might, consequently, result in many types of cancers. Using As and Pb carcinogens, the total exposure of the residents were assessed centered on the mean CDI values given in Table 4.11. The carcinogenic risk assessment for adults and children is shown in Table 4.11.

For heavy metal, an acceptable carcinogenic risk value of less than 1×10^{-6} is considered as insignificant and the cancer risk can be neglected; while an acceptable carcinogenic risk value of above 1×10^{-4} is considered as harmful and the cancer risk is troublesome. For the total of all heavy metals through all exposure routes, the acceptable level is 1×10^{-5} (Cao et al., 2014, Wcislo et al., 2002 and Yang et al., 2014). Amongst the studied heavy metals, only the maximum level of lead for both adults and children has the highest chance of cancer risks (2.09E-03 and 8.00E-03) and Arsenic has no chance of cancer risk both adults and children with a value (1.09E-05 and 2.10E-12). The results of this research present that there was a cancer risk of only lead from the contaminants to residents through the cumulative ingestion in the drinking water samples of the studied area.

5.6.6 Summary of the chapter

This chapter discussed the results obtained with reference to relevant literature. The data revealed that there was high contamination in the household water stored in containers.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter presents conclusion and recommendations from the study, based on the data analyzed in the previous chapter.

6.2 Conclusion

The results indicated that awareness on good hygienic practices will be required while storing and using water. Unhygienic handling practices at any point between collection and use contributes to the deterioration of drinking water quality in the study area. Based on this it can be said that as distance increases from the treatment reservoir the cross-contamination rate also increases.

In this study, the physicochemical and bacteriological quality and heavy metals of water samples from treated source, street taps and household storage container were analyzed. Majority of them were within the permissible range of both WHO and SANS drinking water standards although some did not meet the standards. Microbiological samples from street taps (n=8, 87.5%) tested positive during the wet season for total coliform while all samples tested negative for E. coli. The presence of Total coliform and E. coli in drinking water presented a potential health risk to consumers.

Physico-chemical parameters result showed that drinking water sources have a reasonably good chemical quality. All the parameters were within the permissible standards range of SANS with values that ranged between 7.15 to 9.92 and 28 to 903 µS/cm for pH and total dissolved substances varied between 18 mg/l to 572 mg/l respectively. Sodium, Magnesium, Potassium and Calcium were all within recommended range of SANS water standard.

HQ and CDI for both children and adults were less than 1 unity, suggesting that the drinking water poses less significance health threat to both children and adults. The HI through ingestion as well as total HI were obtained to be 1.16E-01 for children and 5.28E-02 for adults respectively. Amongst the studied heavy metals, only the maximum level of lead for both adults and children has the highest chance of cancer risks (2.09E-03 and 8.00E-03) and arsenic has no chance of cancer risk both adults and children with a value (1.09E-05 and 2.10E-12).

6.3 Limitation of the study

The study focused on Lufule village in the Thulamela Municipality of Limpopo Province and therefore the findings cannot be generalized, however, a detailed description of the study was provided.

6.4 Recommendations

- Water samples should be assessed for the entire year to study the quality of water trend in different seasons
- Training should be provided to people on the practices of handling storage water containers
- The concerned authorities should take appropriate measures to maintain residual free chlorine at the distribution points.

6.5 Summary

The findings of this study revealed that the unhygienic handling practices at any point between collection and use contributes to the deterioration of drinking water quality in the study area. The presence of Total coliform and E. coli in drinking water present a potential health risk to consumers. And in the evaluation of human health risk on heavy metals, there was a cancer risk of only lead from the contaminants to residents through the cumulative ingestion in the drinking water samples of the studied area.

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APPENDIX A: INFORMATION SHEET

My name is Luvhimbi Ndivhudzannyi. I am a student at the University of Venda registered for Masters of public health degree (MPH). My research focuses on the Quality Assessment of Drinking Water at Thulamela Municipality, Limpopo Province. You are kindly requested to take part in this study because your participation is very important in improving the knowledge towards practices regarding collection and storage of water for the benefit of the end users health.

Research data will be collected by the researcher. Before data collection I will explain the purpose and the ethical principles to be adhered to furthermore you as the participants will be required to give informed consent. I will use the checklist guide as means of collecting information from those who meet the inclusion criteria. Data will be collected individually in a separate office to maintain privacy and codes rather than participants' real names will be used to ensure anonymity

In this research project participants is free and voluntarily. You are allowed to withdraw from the project at any time should you feel uncomfortable or threatened in any way to continue participating in the study.

During the research I will ensure that the benefits surpass the risks I will also ensure that no physical, psychological or emotional harm is inflicted on you during the course of the study. Other possible dangers will be looked at the researcher will guard against them. In addition, in case you are harmed, the researcher will do follow up and refer to appropriate in the study will enable the researcher to draw conclusions from the findings and be able to give recommendations that may assist the Water Service Delivery Section at Vhembe District Municipality to come up with appropriate measures that may improve the quality of water at Thulamela Municipality

For more information contact Luvhimbi N (Researcher)

Cell: 073 373 6522

Email address: ndivhudzas@gmail.com

APPENDIX B: CONSENT FORM

I ………………………………………………………………………………..confirm that the person asking my consent to take part in this study has told me about the nature, processes, and benefits of the study. I am aware that the results of the study including personal details will be anonymously processed into research reports. I have had time to ask questions and have no obligation to participate in the study. I understand that there is no penalty should I wish to discontinue with the study. I have read and understood the consents and terms of this invitation to participate in this study. I am hereby declaring that I am voluntarily participating in this research.

Participant Signature………………………… Date……………………………

APPENDIX C: QUESTIONNAIRE ON DRINKING WATER SERVICES

Name of Investigator: ______________________ Starting Time: ______________________

Date: ___________________________________ Ending Time: _______________________

Investigator Introduction:

Hello, my name is ______________, and I am a student who is collecting information on drinking water services in ____________. May I speak to an adult member of your household? (Modify the introduction to sound as natural as possible.)

Instruction to investigator: please use pencils and circle the code where applicable and write the answers in legible handwriting in the spaces provided for responses.

LUVHIMBI N

#	Question	Code	Response
1	What is your age?	10-65(years)	
2	Record sex	Male = 01; female = 02	
3	Are you currently married, divorced, widowed or never married?	Never married = 01; married = 02; Divorced = 03; widowed = 04	
4	What is the highest-grade level you have completed?	None = 01; primary = 02; Secondary = 03; Matriculation = 04; Undergraduate = 05; post-graduate = 06	
5	What is your average income	Employed permanently = 01 Employed temporarily = 02 Self-employed = 03 Grant = 04 Other = 05	
6	What is the most frequent primary source of drinking water for members of your household that is used?	Piped into the house = 01 piped into the yard/plot = 02 neighbour's pipe = 03 public tap/stand pipe = 04 other = 05	

8	Is your primary source of water supply continuous or is it sometimes interrupted?If interrupted skip to question 10	Continuous = 01 Sometimes interrupted = 02	
9	If sometimes interrupted, during the last interruption, how many days did the interruption last?	000-999 days (enter 000 if less than 1 day)	
10	During interuptions in your primary water supply, what is your secondary source of drinking water?	Municipal treated source = 01 Communal tap = 02 Private borehole = 03 Other = 04	
11	How long does it take to get the secondary water source, get water and come back in one trip? If water is located in the household, response is 000	000 – 999 minutes	
12	How long do you have to take water from this secondary source?	At least once a week = 01 At least once a month = 02 Less than once a month = 03	
13	Do you usually treat water before you drink? If no skip to question 16	Yes = 01 No = 02	
14	Which method of treatment do you usually use to make water safe to drink?	Let it stand and settle Solar disinfection Use water filter (ceramic/ sand / etc.) Strain through a cloth Add bleach / chlorine Boil Other	
15	What do you use to store your drinking water	Ceramic vessels = 01; metal buckets = 02; plastic buckets = 03; jerrycan = 04;	

		small pans = 05; cooking pots = 06; water tank = 07; other = 08	
16	If other specify		
17	How long does water stay in the storage container	Less than a week = 01 Between one week and two weeks = 02 Less than a month = 03	
18	Are your storage vessels covered	Yes = 01 No = 00	
19	What do you use to get the water from the storage container?	Pour directly = 01; use cup with handle = 02; use cup with hands = 03; other = 04	
20	Do you think that you can get sick from the water you use If no skip to question 24	Yes = 01 No = 00	
21	What kind of sicknesses do you think you can get from water? (record responses for specific illnesses listed below, and record others and listed)		
	Fever	Yes = 01 No = 00	
	Vomiting		
	Diarrhea		
	Ear pain		
	Malnutrition		
	If other – write in illness		
24	Are you satisfied with the quality of water you use? if yes skip question 25	Yes = 01 No = 00	
25	Why are you satisfied with your water? (record responses for specific reasons listed below, and record other not listed)		
	Insufficient quantity(not enough water)	Yes = 01 No = 00	
	Shared		
	Not clean		
	Cloudy or not clear		
	Bad odor or taste		
	If other-write reason		

26	What kind of toilet facility do members of your household usually use?	No facility / bush / fiels or bucket toilet = 01 Pit latrine = 02 Improved pit latrine without flush = 03 Flush to piped sewer system = 04 Flush to pit (or septic) tank = 05 Other = 06	
27	Does the toilet/lactrine you use have a concrete floor	Yes = 01 N0 = 00	
	Do you share this toilet facility with other households	Yes = 01 N0 = 00	
	How many households use this toilet facility?	00 – 09; 10 or more households = 10	
	Is there a designated place to wash hands by this toilet	Yes = 01 No = 00	
	How often do you wash your hands after using the toilet?	Never = 01; rarely = 02 Often = 03; always = 04	
	How often do you use toilet paper?	Never = 01; rarely = 02 Often = 03; always = 04	
	How often do you wash your hands before preparing food?	Never = 01; rarely = 02 Often = 03; always = 04	
	How often do you use soap when you wash your hands? (soap can include ash, sand, or the use of hand sanitizer gel/ cream)	Never = 01; rarely = 02 Often = 03; always = 04	
	Is there a latrine within 30m of the main source?		
	Is there animal breeding of pigs, cows, goats or others within 30min of the main source?	Yes = 01 No = 00	
	Is there any cultivation (use of manure or fertilizer) within 30m of the main source?		

APPENDIX D: LETTER REQUESTING PERMISSION TO CONDUCT RESEARCH

Vhembe District Municipality
Private Bag x5006
Thohoyandou
0950

Re: Request for permission to conduct research

I Ndivhudzannyi Luvhimbi, a masters student at the department of public health of the university of Venda hereby request for permission to undertake a study at Nandoni Dam and the selected villages (Ha-Mutoti, and Lufule village). My research study is titled: **Quality Assessment of Drinking Water at Thulamela Municipality, Limpopo Province.** This study has been prompted by the challenge that Limpopo Province is facing of deterioration of the quality of water as reported by blue drop reports
Attached is the ethical clearance from the University of Venda. Arrangements with the participants will be made regarding convenient time, to avoid interference with their day to day life

Please do not hesitate to contact me for further details.
Yours faithfully
Ndivhudzannyi Luvhimbi
Cell: 073 373 6522

APPENDIX F: WATER SAMPLE LOCATION

Sample code	**Latitude**	**Longitude**
D1 & D2	S 22° 59' 11 99"	30° 36' 16' 19"
ST1	S 22° 57' 01, 66"	30° 30' 06, 54"
ST2	S 22° 56' 48, 52"	30° 30' 02' 17"
ST3	S 22° 57' 01, 07"	30° 30' 06' 20"
ST4	S 22° 57' 01, 65"	30° 30' 56' 34 "
ST5	S 22° 56' 50, 34"	30° 29' 57, 13"
ST6	S 22° 57' 01, 15"	30° 29' 57, 96"
ST7	S 22° 56' 47, 77"	30° 30' 09, 37"
ST8	S 22° 56' 47, 86"	30° 30' 03, 33"
HT1	S 22° 57' 01, 07"	30° 30' 06 20"
HT2	S 22° 57' 05, 97"	30° 30' 00, 52"
HT3	S 22° 57' 04, 98"	30° 30' 060,36"
HT4	S 22° 56' 57, 78"	30° 30' 09, 96"
HT5	S 22° 56' 57, 59"	30° 30' 10, 26"
HT6	S 22° 56' 50, 25"	30° 30' 12, 60"
HT7	S 22° 57' 01 07"	30° 30' 06 20"
HT8	S 22° 57' 01 07"	30° 30' 06 20"
HSC1	S 22° 57' 01, 07"	30° 30' 06 20"
HSC2	S 22° 57' 02, 25"	30° 30' 06, 15"
HSC3	S 22° 57' 03, 27"	30° 30' 06, 64"
HSC4	S 22° 57' 04, 27"	30° 30' 07, 50"
HSC5	S 22° 57' 04, 79"	30° 30' 06, 33"
HSC6	S 22° 57' 05, 97"	30° 30' 00, 52"
HSC7	S 22° 57' 04, 96"	30° 30' 05,55"

HSC8	S 22° 57' 05,57"	30° 30' 03, 02"
HSC9	S 22° 57' 03, 99"	30° 30' 00, 36"
HSC10	S 22° 57' 04, 98"	30° 30' 060,36"
HSC11	S 22° 57' 02, 53"	30° 29' 59, 77"
HSC12	S 22° 57' 00, 53"	30° 30' 00, 13"
HSC13	S 22° 57' 00, 07"	30° 30' 01, 99"
HSC14	S 22° 56' 59 44"	30° 30' 04, 61"
HSC15	S 22° 56' 58, 51"	30° 30' 07,61"
HSC16	S 22° 56' 57, 68"	30° 30' 09 46"
HSC17	S 22° 56' 57, 78"	30° 30' 09, 96"
HSC18	S 22° 56' 57, 07"	30° 30' 11, 61"
HSC19	S 22° 56' 55, 45"	30° 30' 14,37"
HSC20	S 22° 56' 43, 37"	30° 30' 17, 16"
HSC21	S 22° 27' 30, 16"	30° 30' 19, 16"
HSC22	S 22° 57' 00, 35"	30° 30' 07, 31"
HSC23	S 22° 56' 59, 44"	30° 30' 07, 58"
HSC24	S 22° 56' 57, 59"	30° 30' 10, 26"
HSC25	S 22° 56' 56, 75"	30° 30' 12, 74"
HSC26	S 22° 56' 53, 62"	30° 30' 14, 16"
HSC27	S 22° 56' 51, 92"	30° 30' 14, 53"
HSC28	S 22° 56' 50,97"	30° 30' 15, 22"
HSC29	S 22° 56' 51,30"	30° 30' 13, 10"
HSC30	S 22° 56' 50, 25"	30° 30' 12, 60"
HSC31	S 22° 56' 49, 07"	30° 30' 11, 53"
HSC32	S 22° 56' 49, 20"	30° 30' 12, 53"
HSC33	S 22° 56' 48, 95"	30° 31' 11, 45"
HSC34	S 22° 56' 47, 68"	30° 30' 09, 02"
HSC35	S 22° 56' 47, 77"	30° 30' 09, 37"
HSC36	S 22° 56' 46, 77"	30° 30' 06, 69"
HSC37	S 22° 56' 46, 86"	30° 30' 05, 84"
HSC38	S 22° 56' 47, 17"	30° 30' 05, 50"
HSC39	S 22° 56' 47, 86"	30° 30' 03, 33"

UHDC approval.pdf~RF2812