Assessment of the efficiency of water treatment plants in Vhembe District, South Africa

F Masindi

orcid.org/0000-0001-6278-809x

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Supervisor: Dr M Manjoro

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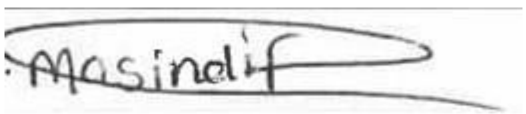
Student number: 29888999

DECLARATION

I, **Fhatuwani Masindi** (student number: 29888999), do hereby declare that this research is my own and that all the contents presented here are original, and that the same work has not been submitted for the award of a degree at any other University or institution of higher learning. Information sources and the work of other authors cited in this research have been duly acknowledged.

Signed…  Date:….07/01/2021………………

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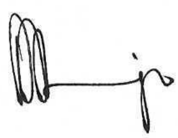
Signed…  Date…07/01/2021………………

ABSTRACT

Various studies have indicated that most rural and small-scale water treatment plants in South Africa face diverse operational challenges. Consequently, the majority of the plants are unable to meet the goal of delivering a reliable supply of safe drinking water. This study aimed to assess the efficiency of two small water treatment plants in the Vhembe District Municipality, in the Limpopo province. Raw and treated water quality at the plants and at the selected villages supplied by each plant was evaluated based on secondary data provided by the Vhembe District Municipality. This data included results of physicochemical and bacteriological water analysis for seven months categorized into dry and wet seasons. A questionnaire survey was also used to assess the operational practices at the plants and the perceptions of consumers about the quality of the water delivered.

The study found that the raw water used in both Vondo water treatment plant (VWTP) and Mutale water treatment plant (MWTP) was of poor quality in relation to turbidity, pH, fluoride, iron, manganese, electrical conductivity, total dissolved solids, and total coliform. On the other hand, the values of free chlorine, fluoride, and sulfate were higher in the treated water at the Vondo water treatment plant. A seasonal analysis of the quality of raw and treated water showed that the raw water quality was better in the wet season at the Vondo water treatment plant. However, in the Mutale water treatment plant, the raw water quality was better in the dry season. For the treated water, the wet season had better water quality in both plants. The results from both water treatment plants indicated that there was no statistically significant seasonal difference between the quality of water produced by the plant and transmitted to the villages as a whole in each season. The study also found no significant seasonal difference between the quality of water produced by the plant and transmitted to village taps. A comparison of the water quality parameters with the SANS 241, DWAF, and WHO water quality guidelines revealed that electrical conductivity, pH, fluoride, total dissolved solids, sulfate, *E. coli*, and total coliforms fell within the SANS 241, DWAF, and WHO drinking water quality limits during the wet and dry seasons for treated water at both plants and villages. However, free chlorine, turbidity, iron, and manganese exceeded WHO standards' limits during the wet seasons for treated water at the plants. Similarly, the values for iron were above the WHO maximum permissible limit for treated water at Tap 2 and 3 for the Mutale water treatment plant.

At the operational level, both water treatment plants were operating below design capacity. Although the water treatment plants were generally performing well in terms of the water treatment process, poor management of chemical dosage, monitoring process and equipment repairs was observed. The study also found that most of the operators and supervisors interviewed did not have specific skills or training on water treatment and water reticulation. This can impact water treatment processes negatively. The majority of surveyed households indicated that they were generally satisfied with water quality. However, one major problem was intermittent water supply and irregular water pressure.

The study offered recommendations to the district municipality and other researchers. Firstly, although the water quality was generally of acceptable quality, there is a need for continuous monitoring of the water treatment processes to address any challenges on time. Similarly, there is a need for continuous maintenance of the equipment. The above will have a positive impact on selected water quality parameters that were found to be not meeting selected guidelines. There is a need for the district municipality to enhance the technical level of the plant managers and operators at each plant. This can go a long way to improve the operational practices at each plant. For researchers in water quality, the use of secondary water quality data kept by the water treatment plants reduces research costs. However, it is recommended that researchers undertake their own water sampling and analysis to provide a more independent water quality assessment that does not depend on the data produced by the same plants being assessed.

Key words: water treatment, water quality**,** Vhembe district, treatment efficiency

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To everyone else who has been there for me, I am perpetually thankful.

DEDICATION

I dedicate this research to myself and my family.

ABBREVIATIONS AND ACRONYMS

DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
DST	Defined Substrate Technology
E. coli	*Escherichia coli*
EC	Electrical conductivity
Mg/l	Milligram per litre
NTU	Nephelometric turbidity unit
SANS	South Africa National Standards
SDG	Sustainable Development Goal
TDS	Total dissolved solids
USEPA	United State Environmental Protection and Agency
VDM	Vhembe District Municipality
WHO	World Health Organisation
WTP	Water treatment plant

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CHAPTER ONE:
INTRODUCTION AND PROBLEM STATEMENT

1.1. Background

Access to safe drinking water is a global concern (UNICEF/WHO, 2012). Although drinking water supplies have increased around the world (Dinka, 2018), access to reliable water quality remains a challenge. Poor water quality is associated with the risk of ill health. The problem may not be limited to untreated surface water, but it can also be caused by poor water quality coming from treated water. According to WHO (2004), there is no guarantee that consumers who get piped water will access water free from contamination. Szabo and Minamyer (2014), reported that people who access unsafe water are at risk of acute and chronic water-borne diseases. Thus, a sustained supply of safe and potable water is important to promote the health and well-being of society. Community water supplies need to be reliable, adequate, of assured quality, and readily accessible to all the users. Water quality may be affected by physical, chemical, and biological impurities that need to be removed or reduced to certain limits to make the water safe and potable. This is done through the process of water treatment. It is necessary to identify the impurities that impact negatively on the water treatment processes and water quality at each water treatment plant (Vieira *et al*., 20008).

It is necessary to continuously monitor the efficiency of the water treatment process. This is done based on performance indicators such as removal of pollutants such as turbidity, color, suspended impurities, etc (Issa, 2017). Ibrahim *et al*. (2014), stated that the efficiency assessment of water treatment plants and their operational processes is very crucial for public health and safety. The efficiency concept is used to describe the best use of treated water in a treatment process, under existing technology by comparing the treated water with water quality standards (Ibraham *et al*., 2014). According to Vieira *et al*. (2008), the traditional approach for water treatment plant efficiency assessment is based solely on water quality standards compliance. The treated water must meet relevant, for example, the World Health Organization (WHO) (Vieira *et al*., 2008). These standards are general and not absolute and may vary depending on local conditions. Drinking water must be healthy, clean, free of contaminants and therefore it is necessary to determine the concentration of impurities allowed in it using the water treatment process (Dinka, 2018). Producing potable water from surface or groundwater sources involves several treatment steps to remove unwanted substances. Due to variations in volume, flow conditions, and quality of natural water, it needs to be abstracted and treated before consumption. Water treatment plants (WTP) are facilities that treat or purify water for human consumption and other purposes. These water treatment plants are classified into small, medium, and large water treatment. Small water treatment plants are defined as water treatment systems that are installed in areas that are not adequately serviced and do not normally fall within the confines of urban areas (Momba *et al*., 20009). They are therefore mostly used in rural and peri-urban areas and include chlorination plants for water supplies from boreholes and springs for rural communities. Most of the small water treatment plants have a design capacity of less than 13 ML/d (DWAF, 1998). Medium and large water treatment plants fall within the confines of urban areas. The medium water treatment has a design capacity of 13 ML/d but less than 20ML/d while the large water treatment has a design capacity of greater than 20ML/d (DWAF, 1998).

The water treatment processes may differ from one region to another depending on the quality of raw water that enters the plant and also the intended uses of the water. According to Maitre *et al*. (2018), 86 % of the water treatment plants in South Africa abstract raw water from surface sources (rivers and dams), with 10% of the plants using groundwater or a combination of two sources (4%). In the Limpopo province, where the current study was conducted there are sixty-one water treatment plants (Nefale *et al*., 2017). About 91% of them abstract raw water from surface sources, 6% from groundwater, and 3% from a combination of the two sources (Du Toit *et al*., 2012; Nefale *et al*., 2017). According to Momba *et al*. (2009), the surface water in the province is generally characterized by high turbidity and some of the dams are heavily contaminated with metals and nutrients resulting from human activities. This impacts the quality of the raw water and increases the intricacies of drinking water purification (WHO, 2004).

Water treatment is aimed at producing water suitable for a given purpose by removing existing contaminants in the water (Reddy *et al*., 2014; Omran, 2011). Although water is mostly treated for human consumption (Mohammed and Shakir, 2012), water treatment may also be designed for a variety of other uses, including meeting the requirements of agricultural, medical, pharmacological, chemical, and other industrial uses.

Various studies have indicated that most of the water treatment plants in South Africa face challenges in ensuring adequate water disinfection and treatment. Consequently, consumers are at risk of developing water-borne diseases even from treated water supplies (Momba *et al*., 2006; Nefale *et al*., 2017). Similarly, according to Momba and Brouckaert (2005), the majority of the water treatment plants do not comply with the water treatment standards or use the best technology available due to poor financial management, insufficient capital funding, and limited technical capacity.

According to House and Street (2018), in the Limpopo province, there are 5 852 553 inhabitants. About 32% of households have access to safe drinking water on-site and 24% to basic sanitation facilities (Nefale *et al*., 2017). This leads to increased incidences of water-borne diseases (Harsheld *et al*., 2009). According to Sibiya and Gumbo (2013), diarrheal diseases are the second leading cause of premature death in adults and infants in this province. This is attributed to the use of untreated water, treatment plant deficiencies, and contaminated distribution systems (Ligon and Bartman, 2016).

1.2. Statement of the problem

Various studies have indicated that most rural and small-scale water treatment plants in South Africa face diverse operational challenges (Momba *et al*., 2009; Carrillo-Gómez *et al*., 2019). Consequently, the majority of the plants are unable to achieve the required drinking water quality standards. These challenges have been attributed to limited financial resources and poor infrastructure, leading to unacceptable water quality and inadequate supply to meet demand. The Vhembe District Municipality (VDM) in the Limpopo province is not an exception. Approximately 80% of the district municipality faces restricted access to portable and safe drinking water (Momba *et al*., 2009; Netshipale, 2016). The municipality typically distributes piped water throughout rural communities but the distribution to household taps is intermittent, sometimes only once or twice a month (Harsheld *et al*., 2009).

A few decades ago, new water treatment plants were either constructed or extended (Nefale *et al*., 2017). There is a need to assess the operational efficiency of these plants as to whether the quality of water produced and distributed meets the set standard. Thus, the present study aims to assess the efficiency of two extended water treatment plants selected from the VDM. This assessment will be undertaken through examining the quality of the water produced and a survey of the consumers.

1.3. Research aim and objectives

1.3.1. Research aim

To assess the operational efficiency of selected water treatment plants in the Vhembe District Municipality to check whether the quality of water produced and distributed meets the set standards.

1.3.2. Specific objectives

1. To compare the quality of raw and treated water produced by each water treatment plant and whether the water quality differs by season;
2. To evaluate the quality of treated water between the water treatment plants and the distribution points in the villages and amongst the villages themselves by season;
3. To determine the level of compliance of the treated water quality with the appropriate standards recommended for domestic use;
4. To examine the operational practices at the water treatment plants to obtain information about their performance;
5. To assess consumer perception of the water quality.

1.4. Hypotheses

In line with the above-mentioned objectives, various hypotheses were put forward.

Hypothesis 1

- The raw and treated water quality is not different in the two water treatment plants.

Hypothesis 2

- There is no seasonal difference between the quality of raw and treated water at the two water treatment plants

Hypothesis 3

- The quality of treated water at the water treatment plants and the distribution points in the villages is not different

Hypothesis 4

- The treated water does not comply with the water quality standards

Hypothesis 5

- The operational practices at each plant affect the water treatment plant's performance.

Hypothesis 6

- Water consumers do not have a favourable perception of the quality of the water they receive.

1.5. Significance of the study

According to WHO (2002), drinking water should be suitable for human consumption and all domestic purposes. Sustainable Development Goal (SDG) IV, aims to provide everyone with equitable access to safe and affordable drinking water (Ait-Kadi, 2016). In South Africa, access to clean and safe drinking water is considered a basic human right (DWS, 2014). This shows that water quality is important. However, many local authorities grapple with providing communities with safe drinking water. This investigation, using two water treatment plants in the Limpopo province, aims to contribute to a better understanding of the water quality challenges that the local government faces in water treatment and provision. A wide-ranging national survey by Momba *et al*. (2009) noted that many municipal water treatment plants in the country are not working efficiently leading to water-borne diseases for the consumers. Thus, research of this type is necessary to provide the authorities the evidence of the bottlenecks and issues affecting the production of water from water treatment. This may help the targeting of remedial actions. This is most important as small to medium size water treatment plants provide water to many of the country's rural population and many small towns. Their proper functioning will help national and local government spheres to achieve their mandate; to provide a safe and consistent water supply.

Inefficient water treatment does not only affect drinking water quality but also human health. Thus, a study of this type has implications for the reduction of water-borne diseases resulting from poor water quality. The study also will explore the water consumers' perceptions of the water quality in their communities. Although in the last decade Momba *et al*. (2009) investigated this issue at the national level, there is an impetus to look at the Vhembe District Municipality due to reports of limited access to potable and safe drinking water (Netshipale, 2016).

1.6. Outline of the dissertation

This dissertation is divided into five chapters. Chapter One provides a background to the study topic and outlines the research problem, the research aim, objectives and hypotheses. The chapter also unpacks the rationale of the study. Chapter Two reviews the literature on water treatment, quality, policy, and regulation for drinking water compliance in the country. Specific emphasis is given to water quality standards and guidelines and challenges of small water treatment plants. Chapter Three describes the study areas, the sampling sites, and the rationale for the selection of laboratory and data analysis procedures used. Chapter Four presents the study findings, interprets, and discusses them in the context of related studies. The conclusions, recommendations, and limitations of this study are presented in Chapter Five.

CHAPTER TWO:
LITERATURE REVIEW

2.1. Introduction

This chapter offers a theoretical background on the water treatment process, without which it will be difficult to understand the study. The chapter also examines the water quality challenges faced in South Africa and regulations for drinking water compliance in the country. The specific emphasis throughout the review is given to the challenges of small to medium water treatment plants.

2.2. The water treatment process

Before the operational efficiency of water treatment can be assessed, an understanding of the entire water treatment and supply system is required (DWA, 2012). Water treatment is the process of making water safe and suitable for the end uses by eliminating biological and chemical contaminants, suspended solids, and gases (Momba *et al*., 2009; DWA, 2012; Netshipale, 2016). The goal of water treatment is to deliver potable water to a community and meeting the requirements of agricultural. medical, industrials, and other water users by applying a treatment regime befitting the size, needs, and appropriate type of water source available for processing (USEPA, 2012). There are many techniques used for water treatment. The quality of the water at the source governs the type and extent of treatment needed (Cotruvo *et al*., 1999). All surface water and groundwater require treatment before consumption to ensure that they do not represent a health risk to the consumers. Most surface water sources are highly polluted and require extensive treatment before utilization (Sasakova *et al*., 2018). However, groundwater generally has a higher mineral content than surface water, it requires less treatment than surface water. (Verlicchi and Grillini, 2020). Thus, groundwater treatment is not as intricate as that of surface water (DWA, 2012).

Traditionally, the most commonly used treatment process for surface water worldwide involves flocculation, sedimentation, filtration, and disinfection (USEPA, 2012; WHO, 2014). Conventionally, when water is abstracted, it is passed through screens to keep out weeds, algae, and floating debris. The main purpose of screening is to remove solid materials that could cause damage to equipment or cause a reduction in the production of good water quality from the whole system (Reddy *et al*., 2014). Screening is usually provided at points where water is abstracted from the source (USEPA, 2012). In many water treatment plants, in addition to screening, the raw water is chlorinated to minimize the growth of fouling organisms, control algae growth, and remove dissolved organic matter. This is called pre-chlorination. Algae diminish the water's taste, damages equipment and interferes with other processes employed in water treatment (White, 1999). Therefore pre-chlorination conditions are used in the water treatment system for alkalinisation and corrosion control.

After screening, the water treatment process proceeds to coagulation and disinfection (Xiao *et al*., 2010). Coagulation separates colloidal particles through the addition of a chemical coagulant to the incoming raw water (Odiyo *et al.*, 2017). Aluminum sulfate (alum) is the most common coagulant used in many parts of the world (Leopold and Freese, 2009). The coagulant aids the removal of particulate, colloidal, and other dissolved substances like heavy metals (Srinivasan *et al*., 1999). Some water treatment plants are known to use other types of chemical coagulants and plant products for the same purpose (Nefale *et al*., 2017). These include the use of bentonite (Freese *et al*., 2003), date seeds (Mukheled, 2012), and *Moringa oleifera* seeds (Eman *et al.*, 2012). However, most natural coagulants are used on low turbidity water (Pritchard *et al*., 2010). The use of natural coagulants in drinking water treatment has been proposed to decrease the coagulant consumption in the water treatment process (Farhaoui and Derraz, 2016).

The disinfection process is used to remove pathogens that are responsible for waterborne diseases and to maintain levels of residual chlorine suitable for the prevention of post-treatment contamination (Thimmaraju *et al*., 2018; Momba and Brouckaert, 2005). The most widely used method for disinfecting water is chlorination (Leopold and Freese, 2009). Numerous nations use chlorine tablets for disinfection due to low cost and effectiveness (Momba and Brouckaert, 2005). Selected biological parameters are used as indicators to evaluate the adequacy of the disinfection procedure. These include total coliform, fecal coliform, and *Escherichia coli* (Obi *et al*., 2007).

Although the water treatment method described above is generally regarded as the best-used method of producing potable water from surface water sources (Ewerts *et al*., 2013), the efficiency of the method depends on the optimization of the coagulation, flocculation, and sedimentation processes (Momba *et al*., 2009). Other processes for treating surface water include non-conventional techniques such as slow sand filtration (Swart, 2000). This process uses sand filter beds through which water is slowly trickled. The slow sand filtration process can successfully remove turbidity, suspended solids, toxic metals, and coliform microorganisms such as *Giardia* in water and produce safe drinking water without costing a lot of money (Swart, 2000). Although the process can successfully remove the impurities in water, it is not well understood in developing countries and faces serious operational problems when chemical flocculation and sedimentation are used as pretreatment (Thimmaraju *et al*., 2018).

2.3. Water quality challenges in South Africa

Water quality is a term used to describe the fitness of water for various uses by describing the physicochemical and microbiological properties of the water (Mathebula, 2016). Many of these properties are influenced by materials dissolved or suspended in the water. Microbiological contamination is the most important risk factor in drinking water quality (DWAF, 1996) as it poses the risk for waterborne diseases. South Africa faces several challenges concerning water quality. The next sections explore various water quality issues in the country.

2.3.1. Causes of decreased water quality

The quality of water is influenced by various natural and human influences (Khatri and Tyagi, 2015). Natural factors include the characteristics of the geological substrate and climatic variables that influence the quantity and quality of available water (Peters *et al*., 2016). Human activities are reported as the main challenge to water quality in South Africa and worldwide (CSIR, 2010: Peters *et al*., 2016). In South Africa, poor infrastructure maintenance has led to raw or partially treated sewage and industrial effluent entering into water resources (Koop and Van Leeuwen, 2017). Additionally, some land-use practices such as intensive farming have led to agricultural runoff enriched with nutrients causing eutrophication in water bodies (Edokpayi *et al*., 2017). Eutrophication is widely recognized as a threat to water quality in the country (Mwangi, 2014; James, 2008). Similarly, mining activities are one of the most important causes of decreased water quality in South Africa (Naicker *et al*., 2003). More than a century-long legacy of unregulated gold mining in the country's most critical river catchments has led to severe water pollution. Naicker *et* *al*. (2003) found that groundwater in the mining area of Johannesburg, South Africa, had elevated concentrations of heavy metals and acid mine drainage. According to Sharma and Rather (2015) heavy metals and acid mine drainage increase water treatment costs.

Another important cause of water pollution is rapid and unplanned urbanization. Some of the highest levels of water pollution have been found in rivers in or passing through urban centers. In the Cape metropolitan area, water pollution arising from treated and untreated sewage effluent is a major concern (Bessong *et al*., 2009; Momba *et al*., 2006). This is also common in many urban centers where sewage is often not treated properly before discharge, due to inadequate or broken sewerage systems. Consequently, a wide range of pathogens, heavy metals, and organic compounds end up in the water sources, and these affect human health and aquatic ecosystems (Edokpayi *et al*., 2017; Peters *et al*., 2016).

Some rural communities also face challenges such as fecal pollution because of a lack of waste collection and disposal facilities or treatment infrastructure. Some on-site sanitation facilities such as latrines drain directly into underground water sources (Sharpley *et al*., 1994). In the Luvuvhu river catchment, Limpopo province, elevated concentrations of nitrates, ammonia, turbidity, and E. *coli* counts in underground water were attributed to pit latrines (Odiyo and Makungo, 2012).

2.3.2. Challenges facing water treatment plants in South Africa

There are diverse challenges affecting water treatment plants in South Africa. Some of these relate to manpower, funding, and monitoring. The Department of Water Affairs (DWA) which is now called the Department of Water and Sanitation (DWS) introduced compulsory registration for water treatment process controllers to be classified in terms of DWS classification systems (DWA, 2012). A process controller, classified under a certain class, is allowed to operate a specific type of water treatment plant. Momba *et al*. (2009) have reported that several rural water treatment plants in South Africa are operated by workers who have been trained to do basic water treatment functions. These authors note that general knowledge of water treatment procedures, such as the determination of water flow rate, coagulant and chlorine dosages is lacking. Consequently, the water treatment plants in rural areas were not producing safe drinking water (Momba *et al*., 2009). Other issues observed were related to inadequate financing of the operation and maintenance of equipment, frequent shortage of chemicals, and lack of water quality monitoring (Momba *et al*., 2008). These challenges need to be addressed through training and capacity building of water treatment plant operators. In the Limpopo province, where this study was conducted, many water treatment plants face similar manpower challenges (Mackintosh and Jack, 2008; Nefale *et al*., 2017).

2.3.3. Effects of decreased water quality

The effects of poor water quality include disturbance to aquatic ecosystem functioning and restricted water use (WHO, 2008). An example of an ecosystem impact is algal blooms, resulting in eutrophication have led to fish kills due to cyanobacteria, enhance biological oxygen demand (Van Ginkel, 2011; Mwangi, 2014). Algal blooms cause thick, green muck that impacts clear water, recreation, businesses, and property values. Nevondo and Cloete (1999) observed that algal blooms impact the aesthetic, recreational, and agricultural use of water. The tourism industry loses billions each year, through losses in fishing and boating activities, as a result of water bodies that have been contaminated (Dinka, 2018). The more water is polluted and not treated, its value reduces.

Water pollution has economic implications. A study by Momba *et al.* (2009) found that polluted water increases chemical water treatment costs. The excessive growth of toxic cyanobacteria and algal blooms impact the operational performance of producing safe drinking water quality by blocking water filters in water treatment. This increases water treatment plant maintenance costs and ultimately, elevated water treatment costs. The increase in water treatment costs may be transferred to consumers. When this happens water pricing becomes a barrier for poor people to access safe and adequate water for household use. Insufficient access to clean water may lead to the use of unsafe drinking water sources which results in the transmission of waterborne diseases. Waterborne diseases account for numerous deaths per year in the country (Sibiya and Gumbo, 2013). For example, diarrhea is one of the leading causes of death among young children. Clean water is important for the economy and overall human health in general as it can reduce the severity of water-borne diseases.

2.4. Policy and regulation for drinking water compliance in South Africa

South Africa's constitution indicates that everyone has the right to have access to sufficient water. A sustainable supply of clean and safe water to the users should always be guaranteed (Momba *et al.*, 2009). The management and provision of safe drinking water in the country is governed by various regulations. National Water Act (NWA), 1998 (Act 36 of 1998) mandates the government to ensure that water is protected, used, developed, conserved, managed, and controlled sustainably and equitably for the benefit of all persons. The Department of Water and Sanitation (DWS) which was then called the Department of Water Affairs and Forestry (DWAF) is responsible for ensuring water services provision and the implementation of the Act. The South Africa National Standards (SANS 241) and Drinking Water Guidelines provide the limits within which treated water quality parameters need to comply. The SANS 241 is the ultimate reference on acceptable limits for drinking water quality. However, it has been found that the SANS 241 does not meet the requirements of socio-economic development (Swartz, 2000). It only protects people who receive treated water.

On the other hand, the DWS introduced the Blue Drop programme. The Blue Drop programme was designed to deal with compliance of potable water supply systems with National Drinking Water Quality Standards SANS 241. The Department of Water and Sanitation implemented the Blue Drop programme to encourage sustained progress and to acknowledge excellence in drinking water services management in South Africa. The Blue Drop Certification provides the public with accurate information about the drinking water quality performance of the water treatment plant (DWAF, 2005). The certification goes beyond drinking water quality and takes into consideration the whole water treatment plant operation. The water treatment authorities are required to submit information to the national Blue Drop System (BDS) regarding water quality management (Rivett *et al.*, 2013). But since 2014, the Department of Water and Sanitation has not been able to conduct any water quality assessments under these programmes. However, the municipalities continue to undertake self-assessment to enable improved management of their systems by monitoring water quality and write a report with all the information. The Blue Drop regulation programs certify that water service providers and water treatment systems are managed adequately, the water is treated and conveyed to the highest possible standards to minimize risk to public health and the environment (DWA, 2012). However, most of the water supply systems are not complying with these regulations (Rivett *et al*., 2013). Many challenges arise due to limited capacity and resources within the local government institutions like municipalities. According to Nefale *et al*. (2017), most of the operators in water treatment plants lack knowledge of plant operational processes and the maintenance of the water treatment systems. This has led to less frequent monitoring of the systems, lack of record-keeping and maintenance (DWAF Blue Drop Report, 2009).

According to the Water Services Act (DWAF, 1997), water treatment plants are required to undertake regular water quality analyses. They are also required to assess the water quality against the SANS 241 standards and the South African Water Quality guidelines of DWS (DWAF, 1996). The water quality assessments are based on the sampling of the raw water intake, final water at the point of treatment, distribution reservoirs and sites along with the reticulation network and the furthest point of water supply. The main concern has been that rural municipalities are neglecting to report the necessary information. Additionally, they fail to meet several regulatory requirements for overall water quality monitoring and management (Momba *et al*., 2009).

2.5. Guidelines for drinking water quality

In South Africa, drinking water quality guidelines are based on the South Africa National Standards (SANS 241) and South African Water Quality Guidelines - Domestic Water Use volume one (DWAF 1996 standards). According to SANS 241 (SANS 241, 2015), the quality of drinking water should comply with the given microbiological, physical, aesthetic, and chemical limits. According to these guidelines municipalities are required to monitor and evaluate the water quality in their areas and regularly report the drinking water status before and after treatment (Rivett *et al*., 2013). The reports are aimed to provide a judgment on the performance of the water treatment plants and help to assess the risk of waterborne hazards (WHO, 2014). Table 2.1 shows selected drinking water quality guidelines used in South Africa and by the WHO.

Table 2.1: Selected drinking water quality guidelines (SANS 241, WHO and DWAF 1996).

Parameters	**SANS 241**	**WHO**	**DWAF 1996**
Free chlorine (mg/L)	≤ 5	0.5-1.5	0.2
Monochloramine (mg/L)	≤ 3	3	3
Colour (Pt-Co)	< 15	15	15
Electrical conductivity at 25 °C (mS/m)	≤ 170	≤ 170	≤ 170
Turbidity (NTU)	≤ 5	1.3	≤ 5
Total dissolved solids (mg/L)	≤ 1200	1000	≤ 1200
pH at 25°C	≥ 5 and ≤ 9.7	6.5-8.5	6.09-9.0
Nitrate as N (mg/L)	≤ 11	3	3
Fluoride as F (mg/L)	≤ 1.5	1.5	≤ 1.5
Chloride as Cl (mg/L)	≤ 300	200	300
Sodium (mg/L)	≤ 200	200	200
Iron (mg/L)	≤ 3	0.3	0.3
Manganese (mg/L)	≤ 4	0.5	0.1
Total coliform	Not detected	absent	≤ 10
E. coli	Not detected	absent	0

The following section explores each of the above water quality parameters. The current study assesses water treatment efficiency in the two selected plants based on the above standards.

2.5.1. pH

pH value is a measure of the relative acidity or alkalinity of water on a scale of 0 to 14. Water pH affects the solubility of solutes, metal toxicity, and pipe corrosion (DWAF, 1996). The pH of the most treated water lies between 6.5-8.5 (Dinka, 2018). According to Issa (2017), pH affects the effectiveness of coagulation, disinfection, and concentration of substances in the treated water. the pH that is too low may not allow the coagulation process to proceed, while high pH can cause a coagulated particle (floc) to break (Cao *et al*., 2013). Coagulation removes many of the particles, such as dissolved organic carbon, that make water difficult to disinfect. According to Cao *et al*. (2013), a pH of 5.5 at the optimum dosage of alum gave excellent operational efficiency by removing impurities in water. A pH of less than 8.0 at the optimum dosage of chlorine during disinfection gave excellent operational efficiency of removing harmful bacteria, but a pH less than 7 is more likely to corrode the water treatment system and creates biofilms inside pipes which also add contaminants to distribution (Hansen, 2014). According to the SANS 241 guidelines, drinking water should have a pH between 5 and ≤ 9.7 (SANS 241, 2015). However, a treated water pH around 7.0 is recommended (Kulthanan *et al*., 2013).

2.5.2. Iron (Fe)

Iron is the second most common element in the Earth΄s crust. Therefore, it most often appears in water sources (Tchounwou *et al*., 2012). The presence of iron in drinking water is not considered a health hazard (WHO, 2011). However, when present in large amounts, iron may cause a metallic taste, and sometimes odor to the water (Casey, 2009). Too much iron may impart a cloudy appearance due to increased turbidity. The influence on turbidity can affect the removal of bacteria in water during chlorination. Like most organic and microbiological contaminants, accumulated iron in the water may encourage undesirable bacterial growth within a water treatment plant and distribution system, leading to clogging of the pumps with the consequent costly repairs (Tchounwou *et al*., 2012). However, an elevated concentration of iron in the distribution network can be an indicator of pipe corrosion (WHO, 2011). Thus, it is important to control the levels of iron in treated water. The SANS 241 recommends 3 mg/L of iron in the water (SANS 241, 2015). However, for the WHO and DWAF guidelines, the level should be no more than 0.3 mg/L.

2.5.3. Manganese (Mn)

Manganese is an element abundant in the Earth's crust and thus can be found in both groundwater and surface water (Tchounwou *et al*., 2012). It occurs naturally in both dissolved and suspended forms, depending on factors such as pH and anions present. The manganese ($Mn^{2+)}$ dissolved predominates in most water at pH 4–7, but oxidized forms may occur at higher pH values of 8 (ATSDR, 2000). Although manganese occurs naturally, Casey (2009) observed that higher levels of manganese in water are associated with industrial pollution. The problems associated with a high concentration of manganese are both aesthetic and operational. DWAF (1996) and WHO (2004) noted discoloration of the water, unpleasant taste, and staining are some of the aesthetic problems caused by excess Mn. Increased concentrations of Mn can also lead to an increase in economic losses due to the constant need for the cleaning of the water distribution system of build-up residue that limits water flow. The SANS 241 recommends a guideline value of 0.5 mg/L of Mn in drinking water. The WHO and DWAF (1996) guidelines are lower at 0.5 mg/L and 0.1 mg/L, respectively.

2.5.4. Sulfates (S)

Sulfates are compounds that can have an anthropogenic origin and are produced naturally by the decay of organic substances containing sulfur compounds. Sulfates are often present in vapors from volcanoes and mineral water (Zimbelman *et al*., 2005). According to Bashir (2012), some of the sulfate content in treated water is associated with the use of aluminum sulfate as a sedimentation coagulant in the water treatment process. However, excessive amounts of sulfates may lead to water hardness, the formation and build-up of hard scales in boilers, a bitter taste and may cause a laxative effect on humans (WHO, 2011). Sulfates are difficult to remove from drinking water (WHO, 2004). However, it has been recommended that in case of high content, either an alternative source be used or the water with a high concentration of sulfates is diluted with lower sulfate-containing water. The WHO and SANS 241 guidelines recommend a value of $\leq$ 5000 mg/L (WHO, 2011; SANS 241, 2015).

2.5.5. Electrical conductivity (EC)

Electrical conductivity measures the ability of water to carry electrical current and is used as an indicator of the amount of total dissolved salt content in the water. EC is an important parameter to assess water treatment efficiency (WHO, 2004) and is widely used to indicate the level of pollution in water. Dallas and Day (2004) identified the following potential causes of high EC values: acid mine drainage, sewage pollution and farm run-off. The inefficiency of the sedimentation and filtration process can increase the EC values of treated water. The three standards recommend the EC of treated water to be less than 170 mS/m.

2.5.6. Total dissolved solids (TDS)

Total dissolved solids (TDS) is a concentration of all inorganic and organic solids dissolved in water (Dallas and Day, 2004). These solids may arise from human activities like wastewater discharge, agricultural and urban runoff (Khatri and Tyagi, 2015). It is important to monitor the

TDS in drinking water and water treatment facility to identify harmful contaminants and pollution in the water (DWAF, 1996). This will help in keeping track of changes that may occur in the water so that, action can be taken immediately. To remove dissolved solids reverse osmosis and convectional water treatment are used. High TDS is usually not a health hazard but can impact the acceptability of the water by consumers due to the colour and taste imparts to water (WHO, 2011; DWAF, 1996). Elevated TDS might also cause water hardness and the blocking of water filters (DWAF, 1996). The WHO and SANS 241 guidelines recommend a value of $\leq$ 1000 mg/L. (WHO, 2011; SANS 241, 2015).

2.5.7. Chloride (Cl)

Chlorides occur naturally in groundwater. However, in surface water, it may be a result of pollution from agricultural and industrial effluents (Khatri and Tyagi, 2015). In treated water, chloride concentration may be considerably increased during the treatment processes due to the addition of chlorine to kill pathogens (WHO, 2011). Excess chlorine increases the electrical conductivity of the water and has implications on metal pipe corrosion (DWAF, 1996). High amounts of chloride may also negatively affect the odor and taste of drinking-water even at concentrations as low as 1.3 mg/L. Chlorine is highly toxic if consumed in high concentrations. Thus, the WHO and SANS 241 guidelines set the critical limit of 5 mg/L (WHO, 2004; SANS 241, 2015). However, WHO (2011) recommends that a residual concentration of $\geq$0.5 mg/L of chlorine at pH <8.0 after at least 30 minutes of contact time, to produce safe water in the distribution. This residual free chlorine at the point of use ensures drinking water remains free of pathogens and is not re-contaminated during the distribution process. A minimum level of 0.2 mg/L of free residual chlorine is recommended according to the SANS 241 (2015).

2.5.8. Turbidity

Turbidity measures the cloudiness of water influenced by the amount of organic and inorganic matter and suspended particles (WHO, 2004; Hansen, 2014). Excessive turbidity in raw water can contain pathogens, which can be adsorbed to the particles. This can affect the quality of water produced during the water treatment process by overloading and clogging filters. Turbidity can also be an indicator of microbial contamination as microorganisms attach to these particles (LeChevallier *et al*., 1981: Hansen, 2014). It is important to monitor or assess turbidity for proper control and operation of water treatment. Thus, turbidity is used to measure the quality of water produced by the treatment processes.

During water distribution turbidity increases may be an indication of biofilms inside pipes or external contamination entering pipes through mains break and other faults (Hansen, 2014). Turbidity can also affect the taste, odor and appearance of the water (DWAF, 1996). Although it does not adversely affect human health, excess turbidity can protect microorganisms from the disinfection process and stimulate bacteria growth (WHO, 2004). Guidelines have been set by SANS 241 and DWAF 1996 to decrease turbidity in the treatment plant as low as possible, depending on the treatment type and technology used (DWAF, 1996). The WHO recommends a maximum concentration of 1 NTU before disinfection although <0.5 NTU is encouraged for large municipal supplies (WHO, 2011). The South African Water Quality Standard (DWAF, 1996) for turbidity in the household water supply is between 0 and 1 NTU.

2.5.9. Fluoride (F)

Fluorides enter a river as a result of industrial effluent (Bessong *et al*., 2009) or naturally from fluoride-rich rocks or soils. Excess fluoride in drinking water is harmful to human wellbeing as it causes dental and skeletal fluorosis (Rivett *et al.*, 2013; Bessong *et al*., 2009). WHO (2011), advised that if fluoride concentration exceeds 2.0 mg/L in drinking water families should be notified to protect children under nine years from dental problems. Sharma and Bhattacharya (2017), reported that excessive fluoride affects mostly children and elderly people. The value of fluoride in the treated water supply is ≤1.5 mg/L in all the guidelines.

2.5.10. ***Escherichia coli* (*E. coli*)**

Escherichia coli (*E. coli*) is the most widely used biological indicator for detecting the presence of microbial contamination in drinking water supplies worldwide (Rivett *et al*., 2013). E. *coli* monitoring plays an important role in providing information on the quality of raw water, adequacy of the treatment plant, the efficiency of the disinfection process, and the safety of the water distributed to the consumer (Stanfield *et al*., 2003). The ability to detect E. *coli* contamination in drinking water are also important as pathogenic microorganisms in drinking water pose the greatest danger to public health. According to DWAF (1996), the treatment of surface water sources should include adequate filtration and disinfection to remove harmful microorganisms. All the drinking water standards recommend non-detectable *E-coli* per 100 mL in the treated water. The presence of E. *coli* in treated water signifies inadequate treatment or the treated water has become contaminated during distribution. For this reason, the monitoring of microbiological quality in drinking water is important as it serves as an early guard of potential health hazards for the population (Stanfield *et al*., 2003).

2.5.11. Total coliforms (TC)

Coliform bacteria are commonly found in the soil as well as animals and human faeces (USEPA, 2012; WHO, 2004). The bacteria themselves are not considered harmful or likely to cause illness. However, the coliform bacteria in drinking water indicate the possible presence of harmful, disease-causing organisms such as giardia and cryptosporidium. The presence of coliforms indicates that the water source has been exposed to contamination from soil, plants, or animals and water supply is at risk of contamination from fecal pollution (DWAF, 1996; WHO, 2011). According to USEPA (2012), coliforms are used as a simple broad test that is economical because it is associated with the sources of pathogens. Adequate chlorination eliminates all bacterial contamination. WHO and SANS 241 guidelines recommend a limit of zero (not detected) for total coliforms in drinking water (WHO, 2004; SANS 241, 2015).

2.6. Assessment of water treatment efficiency

The quality of water before it is used by consumers depends on the efficiency of the water treatment process at the plant which must be safe and within the standard criteria for public health (Vieira *et al*., 20008). The efficiency of water treatment is the basic indicator of water treatment plant function (Kaindl et al., 1999). The efficiency of water treatment measures the operational efficiencies based on some established performance indicators such as a degree of removal of pollutants such as turbidity, color, suspended impurities, and other impurities (Issa, 2017). The assessment of water treatment plant efficiency depends on the raw water characteristics and the characteristics of the treated water compared with the regulatory standards of water quality. These standards are general and not absolute and may vary depending on local conditions and the cost of treatment.

There are various ways of testing the efficiency of water treatment. Firstly, the physicochemical and bacteriological quality of raw and treated water at the plant can be compared (Diersing, 2009). Secondly, a water treatment plant efficiency assessment procedure put forward by Stanfield *et al*. (2003) may be used. Thirdly, an assessment can be done on whether the established standard operating procedures for water treatment plants are being followed at the selected water treatment plant (Wei *et al*., 2010). Each of the above techniques is explained below.

The comparison of the physicochemical and bacteriological parameters of raw and treated water at the plant uses the limits of the standard guidelines approach (Diersing, 2009). This approach bases water quality assessment on the comparison of treated water quality with established standards and guidelines that set limits within which specific water quality parameters should be. In the preceding section, three major water quality guidelines or standards were discussed. This includes SANS 241 (SANS 241, 2015) and DWAF standards (DWAF, 1996), which are commonly used in South Africa, and the WHO guidelines which are used at the international level. Any deviations from the set limits in a given standard mean that the water fails the quality test according to that specific standard. However, it should be noted that when more than one standard is used, the treated water may meet the quality requirements of one standard and fail another.

On the other hand, the efficiency assessment of water treatment plants (Stanfield *et al*., 2003; Wiesner *et al*., 1989) calculates the percentage of contaminants removed by the water treatment plant by comparing selected parameters of the raw water and treated water. According to Sommer and Cabaj (1993), the parameters used are pH, turbidity, residual chlorine, total coliforms, and *Escherichia coli*. Various studies have used this technique (e.g. Sommer and Cabaj, 1993: Jacangelo *et al*.,1995; Issa, 2017).

The use of standard operating procedures is an indirect way of assessing water treatment efficiency. The technique is premised on the fact that no water treatment plant can produce safe water if they do not follow the set standard operating procedures for water treatment. This method was used by Sorlini *et al*. (2015) by checking all operational treatment processes guided by the water service plan (WSP). The WSP is an innovative approach to hazard evaluation and management that aims to ensure the safety of water intended for human consumption in the whole drinking water supply system from catchment to customer.

2.7. Factors influencing the efficiency of water treatment

The goal of water treatment is to deliver potable water to a community and meeting the requirements of agricultural. medical, industrials, and other water use. The following factors influence the water treatment plant efficiency; season, raw water quality, design of the plant, availability or level of training of the plant operators, level of compliance with applicable legal standards, chemical dosage, financial and management issues. The key step in ensuring safe drinking water is to choose the best water source available. LeChevallier *et al*. (1981) observed that raw water quality has a marked influence on the performance and the cost of water treatment. Sasakova *et al*. (2018) and Edokpayi *et al*. (2017) found that most surface water sources have poor water quality and need a rigorous treatment process to yield safe drinking water.

In terms of operational and management issues, Momba *et al*. (2000) observed that in small water treatment plants, the most common problems relate to plant processes such as under or over-dosing of water treatment chemicals and the quality of the chemicals used in the various processes. Another issue that is essential for the performance of water treatment is the correct operation and maintenance of filters. Poor maintenance was found to be the most significant factor in the performance of water treatment plants (Swartz, 2000; Momba *et al*.,2000).

Another factor influencing water treatment is the operator's skill (Momba *et al.*, 2000). An operator is responsible for the production of quality water and plant performance. Water treatment plant operators should know the entire process of the plant. Momba *et al*. (2009) found that many municipal water treatment plants in South Africa had low skill levels amongst the plant operators and this was affecting the operational performance of these plants. In terms of regulations, all the water treatment plant and process controllers on-site are required to be classified and registered (DWAF, 2005). The required knowledge and skills of process controllers are not only important for the day-to-day operation of a water treatment plant, but also in observing the national standards applicable to water quality (Sorlini *et al.*, 2015).

2.8. Summary

The review noted that South Africa faces several challenges concerning water quality. It was revealed that the pollution of water resources affected human health and aquatic life, and. increased the costs of water treatment. Most of the water treatment processes use conventional methods which include screening, pre-chlorination, chemical coagulation, flocculation, and disinfection. The majority of the water treatment plants in South Africa were not functioning optimally, which led to supplying water that was non-compliant with the relevant standards. This led to water-borne diseases in the affected communities. Three major water quality guidelines or standards were reviewed and it was observed that the standards are not uniform as they tend to differ in some aspects.

CHAPTER THREE:
RESEARCH METHODOLOGY

3.1 Introduction

The chapter provides the locational background of the study area and the research methodology. The former includes a description of the physical and socio-economic aspects of the study area. The latter, explains the rationale of the study site selection, data collection and analytic techniques.

3.2 Description of the study area

3.2.1 Location

The Vhembe District Municipality is located in the north eastern part of the Limpopo province of South Africa, see Figure 3.1. It covers an area of approximately 60,500 km^2. The district municipality comprises the following local municipalities: Collins Chabane, Makhado, Musina, and Thulamela. The Vhembe District Municipality has eleven small water treatment plants (Figure 3.1). Table 3.1 identifies the water treatment plants.

Table 3.1: Vhembe District Municipality water treatment plants.

Name of Plant	**Coding**
1 Mutale water treatment plant	MWTP
2 Vondo water treatment plant	VWTP
3 Mutshedzi water treatment plant	MuWTP
4 Nandoni water treatment plant	NWTP
5 Dzingahe water treatment plant	DWTP
6 Malamulele water treatment plant	MaWTP
7 Tshedza /Tshifhire water treatment plant	TtWTP
8 Dzindi water treatment plant	DzWTP
9 Tshikundu water treatment plant	TWTP
10 Albasini water treatment plant	AWTP
11 Tshakhuma water treatment plant	TsTP

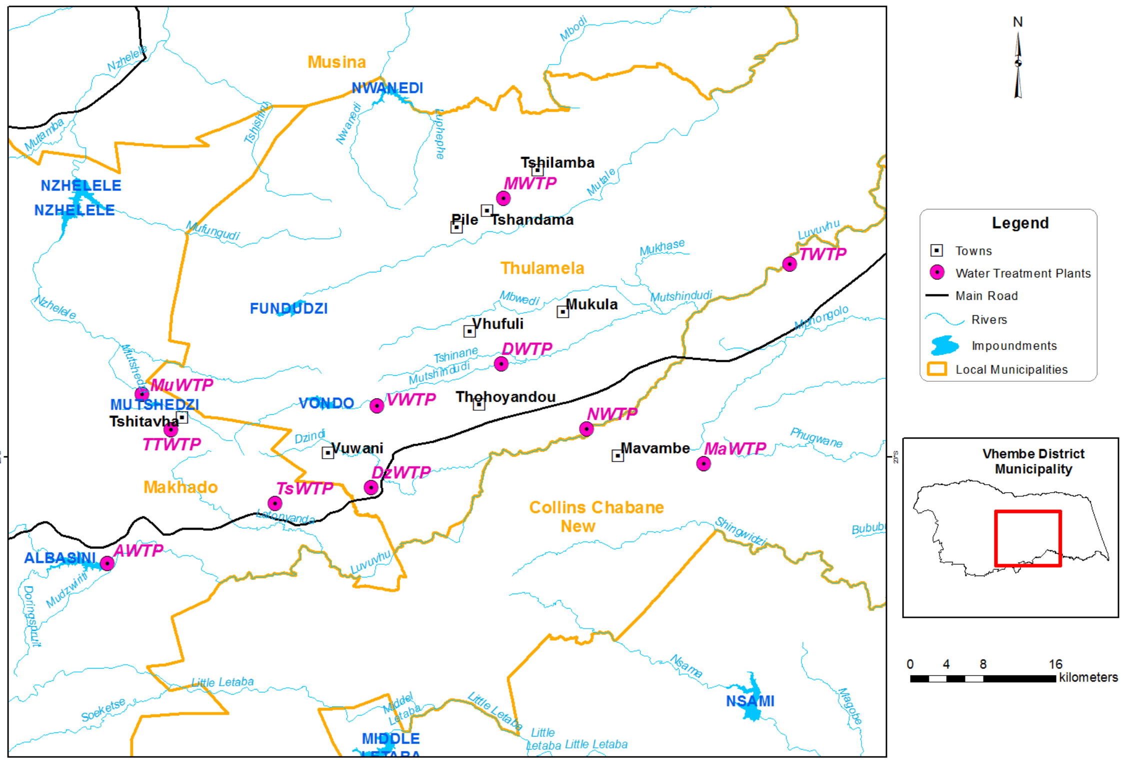

Figure 3.1: Location of the Vhembe District Municipality and its various water treatment plants.

3.2.2 Geology and soils

The Vhembe District Municipality falls within the geology of the Soutpansberg Group of sedimentary and volcanic rocks (Krammers *et al.*, 2006). The Group is best developed in the eastern part, where the maximum preserved thickness is about 5 000 m. The Soutpansberg Group has unconformably overlain the granitoid-greenstone substrate of both the Kaapvall and the Zimbabwe cratons in the Limpopo mobile belt (Akintola, 2018; Brandl, 1999). This belt formed due to a collision between the Kaapvaal craton from the south and the Limpopo Belt from the north (Bumby, 2000). Deposition of the most prominent geology started with basaltic lavas and was followed by the settling of various sedimentary rocks. The Soutpansberg rocks initially formed a flat featureless landscape After an erosional period, pink massive quartzite was deposited (post-rift sequence) which covered a much larger area than the original rift (Barker 1979). Many diabase dykes and sills occur throughout the Soutpansberg. These dykes are of volcanic origin and often intruded along fault planes (Brandl 2003).

According to Brandl (1999), the Soutpansberg Group represents a volcano-sedimentary succession. The succession of the group are Tshifhufhu, Sibasa, Fundudzi, Wyllies's Poort, Nzhelele, Stayt, and Malibogwe formations. The Mutale and Thulamela municipalities are underlain by the Nzhelele and Sibasa Formations, respectively. The Sibasa Formation can reach about 3000m thickness and comprises pyroclastic intrusions with minor intercalation of sedimentary and tuffaceous rocks. The red argillaceous and arenite sediments of the Nzhelele formation can reach about 6000 m in thickness (Akintola, 2018). Phanerozoic Karoo Supergroup sedimentary rocks mostly cover the Musina Local Municipality. The area was subjected to an extensive erosional period to the exposure of resistant sandstone- quartzite rocks. Due to the nature of the geological formation in the study area, groundwater is stored and transmitted through fractures and faults (Brandl, 1986).

The soil of the study area consists of fertile clay soil, sandy soil, and clay loam soil. Soils vary a great deal on a broad scale in the Vhembe District. Red loam soil which is prone to erosion is the most common type of soil in the district (Nethononda and Odhiambo, 2011). The area around Mutale is dominated by dark brown to black high clay content soil. These soils are prone to waterlogging. On the other hand, the area around Phiphidi is dominated by reddish loam soils (Nethononda and Odhiambo, 2011).

3.2.3 Climate

The study area has varied rainfall regimes due to the effect of the Soutpansberg mountains. Annual rainfall can reach 2 000 mm in the middle of the Soutpansberg. However, in the western part rainfall can be as low as 340 mm (Kabanda, 2004). About 80% of the rainfall occurs in the summer months from November to March. The rest occurs in the cool, dry winter months. The region is characterized by high climate variability and is prone to flood and drought incidences (Kabanda, 2004). Temperature ranges from 18°C to 39.9°C in elevated areas and the whole region respectively, while the area is generally frost-free (Akintola, 2018; Kabanda, 2004).

3.2.4 Hydrology

Vhembe District Municipality is characterized by both perennial and non-perennial rivers. The Vondo water treatment plant abstracts water from the Vondo dam which is fed by the Mutshundudi river. The Mutale water treatment plant abstracts water from the Mutale River, which rises from the northern slopes of the Soutpansberg mountains and flows north to the Limpopo river. During drought periods, these rivers have water for most of the year. Summer rainfalls are the major contributions to high flows for a long time. The Mutshundudi and Mutale rivers are mostly used by several communities along their course for domestic and agricultural purposes. Groundwater is also used. However, borehole yields are low and groundwater monitoring is sporadic and unreliable. There are a total of 1358 boreholes in the study area, about 161 of them are non-functional due to drought, 88 vandalized and 52 collapsed and the rest unrecorded (Nthunya *et al*., 2017).

3.2.5 Land cover and land use

Vhembe District Municipality has various biomes namely savanna, grasslands, and forests (Gotze *et al.*, 2008). The district municipality falls within the Venda arid Mountain Bushveld and Mopani woodland, characterized by open grasslands with scattered trees and bushes. However, a semi-deciduous forest prevails along the streams. According to Mulugisi (2015), the most dominant vegetation is the acacia species. The most common land use are agriculture, mining, and pottery making. Tshikondeni is closely associated with mining activities. Animal farming and plantation also play a major role. Smaller animals usually graze closer to households and bigger animals graze all through the region unbounded. Overgrazing is a challenge in grassland areas as they decrease the vegetation cover and exposes soil to erosion. Agriculture occupies the greatest land cover especially the production of tea, citrus, and other tropical fruit. Subsistence farming includes the growing of maize, vegetables and fruits. Deforestation is a major problem in the Mutshundudi and Mutale river basins as people tend to cut down trees for fuelwood.

3.2.6 Socio-demographic characteristics

Vhembe Districts Municipality covers 27 969 148 km² of land with a total population of 1 393 949, living in 382 358 households of which 194 980 are female-headed household compare to 187 378 males (VDM IDP, 2020). Most of the men travel outside the district to seek employment opportunities. VDM consists of four local municipalities Thulamela, Makhado, Musina, and Collins Chabane. According to Stats SA (2016) community survey, Makhado covers 8 310. 586 km² with a 416727 total population. Thulamela covers 2 893.936 km² with 497237 total population, Collins Chabane covers 5 467 216 km² with 347 975 total population and Musina covers 11 297. 41 km², with 132009 total population.

The VDM is generally poor. The unemployment rate is 30.8% while that of poverty is 48%. There is unequal access to basic amenities such as water and electricity and land (McCusker, 2002). Households survive mainly on government grants, and on income generated from working in farms or towns. In-house piped water is available to 11% of households while 34% have taps inside their yards. Communal taps within 200 m of dwellings serve about 19% of households while 28% of households are served by water taps that are further than 200 m away from dwellings (Stats SA, 2016). The rest of the households obtain water from other sources such as boreholes, springs, rivers, and dams. In terms of sanitation, the majority of households (59%) use pit latrines for sanitation (Nethononda and Odhiambo, 2011). Flush toilets are available to 16% of households most of which are connected to municipal sewage systems. A large 55 number of households (23%) do not have access to in-house/yard toilet facilities. Similarly, the water provision is not so different in Thulamela municipality and Mussina where the study areas sites.

The major economic sectors in the district municipality are subsistence farming with emerging commercial farming and eco-tourism activities. Agriculture is a dominant sector (VDM IDP, 2020) with the production of tea, citrus, and other deciduous fruits widespread. All these sectors use a large quantity of water.

3.3. Selection of study sites

The study aimed to assess the efficiency of two water treatment plants in the Vhembe District Municipality. The Mutale water treatment plant located in the Musina Local Municipality and the Vondo water treatment plant located in the Thulamela local municipality were selected for this study. The selection was based on anecdotal reports of poor water quality by residents and also because the plants are known to experience technical management problems and have histories regarding non-compliance with the required standards (Nefale *et al*., 2017). Figure 3.2 shows the location of the water treatment plants selected for this study and the corresponding water distribution sampling points. Table 3.2 offers more information about each point.

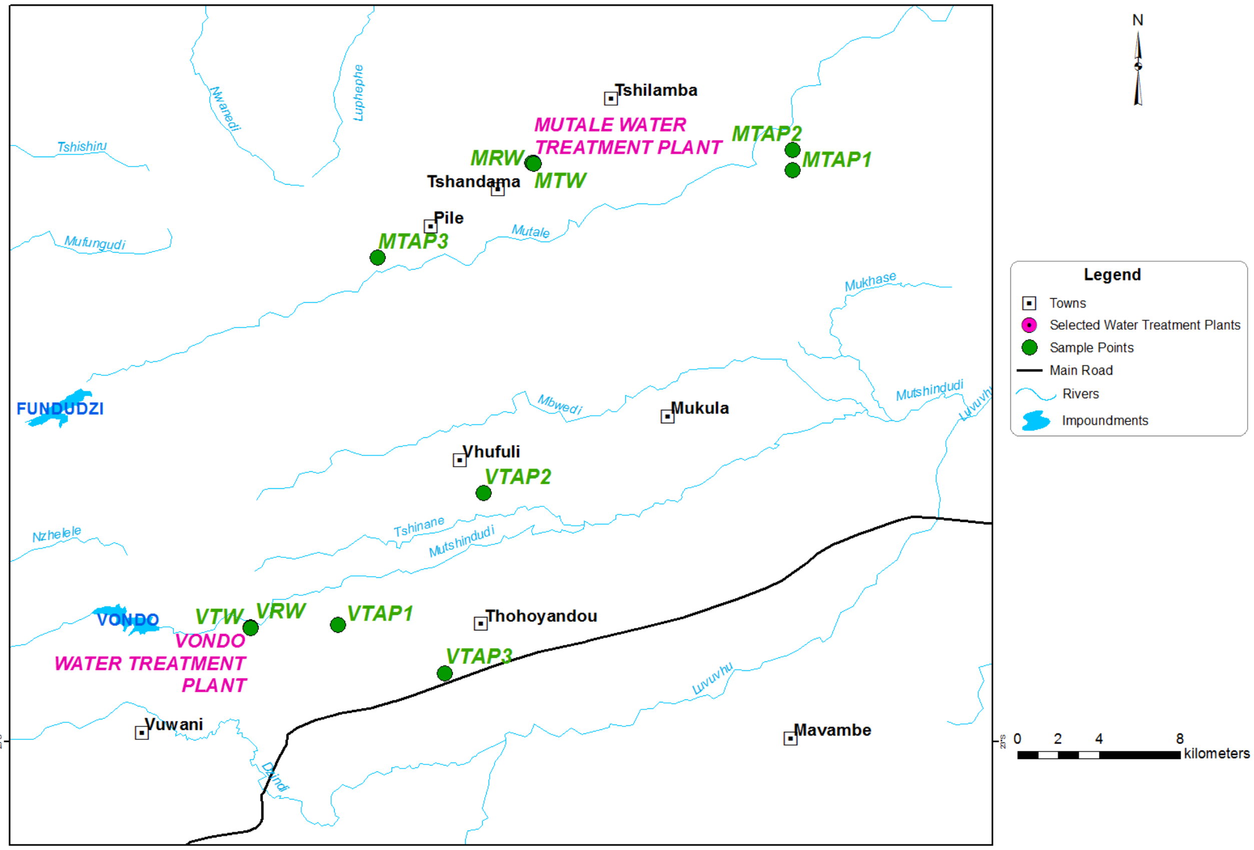

Figure 3.2: Location of the selected water treatment plants and the respective water distribution sampling points.

Table 3.2: Sampling points and codes used in the map.

Sample label	Coding points	Latitude	Longitude	Source of water
Vondo raw water	VRW	-22,949795	30,392535	Mutshundudi/Vondo dam
Vondo treated water at the plant	VTW	-22,950118	30,392213	Mutshundudi/Vondo dam
Vondo tap 1 (Ngovhela tap 1)	VTAP1	-22.948597	30,430808	Vondo water treatment Plant
Vondo tap 2 (Tshitereke tap 2)	VTAP2	-22.890555	30.495143	Vondo water treatment plant
Vondo tap 3 (Thohoyandou Block G 3)	VTAP3	-22.970066	30.478070	Vondo water treatment plant
Mutale raw water	MRW	-22.745056	30.516688	Mutale River
Mutale treated at the plant	MWTP	-22.745353	30.517133	Mutale River
Mutale tap 1 (Tshitavha tap 1)	MTAP1	-22.748315	30.631734	Mutale water treatment plant
Mutale tap 2 (Tshilamba tap 2)	MTAP2	-22.739315	30.631734	Mutale water treatment plant
Mutale tap 3 (Dzimauli tap 3)	MTAP3	-22.786802	30.448485	Mutale water treatment plant

3.4. Data collection

3.4. 1. Water quality data

Water treatment plants and municipalities are by law required to test the quality of water before and after treatment and at selected locations, where it is consumed by the population. Due to the budgetary constraints for the collection and laboratory analyses of the water samples, this study used secondary data that already exists at the plant from past water quality sampling and water quality analyses. These historic data were used to assess water treatment efficiency. The major problem of secondary data is that the researcher cannot vouch for the integrity and accuracy of the data collected (Rangeti *et al.*, 2015). The parameters analysed were selected based on the availability of secondary data to allow comparison. The challenges were that only eleven parameters were used for assessment of the water treatment plant efficiency (turbidity, pH, electrical conductivity (EC), total dissolved solids (TDS, sulfate, free chlorine, manganese, iron, fluorides, total coliforms, and *E.coli*) for eight months.

Another problem with secondary data is that it may not cover those samples of the population researchers want to examine, or not in sufficient detail or the sample used may be small. Despite the challenges that secondary data has, one of the most noticeable advantages of using secondary data is its cost-effectiveness. Because someone else has already collected the data, the researcher does not need to invest any money, time, or effort into the data collection.

In the following section, details are given on how this secondary data was generated at each plant to enable a better understanding of the data that was used in this study.

- Raw water was sampled at the plant before treatment was done to determine whether the source was suitable for treatment for domestic water and to evaluate the impact of the raw water quality on the performance of water treatment at the plant. Workers at the plant sampled the raw water before it entered the plant, following the Surface Water Sampling Procedure (DWAF, 1996). This procedure entails dipping a sampling container to 20 cm into the rectangular channel and collecting the sample
- Treated water was sampled at the plant before it was delivered to the consumers to determine operational control and product quality.
- Treated water was also sampled from various taps at selected households to determine any changes in the water quality in the distribution network and whether the water quality from the tap met the recommended standard (SANS 241, 2015). These households were selected randomly by the district authorities. At each point, one tap was turned on at maximum flow rate, and the water was allowed to flowed for 2 minutes. The tap was disinfected for a minute using 70% alcohol and allowed to flow at a medium rate for 2 minutes before sampling following the procedure Sisay *et al*. (2017).
- At each sampling point, water was collected in 500 ml labeled sterilized bottles once each month to see how water quality was varying throughout the year.

- The samples were sealed, labeled, and transported in a cooler box with ice to the Department of Water Affairs Laboratory in Sibasa for chemical and biological analyses within 24 hours.

Because this study depended on secondary data, the procedures used for water analysis by the accredited lab are included in Appendix 1 for information purposes.

Each water treatment plant has a logbook of all the test results coming from the Sibasa water analysis laboratory (see Appendix 2 to 5 and table 4.1 to 4.13 for transcribed descriptive statistics for the water quality). This data contains the following parameters: physical water quality parameters (turbidity, pH, electrical conductivity (EC), total dissolved solids (TDS)); chemical water quality parameters (sulfate, free chlorine, manganese, iron, and fluorides) and biological water quality parameters (Total coliforms and *E.coli*). The records from August 2017 to March 2018 were collected at each plant and transcribed for analysis.

3.4.2. Questionnaire survey

To assess the factors influencing the water treatment efficiency at the two water treatment plants, a questionnaire survey of the plant supervisors and plant operators (see a sample questionnaire in Appendix 6) was used. The information requested was related to the design capacity of the plant, the number of villages that the plant supplied with water, and the type of water treatment plant among other aspects.

Another questionnaire was also used to assess consumer perception of the quality of water (see Appendix 7). The purpose of the questionnaire was to evaluate user satisfaction with the quality and quantity of the water supply. The questionnaire enclosed the following topics: water sources used, frequency of water availability, type of water storage, and reliability of water supply systems. Several questions were aimed to understand the views of community members concerning water quality and the safety of drinking water distributed from the water treatment plants.

The respondents were selected using a stratified random sampling (Walsh *et al*., 1992) with each area served by each plant as strata and villages and towns in the area having been selected randomly. Households were visited in the selected areas and any available residents were selected for the survey. The data collection process was conducted for five days during April 2019. A total of 80 respondents availed themselves for the survey, 40 each from the areas served by each water treatment plant.

3.5. Data analysis

Statistical analyses were performed on the secondary data obtained from the two water treatment plants. Firstly, the data was separated into two seasons; dry (August, September, and October) and wet (November, December, January, February and March) following Kabanda (2004). The data was then separated into various sets to assess the mean and standard deviation. These sets included: raw water, treated water sampled at the plant, treated water sampled at three taps in the surrounding villages. The analysis of variance (ANOVA) was used to evaluate whether there were any seasonal differences between the quality of raw and treated water at the water treatment plants, between the treated water at the plant, and selected distribution points in the villages supplied by the plants. This test is used to assess whether there are any statistically significant differences between the means of two or more independent groups (Du Prel *et al*., 2010).

To determine the level of compliance of the water quality with the appropriate standards recommended for domestic use, the mean and standard deviation of the selected treated water quality parameters were compared with the SANS 241, drinking water quality standards (DWAF, 1996) and the World Health Organisation (WHO) drinking water quality standards (WHO, 2011). The results from the above analyses were also used to assess whether the water treatment processes at the plants are able to meet the water quality standards set.

3.6. Assessing water treatment plant efficiency

The assessment of water treatment plant efficiency in this study was carried out by comparing the physicochemical and bacteriological parameters of raw and treated water at the plant using the limits of the standard guidelines approach. The comparison of the physicochemical and bacteriological parameters of raw and treated water at the plant was to determine if the treatment plant can treat raw water and meet the standards set by the end-user or a community through its regulatory agencies. This approach uses the quality of water as a surrogate of the efficiency of treatment. The three major water quality guidelines or standards were acknowledged. This includes SANS 241 (SANS 241, 2015) and DWAF standards (DWAF, 1996), which are commonly used in South Africa, and the WHO guidelines which are used at the international level. Any deviations from the set limits in a given standard mean that the water fails the quality test according to that specific standard. The operation of each treatment process in a water treatment plant is important and needs to be evaluated to ensure the unit's performance. According to Vieira *et al*. (2008), assessing the efficiency of the treatment plant helps to identify the factors that are inhibiting the treatment plant (treatment processes) from producing water of acceptable quality. This approach will assist in judging the water quality changes from source water to consumer, which may be useful in deciding appropriate remedial measures for preventing drinking water from contamination and help in the safe drinking water supply to consumers and for environmental uses.

3.7. Research ethics

The North-West University Ethics Committee cleared this study (Ethics Clearance Number: NWU-01641-20-A9). Permission to apply the questionnaire survey to the key informants at each plant and to collect the secondary water quality data was obtained from the Vhembe District Municipality (see Appendix 9). The permission to undertake the study was also sought from the Village Head (see Appendix 10). The research issue was explained to respondents. Additionally each respondent was assured that their contribution would remain anonymous and that participation in the study was voluntary. It was also emphasized to them that they could reject giving any information at any time without explanations if they felt uncomfortable.

CHAPTER FOUR:
RESULTS AND DISCUSSION

4.1. Introduction

The results of this study are presented, interpreted, and discussed in this chapter. Firstly, the results of water quality data analysis are presented. Secondly, the analysis of the level of compliance of the treated water at the two plants and the distribution points with the relevant water quality standards is undertaken. Thirdly the results of a questionnaire survey are presented to assess whether the water treatment plants follow established standard operational practices. Lastly, consumer perceptions of the water quality in the two areas studied are presented.

4.2. Comparison of the raw and treated water parameters at the two water treatment plants

Table 4.1 presents the mean and standard deviation of raw and treated water quality parameters of the VWTP and MWTP. It is evident that the raw water intake for both VWTP and MWTP was poor in relation to turbidity, pH, iron, manganese, TDS, and total coliform. However, this was not unexpected as most surface water sources in the Limpopo province are known to be contaminated (Obi *et al*., 2002; Germs *et al*., 2004). The values treated water parameters (turbidity, pH, iron, manganese, TDS, fluoride, sulfate, and total coliform) are lower than those of the raw water, at the MWTP except for electrical conductivity. The values of treated water parameters (pH, turbidity iron, manganese, TDS, electrical conductivity, and total coliform) are lower than those of the raw water except for sulfate, fluoride, and a treatment chemical (chlorine) in VWTP. In the MWTP only, the value of free chlorine increased in the treated water. The increase in free chlorine in both plants resulted from the addition of chlorine during the treatment process.

Residual chlorine is recommended to keep the water safe during transmission and storage (Momba and Brouckaert, 2005; WHO, 2004). Trace concentrations of fluoride and sulfate are not uncommon due to the influence of geology (WHO, 2004). Sulfates occur naturally in numerous minerals and also aluminum sulfate (alum) is used as a sedimentation agent in the treatment of drinking water for the control of algae. The increased concentration might be due to the dissolvement of minerals during the treatment process or the use of aluminum sulfate during the water treatment process. According to Bashir (2012), the sulfate content in treated water is associated with the use of aluminum sulfate as a sedimentation coagulant in the water treatment process. Fluoride occurs naturally as a result of the geological composition of soils and bedrock. According to WHO (2011), fluoride can be added to treated water as a public health measure for reducing cavities among the treated population which is prohibited by the Safe Drinking Water Act because of its effects on human health. In this case, the high concentration of fluoride in the treated water of both plants might result from equipment problems or the type of test used to monitor results. In later sections, an evaluation of whether the changes in the concentrations of chlorine and the various other parameters were within the expected standards will be undertaken.

Table 4.1: The mean and standard deviation of raw and treated water quality parameters of the Vondo water treatment plant and Mutale water treatment plant.

	Vondo water treatment plant		Mutale water treatment plant	
	Raw water	**Treated water**	**Raw water**	**Treated water**
Parameter	**Mean±Std**	**Mean±Std**	**Mean±Std**	**Mean±Std**
Electrical conductivity (mS/m)	0.219±0.044	0.075±0.111	0.066±0.088	0.0398±0.008
Free chlorine (mg/L)	0.000±0.000	0.225±0.242	0.000±0.000	0.326± 0.308
pH (pH units)	7.028±0.425	6.782±0.678	7.506±0.601	6.959± 0.456
Turbidity (NTU)	6.468±4.441	1.640±1.598	7.456±4.996	4.843± 6.965
Fluoride (mg/L)	0.205±0.043	0.222±0.177	0.270±0.225	0.219± 0.144
Iron (mg/L)	0.868±0.052	0.099±0.082	0.448±0.282	0.322± 0.277
Manganese (mg/L)	0.237±0.162	0.083±0.124	0.152±0.1152	0.086± 0.186
Total dissolved solids (mg/L)	29.588±11.970	19.967±11.138	21.690±7.484	20.634±5.859
Sulfate(mg/L)	0.0000±0.000	0.063±0.246	0.000±0.000	0.000± 0.000
E-coli per 100 mL	0.0000±0.000	0.0000±0.000	0.000±0,000	0.000± 0.000
Total coliforms/100 mL	468.095±252.800	0.0000±0.000	523.346±379.2	0.000± 0.000

4.3. Seasonal comparison of the raw and treated water parameters at the two water treatment plants

The seasonal assessment of raw and treated water quality is a significant aspect of water quality assessment. It provides a better understanding of the variations in raw water quality and potential impacts on treatment efficiency at the plant (Edokpayi *et al*., 2017). This section examines whether there is a seasonal variation in the raw and treated water parameters in the two water treatment plants (Table 4.2). The raw water intake had better quality in the wet season as compared to the dry season in relation to electrical conductivity, manganese, and TDS at the VWTP except for iron in the wet season. On the contrary, the quality of treated water was better in the dry season in relation to electrical conductivity, turbidity, manganese, and TDS. The rest of the parameters were within the standard deviation of each other.

Table 4.2: The mean and standard deviation of raw and treated water quality parameters of the Vondo water treatment plant by season.

Parameter	Dry season		Wet season	
	Raw water Mean±Std	**Treated water Mean±Std**	**Raw water Mean±Std**	**Treated water Mean±Std**
Electrical conductivity (mS/m)	0.219±0.044	0.075±0.111	0.208±0.054	0.035±0.022
Free chlorine (mg/L)	0.000±0.000	0.225±0.243	0.000±0.000	0.238±0.250
pH (pH units)	7.028±0.425	6.783±0.677	7.026±0.488	6.851±0.701
Turbidity (NTU)	6.468±4.442	1.640±1.598	6.736±4.838	2.211±1.799
Fluoride (mg/L)	0.205±0.043	0.222±0.176	0.220±0.050	0.202±0.157
Iron (mg/L)	0.868±0.052	0.100±0.083	0.886±0.058	0.125±0.094
Manganese (mg/L)	0.238±0.162	0.083±0.125	0.198±0.175	0.126±0.140
Total dissolved solids (mg/L)	29.588±11.970	19.966±11.138	25.420±0.438	21.379±12.46
Sulfate (mg/L)	0.000±0.000	0.063±0.246	0.000±0.000	0.050±0.224
E-coli per 100 mL	0.000±0.000	0.000±0.000	0.000±0.000	0,000±0,000
Total coliforms/100 mL	468.095±252.800	0.000±0.000	553.857±404.480	0,000±0,000

Table 4.3: Wet and dry season ANOVA results for raw and treated water quality parameters at the Vondo water treatment plant.

Parameter	Sum of Squares	df	Mean Square	F	Significance
Electrical conductivity (mS/m)	0.132	1	0.132	12.629	0.001*
Free chlorine (mg/L)	0.323	1	0.323	6.734	0.013*
pH (pH units)	0.383	1	0.383	0.940	0.338
Turbidity (NTU)	149.131	1	149.131	26.079	0.000*
Fluoride (mg/L)	0.002	1	0.002	0.074	0.788
Iron (mg/L)	3.773	1	3.773	622.161	0.000*
Manganese (mg/L)	0.152	1	0.152	8.699	0.005*
Total dissolved solids (mg/L)	592.438	1	592.438	4.643	0.038*
Sulfate (mg/L)	0.025	1	0.025	0.507	0.481
E-coli per 100 mL	0.000	1	0.000		
Total coliforms/100 mL	409010.176	1	409010.176	10.133	0.003*

* Significant at $p \leq 0.05$.

In both seasons the comparison of raw and treated water showed that the values of free chlorine and fluoride increased in the treated water. A deviation was, however, observed in the electrical conductivity values, which were higher in the raw water in the VWTP. This should be expected given adequate filtration and flocculation. It can be also be observed that water treatment reduced the values of the rest of the parameters. The ANOVA results of the VWTP indicated that the values of electrical conductivity, free chlorine, turbidity, iron, manganese, TDS, and total coliforms of the raw and treated water were significantly different between the seasons ($p \leq 0.05$) (Table 4.3).

At the MWTP, the raw water intake had better quality in the dry season as compared to the wet season in relation to manganese, turbidity, and TDS, except for electrical conductivity and fluoride in the dry season (Table 4.4). On the contrary, the treated water was of better quality in the dry season than the wet season in relation to free chlorine, turbidity, iron, TDS, and total coliforms. The rest of the parameters were within the standard deviation of each other. The ANOVA results

(Table 4.5) show that there was a significant seasonal difference between the raw and treated water values of free chlorine and total coliforms ($p \leq 0.05$). Total coliforms and other biological contaminations are a serious public health risk (DWAF, 1996; WHO, 2011). Thus, water treatment managed to eliminate coliforms in both seasons.

Table 4.4: The mean and standard deviation of raw and treated water quality parameters of the Mutale water treatment plant by season.

Parameter	Dry season		Wet season	
	Raw water Mean±Std	**Treated water Mean±Std**	**Raw water Mean±Std**	**Treated water Mean±Std**
Electrical conductivity (mS/m)	0.023±0.005	0.0369±0.006	0.0920±0.106	0.0415±0.0098
Free chlorine (mg/L)	0,000± 0.000	0.182±0.260	0.00±0.000	0.4120±0.308
pH (pH units)	7.247± 0.645	7.263±0.362	7.662± 0.586	6.778± 0.412
Turbidity (NTU)	5.143± 3.119	1.259±0.773	8.844± 5.690	6.993± 8.114
Fluoride (mg/L)	0.313± 0.266	0.248±0.151	0.244± 0.225	0.202± 0.140
Iron (mg/L)	0.160± 0.050	0.137±0.125	0.620± 0.198	0.433± 0.285
Manganese (mg/L)	0.163±0.149	0.145±0.289	0.1464±0.109	0.0499±0.066
Total dissolved solids (mg/L)	19.810±5.22	19.521±7.854	22.818±8.951	21.782 ±4.273
Sulfate (mg/L)	0.000± 0.000	0.000±0.000	0.00±0.000	0.000± 0.0000
E-coli per 100 mL	0.000± 0.000	0.000±0.000	0.00±0.000	0.000±0.0000
Total coliforms/100 mL	0.000± 0.000	0.000±0.000	606.720±553.851	0.000± 0.000

Table 4.5: Wet and dry season ANOVA results for raw and treated water quality parameters at the Mutale water treatment plant.

Parameter	**Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Electrical conductivity (mS/m)	0.004	1	0.004	3.038	0.089
Free chlorine (mg/L)	0.679	1	0.679	8.778	0.005
pH (pH units)	1.914	1	1.914	8.093	0.007
Turbidity (NTU)	43.702	1	43.702	0.989	0.326
Fluoride (mg/L)	0.016	1	0.016	0.625	0.434
Iron (mg/L)	0.101	1	0.101	1.300	0.261
Manganese (mg/L)	0.029	1	0.029	0.939	0.339
Total dissolved solids (mg/L)	3.657	1	3.657	0.095	0.759
Sulfate (mg/L)	0.000	1	0.000		
E-coli per 100 mL	0.000	1	0.000		
Total coliform/100 mL	920272.896	1	920272.896	18.240	0.000

* Significant at $p \leq 0.05$

It was observed in the results presented that there is a seasonal variation in water quality parameters. The characteristics that drive water quality changes during the wet and dry seasons include the water volume, flow, leakage rainfall events, run-off, and evaporation (Edokpayi *et al*., 2017). The raw water sources in this study were heavily polluted with total coliform in both wet and dry seasons for VWTP and MWTP. However, results were higher in the wet seasons than in the dry season. A similar seasonal trend was observed in some studies in the province (Nevondo and Cloate, 1999; Obi *et al*., 2002; Germs *et al*., 2004). This is usually associated with greater runoff in the wet season, carrying microbes from polluted sources to the fundamental waterways. Kumpel and Nelson (2016), also observed that water quality changes with the seasons even when there are no pollutants present. This is related to the changes in the dilution of mineral and pollutant concentrations due to variations in stream discharge, rain, and evaporation (Nevondo and Cloate, 1999).

4.4. Evaluation of the quality of treated water at the water treatment plants and distribution points in the villages

According to DWAF (1996), the sampling for water quality should include raw water intake, treated water at the point of treatment, distribution reservoirs and sites along the reticulation network and the furthest point of water supply. Thus, it was considered necessary to evaluate whether the quality of water changed between the treatment plant and the distribution points. Table 4.6 shows the seasonal mean and standard deviation of each treated water quality parameter at the VWTP and all the villages together. It can be observed that some treated water quality parameters changed during transmission to the distribution points in the villages. These are free chlorine turbidity, fluoride, iron, manganese, TDS, and sulfate which were higher in the water supplied at the villages during the dry season. On the other hand, during the wet season, the electrical conductivity, turbidity, fluoride, iron, TDS, and sulfate were higher in the treated water distributed to the villages. The increase of electrical conductivity, turbidity, fluoride, iron, TDS, and sulfate might be due to deposit accumulation in pipes, pipe corrosion, and chemical reactions in the water during times of intermittent or no water supply. On the other hand, during the treatment process, the plants use the chlorine tablet to disinfect, the increase of free chlorine might be due to the dissolution of the chlorine tablet during distribution or analysis error.   However, the differences in water quality between the plant and the village taps in both water treatment plants were not statistically significant ($p \leq 0.005$) (Table 4.8 and Table 4.9).

However, the observed variations (although not statistically significant) might be due to deposit accumulation in pipes, pipe corrosion, and chemical reactions in the water during times of intermittent or no water supply (Venter, 2001), which is a common problem in the study areas. Higher iron concentration might be a result of rusting pipes. A comparison of the water quality in the villages with the SANS 241 standards revealed that regardless of the noted changes in the water during transmission, the water quality was still within the expected standards, according to the SANS 241 (Table 4.6). An exception was the value of free chlorine, which was lower than the WHO guidelines for both the treated water at the plant and in the villages in both seasons. Such a low residual chlorine value in treated water is a health risk (Ford, 1999; Momba and Brouckaert, 2005). Similarly, the turbidity of the treated water in the villages during the wet season was higher than the WHO guidelines, although it met the requirements of the SANS 214 standards.

Table 4.6: The mean and standard deviation of treated water quality parameters of the Vondo water treatment plant and all the villages it supplies water by season.

	Dry season		Wet season		Guidelines	
	Treat water at the plant	**Treated water at the villages**	**Treat water at the plant**	**Treat water at the villages**		
Parameter	**Mean±Std**	**Mean±Std**	**Mean±Std**	**Mean±Std**	**WHO**	**SANS 241**
Electrical conductivity (mS/m)	0.2487±0.193	0.1074±0.145	0.025±0.005	0.038±0.024	≥170	≥170
Free chlorine (mg/L)	0.133±0.064	0.227±0.273	0.330±0.317	0.207±0.228	0.5-1.5	≤5
pH (pH units)	6.696±0.514	6.663±0.719	6.940±0.699	6.819±0.723	6.5-8.5	5.0-9.7
Turbidity (NTU)	0.687±0.023	0.691±0.211	1.184±0.611	2.552±1.945	1.3	≤5
Fluoride (mg/L)	0.223±0.058	0.267±0.241	0.180±0.177	0.209±0.155	1.5	≤1.5
Iron (mg/L)	0.05330.040	0.058±0.024	0.116±0.060	0.128±0.105	0.3	≤3
Manganese (mg/L)	0.001670.001	0.016±0.035	0.230±0.163	0.091±0.119	0.5	0.4
Total dissolved solids (mg/L)	17.23000.970	17.740±9.910	13.582±0.612	23.977±13.482	1000	≤1000
Sulfate (mg/L)	0.00±0.000	0.11±0.333	0.00±0.000	0.07±0.258	1000	≤5000
E-coli per 100 Ml	0.00±0.000	0.00±0.000	0.00±0.000	0.00±0.000	Absent	Not detected
Total coliforms/100 mL	0.00±0.000	0.00±0.000	0.00±0.000	0.00±0.000	Absent	≤10

Table 4.7: The mean and standard deviation of treated water quality parameters of the Mutale water treatment plant and all the villages and all the villages it supplies water by season.

	Dry season		Wet season		Guidelines	
	Treat water At the plant	**Treat water at the village**	**Treat water at the plant**	**Treat water at the villages**		
Parameter	**Mean±Std**	**Mean±Std**	**Mean±Std**	**Mean±Std**	**WHO**	**SANS 241**
Electrical conductivity (mS/m)	0.039±0.002	0.036±0.007	0.042±0.013	0.041±0.009	≥170	≥170
Free chlorine (mg/L)	0.087±0.076	0.213±0.295	0.604±0.437	0.348±0.237	0.5-1.5	≤5
pH (pH units)	6.933±0.489	7.373±0.258	6.784±0.435	6.775±0.421	6.5-8.5	5.0-9.7
Turbidity (NTU)	0.870±0.450	1.389±0.834	10.086±11.166	5.963±7.013	1.3	≤5
Fluoride (mg/L)	0.213±0.097	0.260±0.169	0.154±0.150	0.218±0.139	1.5	≤1.5
Iron (mg/L)	0.097±0.083	0.150±0.138	0.544±0.345	0.397±0.266	0.3	≤3
Manganese (mg/L)	0.171±0.293	0.137±0.305	0.020±0.019	0.060±0.074	0.5	0.4
Total dissolved solids (mg/L)	17.673±0.869	20.137±9.106	21.680±4.194	21.816±4.445	1000	≤1000
Sulfate (mg/L)	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	1000	≤5000
E-coli per 100 mL	0.000±0.000	0.000±0.000	0.000±0.000	0.00±0.000	Absent	Not detected
Total coliforms/100mL	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	Absent	≤10

Table 4.8: Dry and wet season ANOVA results for raw and treated water quality parameters at the Mutale water treatment plant and all the villages.

Parameter	Sum of Squares	df	Mean Square	F	Significance
Electrical conductivity (mS/m)	0.001	1	0.001	1.378	0.256
Free chlorine (mg/L)	0.057	1	0.057	0.908	0.353
pH (pH units)	0.055	1	0.055	0.106	0.748
Turbidity (NTU)	7.025	1	7.025	2.321	0.145
Fluoride (mg/L)	0.003	1	0.003	0.126	0.727
Iron (mg/L)	0.001	1	0.001	0.058	0.813
Manganese (mg/L)	0.072	1	0.072	4.296	0.053
Total dissolved solids (mg/L)	405.236	1	405.236	2.865	0.108
Sulfate (mg/L)	0.017	1	0.017	0.321	0.578
E-coli per 100 mL	0.000	1	0.000		
Total coliforms/100 mL	0.000	1	0.000		

Table 4.9: Dry and wet season ANOVA results for raw and treated water quality parameters at the Vondo water treatment plant and all the villages, it supplies water.

Parameter	Sum of Squares	df	Mean Square	F	Significance
Electrical conductivity (mS/m)	0.000	1	0.000	0.016	0.900
Free chlorine (mg/L)	0.246	1	0.246	2.856	0.108
pH (pH units)	0.000	1	0.000	0.002	0.966
Turbidity (NTU)	63.757	1	63.757	0.967	0.339
Fluoride (mg/L)	0.015	1	0.015	0.769	0.392
Iron (mg/L)	0.081	1	0.081	1.000	0.331
Manganese (mg/L)	0.006	1	0.006	1.385	0.255
Total dissolved solids (mg/L)	0.069	1	0.069	0.004	0.953
Sulfate (mg/L)	0.000	1	0.000		
E-coli per 100 mL	0.000	1	0.000		
Total coliforms/100 mL	0.000	1	0.000		

In the case of the MWTP, the values of pH, turbidity, fluoride, iron, and TDs increased in the water delivered to the villages as compared to the treated water at the plant in the dry season. Despite this, the water quality transmitted to the villages met the expected standards according to the SANS 241 except for turbidity in the wet season, which was 10.09 NTU and 5.96 NTU in the treated water at the plant and the villages, respectively. If the WHO guidelines are considered, both the dry and wet seasons did not meet the required water quality standard according to the WHO for turbidity, fluoride, and manganese. the parameters TDS, Iron, Sulphate, EC were compliant during both the dry and wet seasons.

Although there was no significant difference between treated water at the treatment plants and all the villages together as observed above (Tables 4.8 and 4.9), it was necessary to assess whether there were any differences amongst the villages themselves. This would help identify those villages that may have poor water quality and enable authorities to target the solution. Appendices 2 and 3 show the seasonal mean and standard deviation of the treated water quality at the VWTP and each of the sampled taps (Taps 1, 2, and 3) in various villages supplied by the VWTP.

Appendix 4 and 5 show the same information for the MWTP and each of the sampled taps (Tap 1, 2, and 3) in various villages it supplied water. The ANOVA results (Table 4.10, 4.11, 4.12, and 4.13) revealed that there was no significant difference between the treated water at each of the village taps ($p \leq 0.05$) in the dry and wet seasons. This means that the water quality in the villages was consistent regardless of the season.

Table 4.10: Dry season ANOVA results of treated water parameters at Vondo water treatment plant and each tap (Taps 1, 2, and 3) supplied by the plant.

Parameter	**Sum of Squares**	**df**	**Mean Square**	**F**	**Significance**
Electrical conductivity (mS/m)	0.076	3	0.025	0.968	0.454
Free chlorine (mg/L)	0.172	3	0.057	1.010	0.437
pH (pH units)	0.963	3	0.321	0.694	0.581
Turbidity (NTU)	0.071	3	0.024	0.660	0.600
Fluoride (mg/L)	0.121	3	0.040	0.913	0.477
Iron (mg/L)	0.002	3	0.001	1.023	0.432
Manganese (mg/L)	0.003	3	0.001	0.931	0.469
Total dissolved solids (mg/L)	244.564	3	81.521	1.200	0.370
Sulfate (mg/L)	0.250	3	0.083	1.000	0.441
E-coli per 100 mL	0.000	3	0.000		
Total coliforms/100 mL	0.000	3	0.000		

Table 4.11: Wet season ANOVA results of treated water parameters at the Vondo water treatment plant and each tap (Taps 1, 2, and 3) supplied by the plant.

Parameter	Sum of Squares	df	Mean Square	F	Significance
Electrical conductivity (mS/m)	0.001	3	0.000	1.054	0.396
Free chlorine (mg/L)	0.105	3	0.035	0.519	0.675
pH (pH units)	0.536	3	0.179	0.325	0.807
Turbidity (NTU)	21.330	3	7.110	2.832	0.071
Fluoride (mg/L)	0.110	3	0.037	1.646	0.218
Iron (mg/L)	0.004	3	0.001	0.115	0.950
Manganese (mg/L)	0.096	3	0.032	1.832	0.182
Total dissolved solids (mg/L)	479.785	3	159.928	1.035	0.404
Sulfate (mg/L)	0.150	3	0.050	1.000	0.418
E-coli per 100 mL	0.000	3	0.000		
Total coliforms/100 mL	0.000	3	0.000		

Table 4.12: Dry season ANOVA results of treated water parameters at the Mutale water Treatment and each tap (Taps 1, 2, and 3) were supplied by the plant.

Parameter	Sum of Squares	df	Mean Square	F	Significance
Electrical conductivity (mS/m)	0.000	3	0.000	0.680	0.588
Free chlorine (mg/L)	0.269	3	0.090	1.510	0.285
pH (pH units)	0.436	3	0.145	1.148	0.387
Turbidity (NTU)	2.342	3	0.781	1.477	0.293
Fluoride (mg/L)	0.073	3	0.024	1.102	0.403
Iron (mg/L)	0.049	3	0.016	1.056	0.420
Manganese (mg/L)	0.150	3	0.050	0.521	0.680
Total dissolve solids (mg/L)	214.734	3	71.578	1.235	0.359
Sulfate (mg/L)	0.000	3	0.000		
E-coli per 100 mL	0.000	3	0.000		
Total coliforms/100 mL	0.000	3	0.000		

Table 4.13: Wet season ANOVA results of treated water at Mutale water treatment and each tap (Taps 1, 2 and 3) supplied by the plant.

Parameter	Sum of Squares	df	Mean Square	F	Significance
Electrical conductivity (mS/m)	0.000	3	0.000	0.288	0.833
Free chlorine (mg/L)	0.489	3	0.163	1.999	0.155
pH (pH units)	0.066	3	0.022	0.111	0.952
Turbidity (NTU)	241.294	3	8.431	1.275	0.317
Fluoride (mg/L)	0.025	3	0.008	0.385	0.765
Iron (mg/L)	0.317	3	0.106	1.375	0.286
Manganese (mg/L)	0.014	3	0.005	1.054	0.396
Total dissolve solids (mg/L)	20.468	3	6.823	0.334	0.801
Sulfate (mg/L)	0.000	3	0.000		
E-coli per 100 mL	0.000	3	0.000		
Total coliforms/100 mL	0.000	3	0.000		

4.5. Evaluation of the compliance of the water quality with appropriate standards recommended for domestic use

The following section compares the water quality of the two plants with the SANS 241, (2015) DWAF (1996), and WHO (2004) standards for drinking water. The SANS 241 standard is used to manage drinking water quality and public health safety in South Africa. The WHO guidelines are used at the global level. Appendices 2, 3, 4, and 5 show the results of treated water quality produced at the VWTP and MTWP and that transmitted to the village taps in the dry and wet seasons. The results show that EC, pH, fluoride, TDS, sulfate, *E. coli*, and total coliforms fall within the SANS 241 and WHO drinking water quality limits during the wet and dry seasons for treated water both at the plants and villages. However, the results showed that free chlorine, turbidity, iron, and manganese exceeded WHO standards limits during the wet seasons for treated water at the plants. Similarly, the values for iron were above the WHO maximum permissible limit for treated water at Tap 2 and 3 for the MWTP. Based on aesthetic reasons, the WHO and SANS 241 standards recommend that the iron levels should be kept below 0.3 mg/ l and 3 mg/l, respectively. High doses of iron can cause liver, heart diseases, bone ailments, and premature death among others (Kotze, 2010). High iron concentrations alter the colour of the water and also affect the biogeochemical cycling of organic matter (Tchounwou *et al*., 2012).

The ANOVA results (Tables 4.10 and 4.11) show no significant seasonal differences ($p \leq 0.05$). However, manganese levels exceeded the maximum permissible limit established in the SANS 241 at the plant and Tap 1 at the VWTP in the wet season and Tap 2 in Mutale in the dry season. Elevated concentrations of manganese might be due to organic materials that form solid deposits within pipes (WHO, 2011). High concentrations of manganese may cause brain damage and other related diseases. The ANOVA results (Tables 4.12 and 4.13) show that the concentration of manganese was not significantly different by season ($p \leq 0.05$).

In relation to free chlorine, the values were within the guidelines of the SANS 241 except during the wet season at the MWTP. This might be due to the excess dosing of chlorine. In water, the chlorine reacts to form hypochlorous acid and hypochlorite, and could potentially be harmful if consumed. The main health effect that comes from drinking too much-chlorinated water is cancer. This high level of chlorine can also cause lung irritation, skin and eye damage, and provoke asthma (Gorguner and Akgun, 2010). It was also noted in the questionnaire survey that the operators were not aware of the chlorine dosage to use. Sometimes they either overdosed or underdosed the water with chlorine. A minimum level of 0.2 mg/L of free chlorine is recommended at the distribution points. According to WHO (2004), for the compliance of free chlorine during distribution, a residual concentration of ≥ 0.5 mg/l should be present after a contact time of at least 30 minutes at pH <8.0. It was noted that at the VWTP, the chlorine residual during the dry and wet seasons was less, placing water at a very high risk of contamination before it even reaches the consumers.

Turbidity values of treated water in the dry and wet seasons were within guidelines except for treated water at the MWTP. This might be due to a deficiency of the water treatment process at the plants or surface water entering the sump at the plant during rainfall. Although the result of turbidity fell within the recommended limits at the treatment plants, the water distributed to the villages had turbidity values exceeding the recommended limits in both plants. This could be a result of broken pipes, where particles may get into the pipes through runoff or the growth of algae in the pipes during the times of intermittent water supply. Increased turbidity may enhance or habour micro-organisms (WHO, 2011). Turbidity increases during distribution may be indicative of biofilms inside pipes or external contamination entering pipes (LeChevallier *et al*., 1981). A comparison of both plants in the two seasons analysed shows that there was a high disinfecting efficiency as no *E. coli* and total coliform was found in the treated water. All three water quality standards indicate that drinking water should not contain total coliforms, E. *coli,* or any coliforms in a 100 ml water sample.

The study shows that most of the physicochemical and biological water quality parameters fell within the acceptable limits for drinking water standards. Nonetheless, those few physicochemical parameters that were outside the set limits cannot be overlooked. These findings are consistent with similar studies in South Africa. According to Momba and Brouckaert (2005), small water treatment plants in South Africa have challenges in meeting drinking water quality standards due to the poor hydraulic disinfection efficiency of contact tanks and the deficiency of water treatment plants. The non-compliance rate is also explained by using reasons such as lack of resources, lack of skills, lack of understanding of required standards, inadequate maintenance, and limitations on finances (DWA, 2012).

4.6. Characteristics and operational practices at the water treatment plants and how they may affect water quality

According to Issa (2017), operational and maintenance factors must always be taken into consideration for improving the efficiency of the water treatment plant and to ensure that the performance of each process is satisfactory. The study aimed to evaluate the operational performance of the water treatment plants through the analysis of the water quality data. The next section presents the results of the survey that was done to plant operators and management at the two plants.

4.6.1. The design capacity of water treatment plants

The design capacity of the VWTP is 52.6 megalitres per day and the plant supplies water to 167 villages. The plant was in the process of being upgraded. On the other hand, the design capacity of the MWTP is 13.6 megalitres per day. However, the plant produced 8.6 megalitres per day. The MWTP supplied water to 36 villages including two towns. Both water treatment plants were operating below design capacity. Mackintosh and Colvin (2002) and Momba *et al*. (2000) made similar observations about many small rural water treatment plants in South Africa. Consequently, the plants fail to meet the water quality and supply demands of the communities they serve.

4.6.2. The water treatment process at each plant

The VWTP abstracts raw water from two sources; the Vondo dam and the Mutshundudi river. The plant had no flocculation channels and no sedimentation tanks for primary settling as it is a direct filtration plant. The water flows by gravity from the Vondo dam to the treatment plant and goes through coagulation. To adjust pH lime is added and sometimes, pre-chlorination is done during the dry season to remove suspended solids due to high concentrations of iron and manganese. Aluminum sulfate is added at the division box as a flocculant and chlorine tablets are used for disinfection. The final treated water flows by gravity to Reservoir 1 at Maungani (R1) and the rest is pumped to Reservoir 2 (R2) in Gondeni and Reservoir 3 (R3) at Denga Tshivhase.

On the other hand, at the MWTP, the Mutale River is the source of water. Water goes through to screens before being pumped. The raw water is stored in the dam at the plant using submersible pumps before it enters the water treatment plant. Lime is added to adjust pH and then polyelectrolyte is added at the division box to form floc on the sedimentation. The dosing system of polyelectrolyte was not working so they adjust the pump depending on the formation of flocs. In the same way, as at the VWTP, chlorine tablets are used in the filtration chamber for disinfection. Finally, the water is pumped into a concrete storage tank for distribution to consumption points. It is evident that both plants use conventional water treatment methods, which do not need any specialized knowledge.

The following challenges were indicated by the plant operators: lack of consistent maintenance and fixing of leakages, improper chemical dosages, and water flows at less than the design capacity. According to Issa (2017), operational and maintenance factors are very important for better functioning water treatment plants. In both plants, some workers reported a lack of consistent maintenance of filtration systems or leakages within the reticulation system.

4.6.3. Manpower challenges at the water treatment plants

One of the major factors influencing water treatment performance is the operator's skill (Momba *et al.*, 2000). An operator is responsible for the production of water quality and plant performance. Table 4.14 shows some of the attributes of the plant operators and management at the VWTP and MWTP. About 50% and 60% of the plant operators at the VWTP and MWTP, respectively have a certificate, 30% have a diploma in Chemical Engineering for both plants. About 20% and 10% of the plant operators at both VWTP and MWTP had an Honours degree in a water-related field. Seventy percent and 80% for VWTP and MWTP had no specific training in water treatment or reticulation, respectively. This is a serious skill gap. Only 30% and 20% at the VWTP and MWTP, respectively had undergone the appropriate training to allow them to obtain technical skills for process control in water treatment. According to the Blue Drop Regulation (DWA, 2012), all plant operators are required to go for training.

Table 4.14: Characteristics of the manpower at each water treatment plant.

		VWTP	**MWTP**
Education	Certificate	50%	60%
	Diploma	30%	30%
	Degree and honors.	20%	10%
Experience of plant operator	<5	80%	80%
	5-10	10%	10%
	11+	10%	10%
Specific training in water treatment	Yes	30%	20%
	NO	70%	80%

The survey revealed that most of the operators and supervisors did not have good knowledge or understanding of the flow rates at their plants and had no knowledge of chemical dosing. Generally, the chemical dosing level was learned through experience. The fact that 80% of the operators had less than 5 years' experience is a big challenge in the better operation of the plants. During water treatment coagulant doses were added manually, usually based on the appearance of the floc and sometimes based on the taste of the water resulting from the use of aluminum sulfate, instead of calculations or standard procedures. This led to either overdosing or underdosing of chlorine, which poses a potential risk to water quality. Both water treatment plants did not meet the water demand of the consumers. About 70% and 80% for the VWTP and MWTP respectively had no idea of the required water demand of each village. The two plants were facing many issues like chemical supply, lack of equipment, lack of maintenance, and water leakages among others. During the interviews, 40% and 50% of the plant operators at the VWTP and MWTP, respectively, indicated that they were not sure if the water reservoirs were clean while the rest indicated that the reservoirs were not clean. This has serious implications on water quality as water may be contaminated in storage, which will affect the water quality after treatment.

The level of skill and knowledge of the workers of small water treatment plants in South Africa has been considered a concern by some studies in South Africa. Momba *et al*. (2009) found that many municipal water treatment plants in South Africa have low skill levels amongst the plant operators and this was affecting the operational performance of these plants. In terms of regulations, the water treatment plants are required to be classified and register all the water treatment plants and process controllers on-site (DWAF, 2005). The required knowledge and skills of process controllers are not only important for the day-to-day operation of a water treatment plant but also in observing the national standards applicable to water quality (Sorlini *et al.*, 2015).

4.7. User perception and consumer satisfaction with the quality of water

Consumer perception of water quality has existed for thousands of years (Sajjadi *et al*., 2016). The objective of this section was to assess the consumer perception of tap water quality at both plants. Respondents were asked about their water sources. The results in Table 4.15 show that 60% of respondents indicated that their main source of water was a household tap. Ten percent indicated a public tap and neighbours' tap, another 10% got their water from the river and household taps, while 6% from the river and rainfall, and 14% got their water from boreholes. The majority of the respondents (83%) were not satisfied with the supply of water that they had access to. Issues of long periods without water (77%) and low pressure (70%) were among some of the issues the majority mentioned. Water shortage was regarded as a big problem (66%) by the majority of the respondents.

Table 4.15: Consumer perception of water supply.

Source of water supply in the villages		Household tap		60%
		Public tap and neighbours' tap		10%
		River and household taps		10%
		River and rainfall		6%
		Boreholes		14%
The satisfaction of water supply		Yes		No
		17%		83%
How many hours, days, weeks, months on average are you without water?		Days per week		Weeks per months
	Female	3 days/week (65%)		70% 3 weeks
	Male	3 days per week (35%)		(30%) 3 Weeks
Have there been times when the water pressure is low?		Yes		No
		70%		25%
Have there been periods in the past year with no tap water service for several days at a time?		Yes		No
		77%		33%
Do you consider your water shortages to be a:		Big problem	Somewhat of a problem	No problem
		66%	30%	4%
Do you have a water storage tank?		Yes		No
		15%		85%
Do you usually preserve drinking water in a drinking water container?		85%		15%
In what kind of container do you usually preserve your drinking water?		Closed container (e.g., bottle, narrow-neck jug)		Open container (e.g. tin bucket, pan)
Do you usually treat your drinking water at home?		74%		26%
		30%		70%

The survey of plant supervisors and operators revealed that the water treatment plants have challenges of meeting water supply-demand. The study revealed that the municipality was not satisfying all the communities in terms of water service delivery, this is partly because the plant was operating below its design capacity. Consequently, the majority (43%) had to keep water in buckets and tanks as a solution to the water delivery challenges (Figure 4.1). Even then, the majority (85%) did not have large water storage containers (Table 4.15).

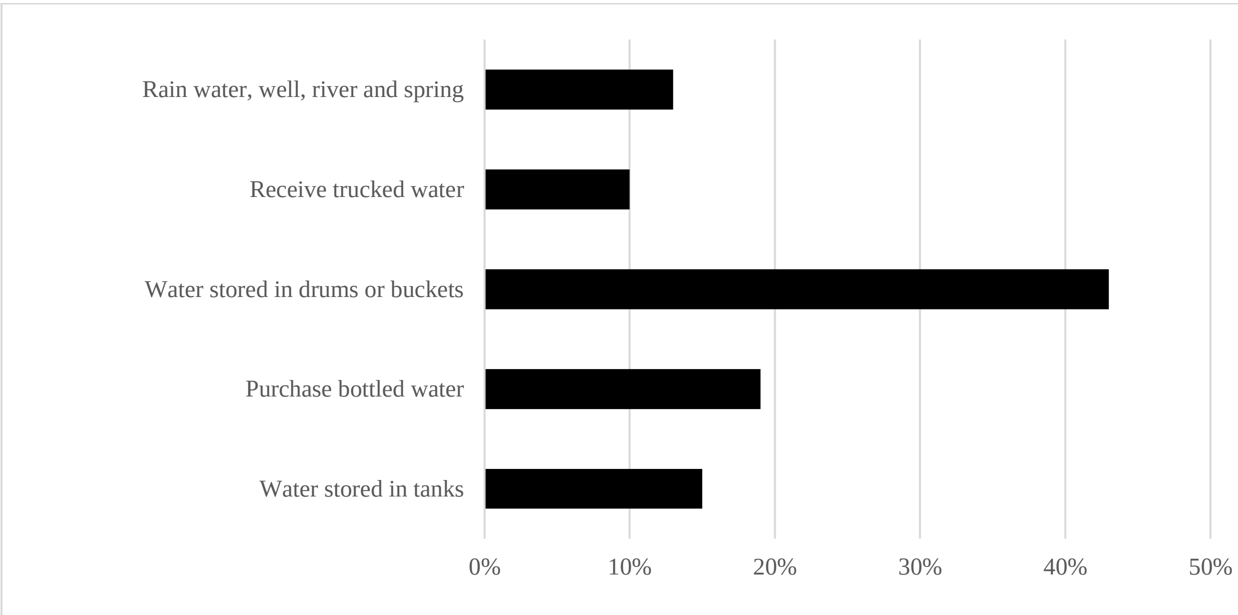

Figure 4.1: Interventions by the survey households to the water delivery challenges.

Despite the above, most respondents (77%) were satisfied with the quality of water received. Those who indicated dissatisfaction with the water quality cited issues of the appearance of the water (dirty, cloudy, colour, particles or muddy) (63%) and unsuitable taste or bad smell (23%) as major problems (Table 4.16).

Table 4.16: Consumer perceptions of water quality.

Question/theme	Respondents
The satisfaction of water quality	77%
Unsuitable Taste or bad smell	27%
Appearance (dirty, cloudy, colour, particles or muddy)	63%
Too much chlorine	5%
Bothers stomach	3%
Others	2%

The general perception of the study is that the water quality was satisfactory. However, the general consumer perception about water quality produced by many municipalities in the country has not always been positive (Slabbert and Pepper, 2011). Consumer perception of water quality depends on the consumer’s sense of taste, odor, and appearance. Information also plays a great role in perceptions (Masanyiwa *et al*, .2019). That is why consumers have a differing opinion about the aesthetic values of water quality.

CHAPTER 5:
CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides the research conclusions on each research objective. The last section provides recommendations for further study.

5.2 Conclusions

This study aimed to assess the efficiency of water treatment plants in the Vhembe District Municipality. The Vondo and Mutale water treatment plants were used as case studies. The first objective was to compare the quality of raw and treated water produced by each water treatment plant and whether the water quality differed by season. The study showed that the raw water used in both VWTP and MWTP was of poor quality in relation to turbidity, pH, fluoride, iron, manganese, EC, TDS, and total coliform. This was not unexpected as the water was untreated. On the other hand, the values of free chlorine, fluoride, and sulfate were higher in the treated water at the VWTP. This may be attributed to chemicals added during treatment such as chlorine and aluminum sulfate. The hypothesis that there was no difference in water quality between the treated and untreated water was rejected, as it was not consistent with the study results. The analysis of variance showed that there was a significant difference ($p < 0.05$) between the raw and treated water in the dry and wet seasons. The quality of the raw water entering the two water treatment plants had some distinct seasonal trends. The raw water quality was better in the wet season at the VWTP. However, in the MTWP the raw water quality was better in the dry season. The hypothesis that there was no difference in the quality of raw and treated water for the dry and wet season was thus rejected. This means that the season does affect the efficiency of water treatment plants.

The second objective was to evaluate the quality of treated water between the water treatment plants and the distribution points in the villages and amongst the villages themselves by season.
The results from both water treatment plants indicated that there was no statistically significant seasonal difference between the water quality produced by the plant and that transmitted to the villages as a whole in each season. This means that there was no post-treatment deterioration of the water quality during transmission. Some studies have shown that the quality of water at the

distribution points relies not only on operating conditions at the treatment plant but also on changes that can occur in the distribution system. The hypothesis that there was no difference in the treated water quality amongst the three selected villages for the dry and wet seasons was thus accepted. Similarly, the treated water quality amongst the distribution points in the villages was not statistically significant in the dry and wet seasons. This means that season does not impact the treated water quality amongst the distribution points in the villages. The observed variations (although not statistically significant) might be due to deposit accumulation in pipes, pipe corrosion, and chemical reactions in the water during times of intermittent or no water supply. The hypothesis that states that season does not impact the treated water quality amongst the distribution points in the villages were thus accepted.

The third objective was to determine the level of compliance of the treated water quality with the appropriate standards recommended for domestic use. This was achieved by comparing water quality parameters with the SANS 241, DWA, and WHO water quality guidelines. The results show that electrical conductivity, pH, fluoride, TDS, sulfate, *E. coli,* and total coliforms fell within the SANS 241 and WHO drinking water quality limits during the wet and dry seasons for treated water both at the plants and villages. However, free chlorine, turbidity, iron, and manganese exceeded WHO standards limits during the wet seasons for treated water at the plants. Similarly, the values for iron were above the WHO maximum permissible limit for treated water at Tap 2 and 3 for the MWTP. A comparison of the water quality in the villages with the SANS 241 standards revealed that regardless of the noted changes in the water during transmission, the water quality was still within the expected standards, according to the SANS 241. An exception was the value of free chlorine, which was lower than the WHO guidelines for both the treated water at the plant and in the villages in both seasons. Similarly, the turbidity of the treated water in the villages during the wet season was higher than the WHO guidelines, although it met the requirements of the SANS 214 standards. This was due to the fact that the standards are not uniform as they tend to differ in some aspects.

The fourth objective was to examine the operational practices at the water treatment plants to obtain information about their performance. Both water treatment plants were operating below design capacity. Although the water treatment plants were mostly performing well in terms of the water treatment process, poor management of chemicals, process monitoring and equipment repairs were observed. The study also found that most of the operators and supervisors surveyed did not have specific skills or training on water treatment and water reticulation. This can impact water treatment processes negatively.

The last objective was to assess consumer perception about water quality. Understanding consumer perceptions of tap water quality is important as it can contribute to improvements in water quality management and consumer satisfaction. The majority of the surveyed households indicated that they were generally satisfied with water quality. However, one major problem was the intermittency of the water supply and irregular water pressure.

The overall conclusion emerging from this study is that the operational efficiency of the investigated water treatment plants in the Vhembe District Municipality was affected by several challenges that include: inadequate use of chemicals, poor process monitoring, equipment repairs, and inadequate training and skills levels of the plant operators. The operational efficiency of each treatment process in a water treatment plant is important to ensure that the unit's performance is successful in removing pollutants in the treated water. However water treatment was able to treat water and meet the standards. This was achieved by comparing the raw water and treated water. It was found that all the pollutant that was found on raw water were removed. The water that was produced and distributed by the two plants generally meets the set standards. An exception was the value of free chlorine, which was lower than the WHO guidelines for both the treated water at the plant and in the villages in both seasons. However, the observed variations might be due to deposit accumulation in pipes, pipe corrosion, and chemical reactions in the water during times of intermittent or no water supply, which is a common problem in the study areas. This study revealed that monitoring of water quality is essential to ensure adequate free chlorine residual at the consumer end. Public response was quite interesting as revealed by the questionnaire survey. People were satisfied with water quality. However, one major problem was the intermittency of the water supply and irregular water pressure. The result of this study may help the Municipality to take appropriate action concerning appropriate chlorination practices in the area.

5.3. Recommendations

The study offers the following recommendations to the district municipality and other researchers.

To the district municipality:

- Although the water quality was generally of acceptable quality, there is a need for continuous monitoring of the water treatment processes to address any challenges on time. Similarly, there is a need for continuous maintenance of the equipment. The above will have a positive impact on selected water quality parameters that were found to be not meeting some selected parameter guidelines.
- Most of the operators and supervisors interviewed did not have enough technical skills in water treatment and water reticulation. There is a need for the district municipality to enhance the technical level of the plant managers and operators at each plant. This can go a long way to improve the operational practices at each plant.
- The available water quality data for this research did not include tests for levels of heavy metals and Total Organic Carbon concentrations. The monitoring program for water quality in the district should consider including heavy metals and Total Organic Carbon concentrations as they are some of the water quality challenges countrywide.

For further research:

- Due to the budgetary constraints for sample analyses, the study used secondary water quality data produced and kept by the water treatment plants. This data is readily available. However, future studies should consider within the constraints of available funds, to undertake their own water sampling and analysis. This will provide a more independent water quality assessment as it does not depend on the data produced by the same plants being assessed.

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APPENDICES

APPENDIX 1: Water Analysis Procedures

The physical analysis was performed on-site by measuring the pH, total dissolved solids (TDS), and electrical conductivity (EC) with a multi-meter (PCSTestr 35, Eutech Instruments Pte Ltd, Singapore). The multi-meter, as well as the measurement beaker, were cleaned with distilled water and rinsed with the specific water sample before the measurements were taken.

The procedure that was followed to measure pH

1. The probe and meter were calibrated according to the manufacturer's directions using two buffers (pH 4 and 7).
2. Sample water was collected in a plastic container. Enough sample water was collected, so that the tip of the probe was submerged. The probe was rinsed before it was placed in the sample.
3. The probe was placed in the sample until the meter equilibrates. The meter would have come to equilibrium when the signal becomes steady. If it takes a long time to equilibrate, the probe was gently stirred. However, it should not agitate the sample since it causes changes in the pH.
4. The pH was directly read from the meter.

The procedure that was followed to measure electrical conductivity (EC)

1. The EC probe was rinsed with one or more portions of the sample.
2. The EC meter was immersed in the water sample. The EC meter was immersed only up to the level indicated in the instructions.
3. The sample water with the EC meter was slightly stirred.
4. The reading was taken after the reading has stabilized.

The procedure that was followed to measure total dissolved solids (TDS)

1. The TDS probe was rinsed with one or more portions of the sample.
2. The TDS meter was immersed in the water sample. The TDS meter was immersed only up to the level indicated in the instructions.
3. The sample water with the TDS meter was slightly stirred.
4. The reading was taken after the reading has stabilized.

The procedure that was followed to measure turbidity

The collected data was used to check the cloudiness of water. Turbidity was measured using a turbidity meter instrument called Orion Aquafast II

Procedure

1. The turbidity meter was calibrated for use according to the manufacturer's directions.
2. The turbidity standards which were provided with the meter were used to calibrate it. That has made sure that the readings were accurate.
3. The sample was shaken vigorously until the bubbles have disappeared. The sides of the bottle were tapped gently to accelerate the process.
4. A lint-free cloth was used to wipe the outside of the tube into which the sample was poured. It was made sure that the tube below the line where the light was passing when the tube was placed in the meter was not handled.
5. The sample water was poured into the tube. Any drops on the outside of the tube were wiped.
6. The meter for the appropriate turbidity range was set. The tube in the meter was placed and read the turbidity measurement directly from the meter displayed.
7. The result of the lab sheet was recorded.

Steps 3-7 for each sample were repeated.

The chemical analysis was done in the laboratory at the Sibasa laboratory. The concentrations of free chlorine (method 8021), fluoride (8029), iron (8147) manganese

(8149) were measured using the Hach Lange DR 2800 spectrophotometer as per the manufacturer's instructions (Hach Company, 2007).

The procedure that was followed to measure free chlorine

Following the manufacturer's instructions 8021 (Hach Company, 2007)

1. Fill a square sample cell with 10 mL of sample
2. Wipe the blank and insert it into the cell holder with the fill line facing right.
3. Press ZERO. The display will show: 0.00 mg/L Cl
4. Fill a second square cell with 10 mL of sample. Add the contents of one DPD Free Chlorine Powder Pillow to the sample cell
5. Swirl the sample cell for 20 seconds to mix. The pink colour will develop if chlorine is present. Proceed to step 6 immediately
6. Within one minute of adding the reagent, insert the prepared sample into the cell holder with the fill line facing right. Press READ. Results are in mg/L Cl2

The procedure that was followed to measure fluoride

The analysis of the fluoride levels in the samples was done according to the manufacturer's instructions (Hach Company, 2007).

1. Insert Adapter B. Install the Pour-Thru Cell with the 1-inch pathlength in line with the adapter arrow.
2. Flush the Pour-Thru Cell with 50 mL of deionized water.
3. Rinse two clean 125-mL Erlenmeyer flasks with the sample three times
4. Rinse a clean 50-mL plastic graduated cylinder three times with the sample.
5. Fill the rinsed cylinder to the 50-mL mark with sample
6. Pour the contents of the 50-mL cylinder into one of the flasks.
7. Add 1.0 mL of FerroZine Iron Reagent Solution to one of the flasks using the Repipet Dispenser. Swirl to mix
8. Measure a second 50 mL portion of the sample into the graduated cylinder and pour the contents into the second flask.

9. A five-minute reaction period will begin.
10. When the timer expires, the display will show: mg/L Fe Pour the contents of the flask containing the blank into the Pour-Thru Ce
11. When the flow stops, press ZERO. The display will show: 0.000 mg/L Fe
12. Pour the contents of the flask containing the prepared sample into the Pour-Thru Cell.
13. When the flow stops, press READ. Results are in mg/L Fe
14. Flush the Pour-Thru Cell with at least 50 mL of deionized water immediately after use.

The procedure that was followed to measure manganese

The analysis of manganese levels in the samples was done according to the manufacturer's instructions (Hach Company, 2007).

1. Pour 10.0 mL of deionized water into a square sample cell.
2. Pour 10.0 mL of sample into another square sample cell.
3. Add the contents of one Ascorbic Acid Powder Pillow to each cell. Stopper and invert to dissolve the powder
4. Add 12 drops of Alkaline-Cyanide Reagent Solution to each cell. Swirl gently to mix. A cloudy solution may form. The turbidity should dissipate after step 5
5. Add 12 drops of PAN Indicator Solution, 0.1%, to each sample cell. Swirl gently to mix. The orange colour will develop in the sample if manganese is present.
6. A two-minute reaction period will begin
7. When the timer expires, wipe the blank and insert it into the cell holder with the fill line facing right.
8. Press ZERO. The display will show: 0.000 mg/L M
9. Wipe the prepared sample and insert it into the cell holder with the fill line facing right.
10. The results are in mg/L Mn.

The procedure that was followed to measure sulfate

The analysis of sulfate levels in the samples was done according to the manufacturer's instructions (Hach Company, 2007).

1. Fill a square sample cell with 10 mL of sample.
2. Add the contents of one SulfaVer 4 Reagent Powder Pillow to the sample cell. Swirl vigorously to dissolve the powder. White turbidity will form if sulfate is present.
3. A five-minute reaction period will begin. Do not disturb the cell during this time.
4. Fill a second square sample cell with 10 mL of sample.
5. When the timer expires, insert the blank into the cell holder with the fill line facing right. Press ZERO. The display will show 0 mg/L SO4
6. Within five minutes after the timer expires, insert the prepared sample into the cell holder with the fill line facing right. Press READ. Results are in mg/L SO4 2–. Clean sample c

The procedure that was followed to analyse for total coliform and E.Coli

Total Coliform and E.Coli were measured using Defined Substrate Technology (DST). DST is used for the bacteriological analysis of the water samples (Ediberg, 1991). The microbiological water quality parameters Total coliforms and E. coli bacteria are used to determine the general hygienic quality of water and to evaluate the efficiency of treatment procedures. Water samples are taken using 500ml labeled sterilized bottles from each sampling point. Labeled samples are transported to the Sibasa laboratory within 24 hours using a cool box container with ice bricks maintaining temperature (2-8°C). Water samples of IDEXX Colilert are incubated for 22 hours at 37uC and 41uC, respectively. After incubation, any fecal coliforms that will have grown to form colonies can be seen with the naked eye and counted. Total coliform is determined visually by identifying all test wells that turned yellow and subsequently, the Most Probable Number (MPN) is determined by counting the number of test wells that showed yellow colour. After determining the MPN, put all the IDEXX Colilert Quanti-Tray plates individually under a long wave (366 nm) ultraviolet light to detect any wells that had fluorescence. Count the yellow wells that fluoresced to determine the MPN for *E. coli.*

APPENDIX 2:

Dry season mean and standard deviation of treated water parameters of the Vondo Water Treatment Plant and each tap (Taps 1, 2, and 3) supplied by the plant.

	Plant	**Tap1**	**Tap 2**	**Tap 3**	**Guidelines**		
Parameter	**Mean±Std**	**Mean±Std**	**Mean±Std**	**Mean±Std**	**WHO**	**SANS 241**	**DWA**
Electrical conductivity mS/m)	0.249±0.193	0.1387±0.192	0.159±0.177	0.025±0.004	≥170	≥170	≥170
Free chlorine (mg/L)	0.133±0.063	0.103±0.029	0.406±0.445	0.170±0.156	0.5-1.5	≤5	0.2
pH (pH units)	6.697±0.514	6.267±0.947	6.657±0.439	7.067±0.704	6.5-8.5	5.0-9.7	6.0-9.0
Turbidity (NTU)	0.687±0.023	0.817±0.029	0.630±0.036	0.627±0.375	1.3	≤5	≤5
Fluoride (mg/L)	0.223±0.058	0.243±0,202	0.140±0.096	0.417±0.352	1.5 l	≤1.5	≤1.5 l
Iron (mg/L)	0.053±0.040	0.043±0.023	0.080±0.026	0.053±0.005	0.3	≤3	0.3
Manganese (mg/L)	0.002±0.001	0.001±0,001	0.007±16.239	0.038±0.062	0.5	0.4	0.1
Total dissolved solids (mg/L)	17.230±0.968	15.116±2.64	25.010±0.577	13.093±0.352	1000	≤1000	≤1200
Sulfate (mg/L)	0.00±0.000	0.00±0.000	0.33±0.000	0.00±0.000	1000	≤5000	≤250
E-coli per 100 mL	0.00±0.000	0.00±0.000	0.00±0.000	0.00±0.000	Absent	Not detected	0
Total coliforms/100 mL	0.00±0.000	0.00±0.000	0.000±0.000	0.00±0.000	Absent	≤10	≤10

APPENDIX 3:

Wet season mean and standard deviation of treated water parameters of the Vondo Water Treatment Plant and each tap (Taps 1, 2 and 3) supplied by the plant

Parameter	**Plant**	**Tap1**	**Tap 2**	**Tap 3**	**Guidelines**		
	Mean±Std	**Mean±Std**	**Mean±Std**	**Mean±Std**	**WHO**	**SANS 241**	**DWA**
Electrical conductivity (mS/m)	0.025±0.005	0,029±0.019	0.038±0.013	0.047±0.036	≥170	≥170	≥170
Free chlorine (mg/L)	0.330±0.317	0,128±0.098	0.232±0.252	0.260±0.311	0.5-1.5	≤5	0.2
pH (pH units)	6.940±0.699	6.676±0.484	6.710±0.774	7.072±0.935	6.5-8.5	5.0-9.7	6.0-9.0
Turbidity (NTU)	1.184±0.611	1.268±0.467	2.756±1.271	3.634±2.799	1.3	≤5	≤5
Fluoride (mg/L)	0.180±0.177	0.140±0.1078	0.160±0.122	0.328±0.176	1.5	≤1.5	≤1.5
Iron (mg/L)	0.116±0.061	0.120±0.0721	0.116±0.121	0.148±0.133	0.3	≤3	0.3
Manganese (mg/L)	0.230±0.163	0.147±0.178	0.058±0.058	0.068±0.091	0.5	0.4	0.1 l
Total dissolved solids (mg/L)	13.582±0.612	23.094±13.782	27.040±15.745	21.798±13.404	1000	≤1000	≤1200
Sulfate (mg/L)	0.00±0.000	0.00±0.000	0.00±0.000	0.20±0.447	1000	≤5000	≤250
E-coli per 100 mL	0.000±0.000	0.000±0.000	0.000±0.000	0.00±0.000	Absent	Not detected	0
Total coliforms/100 mL	0.000±0.000	0.000±0.000	0.000±0.000	0.00±0.000	Absent	≤10	≤10

APPENDIX 4:

Dry season mean and standard deviation of treated water parameters of the Mutale Water Treatment Plant and each tap (Taps 1, 2 and 3) supplied by the plant

Parameter	Plant	Tap1	Tap 2	Tap 3	Guidelines		
	Mean±Std Deviation	Mean±Std Deviation	Mean±St Deviation	Mean±Std Deviation	WHO	SANS 241	DWA
Electrical conductivity (mS/m)	0.039±0.002	0.035±0.005	0.040±0.000	0.033±0.012	≥170	≥170	≥170
Free chlorine (mg/L)	0.087±0.076	0.063±0.055	0.437±0.458	0.140±0.140	0.5-1.5	≤5	0.2
pH (pH units)	6.933±0.489	7.377±0.309	7.370±0.140	7.373±0.389	6.5-8.5	5.0-9.7	6.0-9.0
Turbidity (NTU)	0.870±0.450	1.323±0.694	1.957±1.144	0.887±0.350	1.3	≤5	≤5
Fluoride (mg/L)	0.213±0.097	0.320±0.036	0.137±0.100	0.323±0.261	1.5	≤1.5 l	≤1.5
Iron (mg/L)	0.097±0.083	0.110±0.085	0.093±0.015	0.247±0.217	0.3	≤3	0.3
Manganese (mg/L)	0.171±0.293	0.037±0.063	0.055±0.056	0.317±0.539	0.5	0.4	0.1
Total dissolved solids (mg/L)	17.673±0.869	16.680±2.679	26.820±14.536	16.910±3.561	1000	≤1000	≤1200
Sulfate (mg/L)	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	1000	≤5000	≤250
E-coli per 100 mL	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	Absent	Not detected	0
Total coliforms/100 mL	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	Absent	≤10	≤10

APPENDIX 5:

Wet season mean and standard deviation of treated water parameters of the Mutale Water Treatment Plant and each tap (Taps 1, 2 and 3) supplied by the plant

Wet season							
Parameter	**Plant**	**Tap1**	**Tap 2**	**Tap 3**	**Guidelines**		
	Mean±Std	**Mean±Std**	**Mean±Std**	**Mean±Std**	**WHO**	**SANS 241**	**DWA**
Electrical conductivity (mS/m)	0.042±0.013	0.044±0.009	0.042±0.008	0.038±0.011	≥170	≥170	≥170
Free chlorine (mg/L)	0.604±0.437	0.194±0.154	0.506±0.278	0.344±0.187	0.5-1.5 l	≤5	0.2
pH (pH units)	6.784±0.435	6.684±0.529	6.800±0.420	6.840±0.385	6.5-8.5	5.0-9.7	6.0-9.0
Turbidity (NTU)	10.086±11.166	3.542±3.957	10.828±10.454	3.518±1.670	1.3	≤5	≤5
Fluoride (mg/L)	0.154±0.150	0.182±0.074	0.240±0.213	0.232±0.118	1.5	≤1.5	≤1.5
Iron (mg/L)	0.544±0.345	0.222±0.097	0.458±0.236	0.510±0.351	0.3	≤3	0.3
Manganese (mg/L)	0.020±0.019	0.086±0.108	0.064±0.066	0.030±0.037	0.5	0.4	0.1
Total dissolved solids (mg/L)	21.680±4.194	23.464±4.967	21.046±4.435	20.938±4.441	1000	≤1000 /	≤1200
Sulfate (mg/L)	0.000±0.000	0.00±0.000	0.000±0.000	0.000±0.000	1000	≤5000	≤250
E-coli per 100 mL	0.000±0.000	0.00±0.000	0.000±0.000	0.000±0.000	Absent	Not detected	0
Total coliforms/100 mL	0.000±0.000	0.00±0.000	0.000±0.000	0.000±0.000	Absent	≤10	≤10

APPENDIX 6:

Questionnaire survey for water treatment plant operators

<table>
<tr><td colspan="2">Qualification of plant operator</td><td colspan="4"></td></tr>
<tr><td colspan="2" rowspan="2">Experience of plant operator</td><td><5</td><td colspan="2">5-10</td><td>11+</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="2">Name of the plant</td><td colspan="4"></td></tr>
<tr><td colspan="2">Year constructed</td><td colspan="4"></td></tr>
<tr><td colspan="2">Year upgraded</td><td colspan="4"></td></tr>
<tr><td colspan="2">Plant capacity</td><td colspan="4"></td></tr>
<tr><td colspan="2">Description of upgraded</td><td colspan="4"></td></tr>
<tr><td colspan="2">Design capacity</td><td colspan="4"></td></tr>
<tr><td colspan="2">Raw water source</td><td colspan="4"></td></tr>
<tr><td colspan="2">How do you abstract water from the source to the treatment plant?</td><td colspan="4"></td></tr>
<tr><td colspan="2">What is the capacity of the pump that you use to abstract water from the River to the treatment plant? (flow)</td><td colspan="4"></td></tr>
<tr><td colspan="2">Abstraction method</td><td colspan="4"></td></tr>
<tr><td colspan="2" rowspan="2">Do you monitor water quality</td><td colspan="2">Yes</td><td colspan="2">No</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Parameter</td><td>Raw water</td><td colspan="2">Treaded water</td><td colspan="2">Final water tap</td></tr>
<tr><td>pH</td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Turbidity</td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Free chlorine</td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Total chorine</td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Fecal coliform</td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Total coliform</td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Other (specify)</td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

How is the water from the Water Treatment Plant supplied to the communities?		
Which communities (villages) receive water from the Water Treatment Plant?		
How much water does the Water Treatment Plant supply to each village?		
Does the water supply meet the demand	yes	No
How much water is required (demand) by each village?		
Do the communities (villages) complain about the amount and quality of water you supply to them?		
What are the problems that make it difficult for the water treatment plant not to supply enough water or produce water of good quality?		
Do you experience any water losses in the treatment plant?		
Do you have any problems with the supply of chemicals and equipment for water treatment?		
Is there any problem with the volume of water abstracted from River?		
Is there any alternative source of water?		
How do you manage the water treatment plant?		
Is there any problem with the management of the plant?		
What are the current challenges facing for water treatment plant?		
Is the reservoir clean?	yes	No
When last did you clean it?		

APPENDIX 7:

Questionnaire survey on consumer perception about water quality

1.Area of the house:				
2.Gender of respondent	a. Female	b. Male		
3.Age of respondent (yrs)	a. 18-29	b. 30-39	c. 40-49	d. 50+
4. Number of people living in the household?	a.<3	b. 4-5	c. 6-8	d. >8
5.ownership of the house	a. Owned	b. Rented		
	c. Rent-free	d. other		
6. Where do you get the water you use at home?	a. Household tap	b. Rainwater collection		
	c. Private tap in the yard (borehole)	d. River/Stream		
	e. Public/shared standpipe	f. Neighbour's tap		
	g. Spring	h. Refilling Station		
	i. Purchased bottled water	j. Other (*specify*		
7. Does the tap provide water 24 hours a day?	Yes	No	No tap	
8. If no, indicate much time on average are you *without* water?	Hours per day	Days per week	Weeks per month	
9. Are there times when the water pressure is low?	Yes	No		
10. Have there been periods in the past year with no tap water service for several days at a time?	Yes	No		
11. where do you get your water? When there is no water or the pressure is low	a. Water stored in the tank.	b. Purchase bottled water		
	c. Water stored in drum or bucket	d. Receive trucked water		
	e. Rainwater	f. Do nothing/wait for the water to return		
	g. Well	h. Creek/river/spring		
	i. Other (*specify*):			
12. Do you consider your water shortages to be a …?	a. Big problem	b. Somewhat of a problem	c. No problem	
13. Do you have a water storage tank?	Yes	No		

14. If Yes is tank…	a. Elevated	b. Ground-level	c. Underground

15. When the last time your tank was cleaned?	a. <3 months	b. 3-12 months
	c. 1-5 yrs.	d. . >5 yrs
	e. never	f. Don't know
17. Do you think that the water from your tap is safe to drink?	a. Yes (always/most of the time)	b. No
	c. Not sure/sometimes	d. No tap
18. If not Yes, why not?	a. Water's appearance (dirty/cloudy/color/particles)	b. Bugs/worms/bacteria
	c. Chemical or pesticide contamination (do not include chlorine)	d. Too much chlorine
	e. Tastes or smells bad (incl. chlorine) … of what? …….	f. Makes me ill/bothers stomach
	g. Heard through media coverage or word of mouth	h. Other (sp*ecify*) ____________________

19. Do you usually treat your drinking water at home?	a. Boil	b. Filter	c. Add chlorine or bleach
	d. Solar disinfection	e. Other (*specify)*	

20. Do you normally keep drinking water in a drinking water container?	Yes	No

21. In what kind of container do you usually preserve your drinking water?	a. Closed container (e.g., bottle, narrow-neck jug)	b. Open container (e.g, bucket, pan)
	c. Other (*specify*)	

21. Does the water quality differ in the dry and wet seasons?	Yes	No
22. If yes How so?		
In which season are the water quality problems worst? Tick box	Dry season (March-October)	Wet season (November -February)

Name the specific water quality problem in each season		

Thank you very much for taking part in this interview.

APPENDIX 8:

Letter from North West University to the water treatment plants requesting for permission to undertake the study**.**

NORTH-WEST UNIVERSITY ®
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
MAFIKENG CAMPUS

Geography and Environmental Sciences
Private Bag X2046, Mmabatho
South Africa, 2735
Tel: +2718 389-2357
Fax: +2718 392-2637
Email: munyaradzi.manjoro@nwu.ac.za

08 November 2017,

TO WHOM IT MAY CONCERN

Dear Sir/Madam

RE: REQUEST TO UNDETAKE A STUDY ON WATER TREAMENT PLANTS

Miss Masindi Fhatuwani (student number: 29888999) is doing a Master of Science degree in Environmental Sciences and Management at the North-West University, Mafikeng Campus. Her research proposal has been approved by the department on the following topic: Assessment of the efficiency of water treatment plants in Vhembe District, South Africa. The specific objectives of the study are:

1. To examine the operational practices at the water treatment plants to obtain information about the routine practices and their performance.
2. To evaluate the quality of raw and treated water at the water treatment plants;
3. To determine the level of compliance of the water quality with the appropriate standards recommended for domestic use

To undertake the study Miss Masindi will need to interview the authorities at the water treatments plants or any other relevant personnel in order to understand the design capacity of the plant, the number of villages that the plant supplies water, where water is abstracted, the type of data monitoring data available and any other relevant issues. She will also need to collect at each selected water treatment plant raw and treated water samples for laboratory analysis. This will be done monthly between November 2017 and October 2018.

This study will benefit the municipality as it envisages monitoring water quality and identifying any challenges that need to be addressed. The study is only for academic purposes and the outcomes will be communicated to the municipality.

Please kindly allow Miss Masindi access to you facilities and personnel. Your assistance will be highly appreciated.

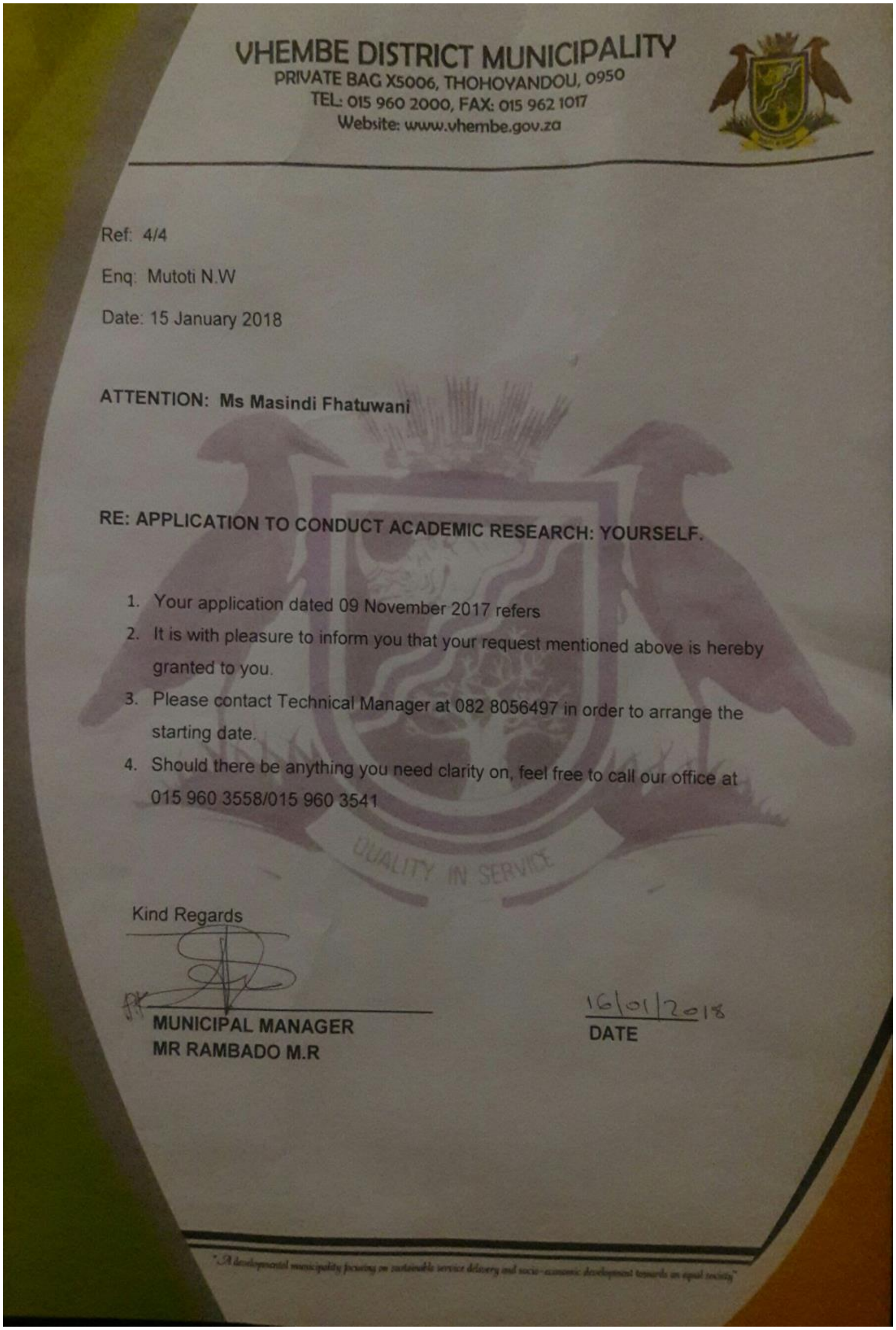
Yours Sincerely,

M. Manjoro (BScEd, BSc.Hons, MSc.PhD)
Head of Department and study supervisor

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
MAFIKENG CAMPUS
OFFICIAL
09 -11- 2017
Tel:018 389 2051/2317 Fax:018 389 2052
FACULTY OF NATURAL & AGRICULTURAL SCIENCES
OFFICE OF THE DEPUTY DEAN

APPENDIX 9:

Letter from Vhembe District Municipality granting permission to undertake the study.



VHEMBE DISTRICT MUNICIPALITY
PRIVATE BAG X5006, THOHOYANDOU, 0950
TEL: 015 960 2000, FAX: 015 962 1017
Website: www.vhembe.gov.za

Ref: 4/4

Enq: Mutoti N.W

Date: 15 January 2018

ATTENTION: Ms Masindi Fhatuwani

RE: APPLICATION TO CONDUCT ACADEMIC RESEARCH: YOURSELF.

1. Your application dated 09 November 2017 refers
2. It is with pleasure to inform you that your request mentioned above is hereby granted to you.
3. Please contact Technical Manager at 082 8056497 in order to arrange the starting date.
4. Should there be anything you need clarity on, feel free to call our office at 015 960 3558/015 960 3541

QUALITY IN SERVICE

Kind Regards

MUNICIPAL MANAGER
MR RAMBADO M.R

16/01/2018
DATE

"A developmental municipality focusing on sustainable service delivery and socio-economic development towards an equal society"

APPENDIX 10:

Letter to the head of the village asking for permission to undertake the study.

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Geography and Environmental Sciences
Private Bag X2046, Mmabatho
South Africa, 2735
Tel: +2718 389-2357
Fax: +2718 392-2637
Email: munyaradzi.manjoro@nwu.ac.za
Web: http://www.nwu.ac.za

29 March 2019,

TO WHOM IT MAY CONCERN

Dear Sir/Madam

RE: REQUEST TO CONDUCT QUESTIONNAIRE INTERVIEWS ON WATER QUALITY IN VHEMBE DISTRICT MUNICIPALITY

Miss Fhatuwani Masindi (student number 29888999) is doing a Master of Science degree in Environmental Sciences and Management at the North-West University, Mafikeng campus. Her research topic is: Assessment of the efficiency of water treatment plants In Vhembe District Municipality, South Africa, a case study at Mutale and Vondo water treatment plants. Miss Masindi has the permission to undertake the study from the district municipality.

Two of the objectives of her study is:

- To evaluate whether there is any differences in the water quality between the treatment plant and selected distributions points in the villages supplied by the plants;
- To assess the end user perception of the water quality

To achieve these objectives Miss Masindi will need to interview the water consumers in the selected villages supplied by the two named water treatment plants. Interviews will also help a student to understand the challenges that the community is facing through the supply of water from water treatment plant. This study will benefit the municipality as it envisages monitoring water quality and identifying any challenges that need to be addressed.

The study is only for academic purposes and the anonymity of respondents will be protected. I will be grateful if you can allow the above named student to undertake the interviews in your area.

With regards,

M. Manjoro (BScEd, BSc.Hons, MSc.PhD)
Senior Lecturer and research supervisor

NORTHWEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES UNIVERSITEIT
MAFIKENG CAMPUS
OFFICIAL
28 -03- 2019
Tel:(018 389 2344/2027 Fax:(018)389 2377/2062
SCHOOL OF GEO & SPATIAL SCIENCES
DIRECTOR'S OFFICE