Assessment of physico-chemical properties and heavy metal contents from the Middelburg Dam in Steve Tshwete Municipality, Mpumalanga

by

MAPYANE CLIFF MALATJIE

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SUPERVISOR: Ms T N Mhlongo

CO-SUPERVISOR: Ms M D Matlala

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DEDICATION

To Yahweh

DECLARATION

I, Mapyane Cliff Malatjie hereby declare that the dissertation, with the title: Assessment of physico-chemical properties and heavy metal contents from the Middelburg Dam in Steve Tshwete Municipality, Mpumalanga which I hereby submit for the degree of Master's in Environmental Management at the University of South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

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I declare that during my study I adhered to the Research Ethics Policy of the University of South Africa, received ethics approval for the duration of my study prior to the commencement of data gathering, and have not acted outside the approval conditions.

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PREFACE AND ACKNOWLEDGEMENTS

This study was conducted by assessing physico-chemical properties and heavy metal contents of the Middelburg Dam in Steve Tshwete Municipality in Mpumalanga to understand the water quality of the dam, before and after treatment. Recommendations for improving water quality are provided in the study.

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ABSTRACT

Poor water quality is a global concern as water contaminated with high levels of both physico-chemical parameters and heavy metals has serious effects on both human health and the environment. Surface water quality is mainly affected by changes in physico-chemical parameters and heavy metals which mostly find their way into the water bodies through anthropogenic activities causing deterioration of the quality of water in the receiving water bodies. The consumption of polluted surface water with poor quality contributes to many waterborne related illnesses and also shows detrimental effects on aquatic life. The study aimed at utilising historical data in analysing physico-chemical properties of water quality and determining the presence and concentrations of heavy metals in water in the Middelburg dam, before and after treatment. A total of ten (10) sampling points were selected between raw water from the dam and water that is consumed after treatment, where both physico-chemical parameters as well as heavy metals were assessed.

The results suggested that the mean values and mean concentrations of physico-chemical parameters such as pH, turbidity, electrical conductivity, true colour, free chloride, nitrate, nitrite, fluoride, chloride, sodium, and total dissolved solids (except for sulfate) for all ten sites were within the acceptable limits of South African Standard for drinking water (SANS 241:2015). The mean concentrations of sulfate at all sampling points were above 250 mg/l, associated with aesthetic risk, while a mean concentration above 500 mg/l was in the raw water from the Middelburg Dam. Calcium, magnesium, and potassium mean concentrations for all the sampling points were also within the acceptable limits. The mean concentrations for alkalinity were very low (less than 150 mg/L) for all sampling points, which indicated that the water was corrosive, and this is related to acidity while the mean concentrations for total hardness were high (greater than 200 mg/L) indicating hard water. Aluminium and iron mean concentrations for all the sampling points were within the acceptable limits. The mean concentrations of manganese were higher at the water treatment plant and the reservoirs and slightly higher at most sampling points (above the limit of $\leq$ 0.1 mg/L), associated with aesthetic risk. The high levels of sulfate suggest pollution of water by activities such as coal mining. The levels of manganese suggest a considerable pollution of water with steel production and mining activities. The findings of the study can be used in Steve Tshwete Local Municipality and in any other area with the same environmental conditions by national authorities and policy makers in designing suitable strategies and approaches for water quality management. Moreover, the study recommends an in-depth analysis of the impacts of mining and other anthropogenic activities on the Middelburg dam and Klein-Olifants River catchment.

All the studied physicochemical parameters and metal concentrations were within the permissible limits, so this was an indication that the current water treatment processes used by the municipality were effective.

Keywords: Water quality, Physico-chemical parameters, Heavy metals, Middelburg dam, Steve Tshwete Local Municipality

ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectroscopy
APHA	American Public Health Association
Al	Aluminium
Ca	Calcium
$CaCO_3$	Calcium Carbonate
Cd	Cadmium
COD	Chemical Oxygen Demand
Cr	Chromium
Cu	Copper
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EPA	Environmental Protection Agency
Fe	Iron
HCl	Hydrochloric Acid
Hg	Mercury
HNO_3	Nitric acid
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
Ni	Nickel
Pb	Lead
SANS	South African National Standard
TDS	Total Dissolved Solids
TSS	Total Suspended Solids

Ti	Titanium
UN-MOGs	United Nations Millennium Development Goals
UN-SDGs	United Nations Sustainable Development Goals
USA	United States of America
V	Vanadium
WHO	World Health Organisation
WISA	Water Institute of South Africa
WTP	Water Treatment Plant
WWTW	Waste Water Treatment Works
Zn	Zinc
Zr	Zirconium

DEFINITIONS

Terms which are used in the study are defined below according to how they are used in this study.

Fertiliser: any synthetic inorganic material that is used to enhance plant growth by supplying nutrients such as nitrogen and phosphorus.

Non - point source pollution: refers to the contamination that occurs when rainwater, snowmelts, or irrigation washes off ploughed fields and city streets.

Pesticides: in this study refers to all chemicals that are used to control or kill pests such as herbicides, insecticides, nematodes, and rodenticides.

Water Contamination: the reduction of possible usefulness of water by chemical solutes present in water above concentrations determined by national or international standards for potable, industrial, recreational, and other use

Water Quality: is the term that is mainly used to describe the chemical, physical and the biological characteristics of water

Water Pollution: is the contamination of water bodies (e.g. lakes, rivers, oceans, aquifers, and groundwater).

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CHAPTER 1 INTRODUCTION

1.1 Background

Poor water quality has become a problem worldwide as the quality of water is deteriorating due to high levels of both physico-chemical properties and heavy metal contents (Su *et al.*, 2017). Physico-chemical properties such as elevated concentrations of alkalinity, chloride, temperature, hardness and dissolved oxygen; as well as the presence of high concentrations of heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), zinc (Zn), mercury (Hg) and copper (Cu), are all responsible for poor water quality (Gupta, Bhatnagar and Bakre, 2016).

Exposures to high levels of heavy metals such as cadmium, chromium, mercury, zinc, lead, and copper is associated with serious health and environmental problems and some of these heavy metals are not required by any organism even at small quantities, these include metals such as lead, cadmium and mercury (Gupta, Bhatnagar and Bakre, 2016; Kobielska *et al.*, 2018). Exposure to lead even at smaller amounts, poses some serious health risks such as damage to the peripheral nervous system and renal system, colic and constipation; and in children very smaller levels of lead may damage the central nervous system, in some cases may cause coma and death (WHO, 2000). Lead is also capable of affecting the behaviour and intelligence of children (Gupta, Bhatnagar and Bakre, 2016). All heavy metals including essential micronutrients are toxic to humans and aquatic organisms depending on the level and duration of exposure (Gupta, Bhatnagar and Bakre, 2016; Kobielska *et al.*, 2018). Some of these important micronutrients include, zinc, manganese, iron and copper which are known to be very toxic to humans when their intake is over the provisional maximum tolerable daily intake (Kobielska *et al.*, 2018).

Changes in the physico-chemical properties of water contribute to poor water quality (Faiza *et al.*, 2012). This refers to fluctuations in the levels of physico-chemical properties such as, temperature, electrical conductivity, pH, total dissolved solids (TDS), total suspended solids (TSS), alkalinity, sodium, dissolved oxygen, chemical oxygen demand and salinity. These changes affect drinking water quality causing most water borne diseases like diarrhoea (Dhawde *et al.*, 2018). High concentrations of magnesium (Mg) increase alkalinity in a human body which causes gastrointestinal issues and skin irritations. Too much alkalinity also has the ability to disturb the body's normal pH, leading into metabolic alkalosis which may result in nausea, vomiting, hand tremors, muscle twitching, tingling in the extremities of face and confusion (Bouaroudj *et al.*, 2019). Both physico-chemical and heavy metal environmental contaminants find their way into the rivers from domestic, industrial wastewater and agricultural effluents. For example, farms, urban expansion and industrial development are regarded as the main human activities that play a bigger role on poor water quality by being the major contributors to changes in physico-chemical properties and an increase in heavy metals which affect aquatic systems (Su *et al.*, 2017; Bouaroudj *et al.*, 2019).

Eutrophication caused by changes in physico-chemical properties and heavy metal inputs causes the degradation of freshwater ecosystems (Bouaroudj *et al.*, 2019). Untreated wastewater also plays a major role on the degradation of surface water quality by introducing most of these contaminants into aquatic environments, rendering surface water unfit for human consumption and agricultural irrigation (Bouaroudj *et al.*, 2019). Therefore, this study aims at assessing the physico-chemical properties and heavy metal contents of water from the Middelburg Dam, before treatment and after treatment.

1.2 Problem statement and rationale for the study

Pollution of surface water is a global concern, both on the environment and the human health (Kobielska *et al.*, 2018). Poor surface water quality is a very important issue in many countries (Şener, Şener and Davraz, 2017) as it has contributed to so many waterborne related illnesses such as diarrhoea. This illness occurs world-wide and has been responsible for 4% of all deaths and 5% of health loss to disability over the past years. The gastrointestinal infections are behind an estimated 2.2 million people killed globally each year, mostly children in developing countries, and it has the ability to spread from person to person due to poor personal hygiene (WHO, 2000). Both physico-chemical properties and heavy metals, are found in water as a result of human activities and are both adsorbed by aquatic vegetation and they are introduced into the food web (Şener, Şener and Davraz, 2017).

Poor water quality is the result of both changes in physico-chemical properties and high levels of heavy metals which find their way into the water bodies through anthropogenic activities including impacts due to agricultural practices (Dhawde *et al.*, 2018). These anthropogenic activities include both the discharge of domestic waste and untreated waste from sewage treatment plant into water sources, improper disposal of car batteries and plastic materials, disposal of personal care products and household chemicals.

Activities such as mining and construction alters physico-chemical properties in the water sources, they change the pH of water, increase water turbidity, and also raise the total content of total dissolved solids and heavy metals (Dhawde *et al.*, 2018). Mine waste and effluents released into the environment before treatment have the potential of elevating heavy metals and altering physico-chemical properties of water (Gyamfi, Appiah-Adjei and Adjei, 2019). Effluents of mine waste from coal mining with low pH contaminates surface water with high levels of acidity, iron, and sulfate. While acid mine drainage from mine effluents lowers pH in water; inappropriate use of Hg and application of other harmful chemicals in mining activities also play a major role to poor water quality (Gyamfi, Appiah-Adjei and Adjei, 2019).

1.3 Justification or motivation of the study

The Water Services Act 108 of 1997, Chapter 1 (3) states that "everyone has the right of access to basic water supply and basic sanitation". Even though access to clean water has over the years been an area of concern in South Africa, Mpumalanga is amongst provinces facing serious poor water quality. The state of poor water quality in Mpumalanga is due to coal mining and related activities. The study conducted by van Zyl in 1998 in the Olifants River Catchment, has shown that mine water in the Olifants River Catchment in Mpumalanga is at times discharged into the local streams, causing acidification, salination and increased sulfate concentrations on surface water sources (Van Zyl *et al.*, 2001). There have not been any published studies on the status of both the physico-chemical properties and the heavy metal contents of water from the Middelburg Dam, and no published studies have compared the general water quality and heavy metal concentrations before and after treatment of potable water supplied in the Steve Tshwete Local Municipality.

The aim of this study was to analyse the physico-chemical properties as well as to determine the presence and concentrations of heavy metals in the water from the Middleburg Dam, before and after treatment. The results from this study will also be recommended to relevant institutions since the lack of access to a safe water supply and the provision of clean drinking water has immediate and negative consequences on human health and the environment.

Water provision is fundamental for a sustainable livelihood, and the lack of availability of adequate, safe, and affordable water supply; has a negative impact on vulnerable groups such as children, the elderly, and the poor. Safe water limits all the hazards posed by poor water quality. Steve Tshwete Local Municipality will benefit from this study to fulfil the right to safe drinking water for its communities and to ensure that there are innovative new technologies and materials to address challenges associated with the provision of safe potable water.

1.4 Research aim/objectives/research questions

The aim of this study is to analyse the physico-chemical properties as well as to determine the presence and concentrations of heavy metals in water from the Middleburg Dam, before and after treatment.

Objectives

1. To analyse physico-chemical properties and heavy metal concentrations of water from the Middelburg Dam, before and after treatment.

2. To assess changes in physico-chemical properties and heavy metal concentrations from the dam before treatment, after treatment and in the water stored in reservoirs and supplied to households after treatment.

3. To determine if the water quality parameters of the Middelburg dam adhere to national as well as global drinking water quality standards, focusing on the concentrations of Aluminium (Al), Iron (Fe), Manganese (Mn), Calcium (Ca), Magnesium (Mg), and Potassium (K)

Research questions

1. What are the physico-chemical properties and heavy metal concentrations of water from the Middelburg Dam, before and after treatment?

2. Do these concentrations change from raw water that flows into the water treatment plant, from the dam to the water stored in reservoirs and supplied to households after treatment?

3. Are both physico-chemical properties and heavy metal concentrations within permissible national and global limits?

1.5 Structure and outline of the dissertation

Chapter one: Outlines the background, the problem statement, justification, or motivation of the research, and provides research questions and the objectives of the study.

Chapter two: Discusses the literature review. The literature review focuses on poor water quality as a global concern. The chapter further gives details on both physico-chemical properties and heavy metal sources and their associated problems on human health and the environment. The chapter also reviews the anthropogenic activities contributing to adverse water quality, treatment, and removal processes for physico-chemical properties and heavy metals and human health effects due to physico-chemical and heavy metals. Tolerable amounts for physico-chemical properties and heavy metals in drinking water and regulations of physico-chemical and heavy metals are also discussed in this chapter.

Chapter three: Gives a discussion on the research design, the description of the data collection points and the study area. The chapter further explains the statistical data analysis, ethical considerations and methodological assumptions and limitations.

Chapter four: Presents data, gives an interpretation of the results and the chapter further provides a discussion of the results. The interpretations are based on what the graphs display, and the discussion focus on the results in depth.

Chapter five: Covers conclusions and recommendations for improving water quality.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Access to safe drinking water is vital for human health and has proven to be lowering costs due to poor health. Provision of safe drinking water can compensate the costs by undertaking interventions that improve access to safe water which favours rural and urban dwellers and mostly the poor which forms part of poverty alleviation strategies (WHO, 2017). The United Nations General Assembly through the Resolution 64/292, have declared that access to clean, safe drinking water is a basic human right, and an essential step toward improving living standards worldwide (Dinka, 2018; Brown, 2016). Treated drinking water free of high levels of physico-chemical properties and associated with heavy metals contamination is important as these can lead to adverse health problems for human beings (Alam *et al.*, 2017). Without human activities that have contributed to the elevated heavy metals concentrations to levels considered toxic leading to irreversible negative effects on the ecosystems and human health, heavy metals would naturally adapt into water environments when existing in low concentrations (Cruz-Lopes *et al.*, 2021). Developed and developing countries have experienced chemical discharge problems coming from agricultural sources, mines and wastewater treatment plants carrying high levels of heavy metals and physico-chemical properties that do not meet the minimum standard guidelines for safe drinking water (Islam et al., 2021; Masindi, 2018; Sharma and Bhattacharya, 2017). Chemical polluted water causes problems to health.

The review focuses on poor water quality of treated drinking water as a global concern. It also looks at the extent to which the whole world is affected by poor water quality due to the high levels of both physico-chemical properties and heavy metals. The review also provides some context on both physico-chemical properties and heavy metals and their impacts on both human health and the environment and further gives information on how both physico-chemical and heavy metals find their way into the water bodies resulting in poor water quality.

2.2 Water Quality as a global concern

Water quality in the environment is determined by testing and monitoring physical, chemical and biological parameters to indicate how suitable water is for human consumption and other domestic uses (Sajitha and Smitha, 2016). The whole world is facing rapid deterioration in water quality due to water pollution. Human activities are amongst the major contributors of water pollution that has led to the alterations of physical, chemical and biological properties of water leading to adverse effects on human health and the ecosystem (Su *et al.*, 2017; Musingafi & Tom, 2014; Nienie *et al.*, 2017).

A third of the African population has no access to clean water, while almost two-thirds have no access to clean sanitation and this has resulted in most of the people suffering from typhoid, dysentery, and many other diseases (Travails, 2010). Africa is not just suffering the effects upon health only, besides that, the lack of access to clean water has also resulted in a loss of productivity that results from water-related illnesses, and this can be seen as one of the factors that hold back the progress of Africa.

The pollution of water resources is a serious problem in South Africa (SA) and needs to be taken into consideration so that the water quality of these resources remain protected (Nyawo, 2017). Polluted streams also play a major role as main sources of contamination to aquifers, even though most effects of contaminants may not be revealed for a long period of time after they have entered the groundwater system (Su *et al.*, 2017). Amongst other countries, South Africa is well known for being a water-scarce country in which most people in the country depend mainly on surface water resources for survival. The state of surface water quality remains an area of concern in South Africa as most water resources are facing pollution mostly from the sewage treatment works, agriculture, and industrial wastewater that mostly contains heavy metals (Nyawo, 2017).

Similar to what is happening in the whole world the major contributors of water pollution such as municipal waste water, industrial waste, and agricultural runoff, they all play a major role on the pollution of both surface water and groundwater resulting in poor water quality (Su *et al.*, 2017). The current accumulated chemical data in South Africa shows that the state of water quality in the South African water resources is deteriorating (Nyawo, 2017). The deterioration of the state of water quality in the South African water resources is mainly due to the increasing impacts of human development in the country and inadequate management of Waste Water Treatment Works (WWTW) by the municipalities which result in a rapid increase in bacteriological content in water resources while the improper management of the final effluent from the industries leads to a rise in macro and micro chemical content of contaminants in water resources (Ncube, 2014; Nyawo, 2017; Su *et al.*, 2017).

In most developing countries water resources used as a source of water abstraction to water treatment plants are subjected to contamination by wastewater treatment plants discharges, mines, industries and agricultural activities (Khatri & Tyagi, 2015; Edokpayi, et al., 2017; Sharma & Bhattacharya, 2017; Inyinbor *et al.*, 2018; Sasakova *et al.*, 2018). Wastewater coming from agricultural areas contains potential toxic materials that includes heavy metal ions like Cu^{2+}, Pb^{2+}, Mn^{2+}, Zn2+, Ni^{2+}, and Fe^{2+} (Ma *et al.*, 2020).

2.3 Heavy metals sources and their problems

Heavy metals are stable and persistent environmental contaminants that cannot be destroyed or degraded that have adversely contributed to human health problems and the ecosystem including the food chain as they can easily accumulate to toxic levels (Das *et al.*, 2013; Chopra, Pathak and Prasad, 2009). Contamination of water resources with heavy metals is a global concern, and these elements can be found in reservoirs, in the atmosphere and in soil due to mostly human activities. Some of the human activities that introduce the heavy metal contaminants into the water resources include the long-term disposal of untreated and partially treated industrial effluents that contain toxic metal, inappropriate application of fertilizers, and pesticides that contain metals in agricultural activities (Taufique Arefin *et al.*, 2016). The use of polluted water in agricultural activities, application of mineral fertilizers such as phosphates, contaminated manure/fertilizers, sewage sludge, waste incineration, the burning of fossil fuel and road-traffic are the potential sources of heavy metals (Chopra, Pathak and Prasad, 2009).

Metals with a density of over 5 g cm^{-3} such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc are considered heavy metals (Kobielska *et al.*, 2018). Continuous exposure to metal trace elements through consumption of contaminated treated drinking water leads to potential adverse consequences to human health (Sall *et al.*, 2020).

2.4 Physico-chemical properties sources and their problems

Physico-chemical parameters are key in the analysis and monitoring of water quality as it relates to water pollution (Chris and Ekperusi, 2021). Throughout South Africa and the world; the commonly assessed physico-chemical parameters for water quality studies are temperature, pH, total dissolved solids (TDS), and electrical conductivity (EC) (Molale, 2012). Surface water systems in South Africa are mostly affected by higher levels of physico-chemical properties as a result of untreated wastewaters, industrial, agricultural and domestic waste that pours into the surface water systems (Molale, 2012). Humans exposed to polluted water systems often suffer from infections and waterborne diseases and research has also proven that a lot of water-related health problems are caused by microbial and chemical contaminants in the water (Molale, 2012).

Quantification and knowledge of physico-chemical properties are important because they provide a reference point for estimating the extent of pollution in both surface and groundwater (Şener, Şener and Davraz, 2017). The process of quantifying the physico-chemical parameters of water gives an indication of the information regarding the quality, productivity, and sustainability of the water body (O'Reilly, 2012) while the changes in the physico-chemical properties also give information about the impacts of the parameters on the functions and biodiversity of the reservoir or any other water body (O'Reilly, 2012).

It is of importance to understand the effects these parameters have when they are above the allowed permissible limits. Evaluating physico-chemical properties against the South African Water Quality Guidelines and South African National Standards for drinking water compliance is key in finding out if the water quality is fit for the intended purposes in communities. Literature shows that in many countries both surface and groundwater quality has become a very sensitive issue, so there is a need to assess water quality, and to understand the effects of drinking water quality on public health and to other aquatic life (Şener, Şener and Davraz, 2017; Kobielska *et al.*, 2018; Salawu, Sunday and Oloyede, 2018). It is also important to identify and understand all anthropogenic activities affecting water quality since each activity has its different way of affecting water quality.

2.5 Anthropogenic activities contributing to adverse water quality

Water quality is highly affected by anthropogenic activities such as impacts due to agriculture, the application of fertilizers, manures and pesticides, animal husbandry activities, inefficient irrigation practices, deforestation of woods, aquaculture, pollution due to industrial effluents and domestic sewage, mining, and recreational activities (Nitasha Khatri and Tyagi, 2015). In the whole world, these anthropogenic activities all play a major role on the pollution of both surface water and groundwater resulting in poor water quality (Su *et al.*, 2017).

2.5.1 Agricultural activities and their contributions of physico-chemical properties and heavy metals contaminants to drinking water

In Canada and the USA agricultural activities are the major sources of water pollution among other non-point sources such as highways, where stormwater picks up oils, grease, metals, dirt, salts, and other toxic or poisonous materials and introduce them into the water bodies (Ncube, 2014). The use of fertilizers and pesticides in farms as an effort to improve the quality and quantity of products has a major contribution to poor water quality. Most of the applied fertilizers enter into the rivers, dams, and other water bodies resulting in an increase in nutrients such as nitrates which are a potential concern (Edokpayi *et al.*, 2018). Nitrates further give rise to an increase in algal blooms and algal growth in water bodies which kill mostly fish and other organisms as the algae have the ability to use all the available oxygen leaving nothing for the other organisms in that environment. It is evident that mostly in rivers and lakes; agriculture is the leading cause of deterioration of water quality.

The agriculture sector is an important economic activity in South Africa; whereby crop farming, cattle, and game farming are promoted in most of the areas. Research conducted in most of the rivers and dams has shown that agricultural nutrients and farmlands are the top contributors of water pollution making a higher contribution to poor water quality (Effendi and Wardiatno, 2015). Previous studies along the upper catchments of the Olifants Catchment have also shown that fertilizers and pesticides used in agriculture; which find their way into the river system, are contributing significantly to the poor water quality of the catchment as they have the ability to introduce a range of physico-chemical properties and heavy metals into the river system (Schöntag *et al.*, 2015; Zhou, Huang, Gilmore, *et al.*, 2016). Current studies have also proven that the addition or the use of fertilizers/manures in agricultural activities contributes to high levels of Cd in the water bodies (Chopra, Pathak and Prasad, 2009; Li *et al.*, 2021).

Due to excessive or improper use or poorly timed application of fertilizers, the water quality in most rivers is compromised and this also affects water potability and use (Effendi and Wardiatno, 2015). All pesticides are toxic at some level, and research conducted on the water quality of few rivers proved that rivers are being contaminated with pesticides and other chemicals commonly used around homes and gardens (Kumar *et al.*, 2013; Nitasha Khatri and Tyagi, 2015; Schöntag *et al.*, 2015) . Garden chemicals are not only a threat to aquatic life, but they also affect the quality of drinking water. The washing of muddy agricultural tools by farmers leads to such points having the highest turbidity affecting aquatic life (Effendi and Wardiatno, 2015). Non-point pollution sources such as agricultural fields, which are more difficult to control than large point sources, have become the main contributors to water pollution in most of the rivers and on this point improvement in water quality has become more difficult (Chopra, Pathak and Prasad, 2009; Zhou, Huang, Gilmore, *et al.*, 2016; Li *et al.*, 2021).

2.5.2 Industrial activities and their contributions of physico-chemical properties and heavy metals contaminants to drinking water

Mining is likely to contaminate surface water with high levels of acidity, metals, and sulfates (Gyamfi, Appiah-Adjei and Adjei, 2019). Some of the common impacts of mining and industrial activities include increased metal content, salinity, and sediment load. Dewatering around mining operations and migration of polluted subsurface plume from mine workings also have an impact on water quality. Mining and industrial activities can potentially have significant impacts on water quality if effluent release and water use are not appropriately managed. Discharging of untreated effluents and mine wastes directly into the environment also have a great potential of polluting the water sources (Gyamfi, Appiah-Adjei and Adjei, 2019). The extent and nature of impact are specific to the type of mining and industrial activities.

There are a lot of chemical contaminants associated with the return water and effluent from the industries that find their way into the rivers and dams (Taufique Arefin *et al.*, 2016). The increasing metal contaminants that enter the rivers are the result of the disposal of untreated and partially treated industrial effluents containing too many toxic metals. It is understood that the contaminants of the return water and effluent must be below the maximum allowable threshold as regulated by the law, but as the number of industries release into the same system, the combined effect of contamination levels become too much and often exceed the maximum tolerable requirements to meet both the environmental and human health standards. The availability of both surface and groundwater have been changing in the last century not only due to industrialization, but also as the result of urbanization (Tiri, Belkhiri and Mouni, 2018).

Population growth and urbanization have a negative impact on water quality and ecosystem health, and environments that are in close proximity to industrial and urban activities are facing challenges in regard to water pollution (Carstens and Amer, 2019). Water quality is highly affected by the effects of land use. The results of population growth and urbanization amongst others include landfills and illegal dumping which can result in very toxic and poisonous chemicals leaching or soaking into the soil and introduced into the groundwater system (Boateng, Opoku and Akoto, 2019). There are also potential impacts on human health associated with the heavy metal pollution that is generated from the landfill leachate (Boateng, Opoku and Akoto, 2019).

The application of more pesticides and fertilizers to lawns and gardens by homeowners becomes a problem to water quality when they are washed off into the water bodies. Poisonous wastes are also flushed and inappropriately disposed. An example is that of routine oil change of motor vehicles and detergents that are often disposed into the stormwater or sewage systems. Other malfunctioning systems and septic tanks have a great potential to contaminate groundwater. Pit toilets or latrines built or located next to surface water or groundwater bodies, which are used after reaching their design capacity are the greatest source of sewage pollution that is responsible for the contamination of both surface water and ground water leading to poor water quality. There are so many effects of contaminants that lead to pollution of South African water resources, hence pollution to these resources must be controlled (Nyawo, 2017). Rapid urbanization and industrialization are well known for metal contamination of riverine ecosystems, which has become a serious environmental problem (Taufique Arefin *et al.*, 2016).

2.5.3 Mining and their contributions of physico-chemical properties and heavy metals contaminants to drinking water

Developing countries like South Africa, whose mineral wealth is found in diverse geological formations with more than 20 different types of precious metals and minerals, energy minerals, non-ferrous metals and minerals as well as ferrous minerals including platinum-group metal ores as well as Mn, Cr, vanadium (V), gold (Au) and alumino-silicates with reserves of titanium (Ti), zirconium (Zr), vermiculite, and fluorspar (Musingafi & Tom, 2014), may contribute in physico-chemical properties and heavy metals contamination of treated drinking water sources. Generally, mining activities involve the use of larger volumes of water and for this reason, they are also regarded as major contributors to the pollution of water resources and poor water quality.

The different types of waste generated at the various stages of mining such as the generation of waste rock, tailings, and effluents could directly pollute surface water or leach through the soil into the aquifers and pollute groundwater. The study by Gyamfi, Appiah-Adjei and Adjei, 2019 also indicates how illegal mining contributes to water pollution and poor water quality. Illegal mining around areas that are prohibited for mining such as forest reserves, water bodies, and environmentally sensitive areas pose a threat to the environment, most of such operations are not regulated and they are using unsafe chemicals in their mining operations, in which these chemicals are often discharged into the already stressed ecosystem and this leads to the contamination of such environments.

2.5.4 Effects of climate change on water quality

There is an increased impact of climate change on the water resource and there are also increased challenges regarding the conservation of the water resource from the impacts of increased flooding and drought. Other changes in climate include long-term changes in the surface temperature, precipitation, wind patterns, and heatwaves (Xia *et al.*, 2015). Climate change is a global concern posing the global community at risk of living without access to clean and safe drinking water and basic sanitation (Travails, 2010).

At the same time, climate change has the ability to change the water quality and ecosystem through different biochemical processes (Travails, 2010). The effects of droughts on water quality include increased pollutant concentrations, a high increase in mineralization coupled with hydrogen production and some delays in the recovery of water bodies from acidification. According to Xia *et al.*, 2015, during drought periods the concentrations of nutrients and major elements also increase and floods also have the ability to bring nutrients, pathogens, and toxins into the water environment through soil erosion. The other impacts of climate change on water quality are mineralization and salinization and these impacts have the potential to affect aquatic ecosystems and the drinking water security in plain lakes and reservoirs.

Alpine lakes and rivers are experiencing increased temperatures, dissolved organic carbon (DOC) concentrations, heavy metal contaminants, and conductivity because of climate change. Temperature increase in alpine lakes has a greater influence on rock weathering and glacier melting which strongly affects the alpine water quality, the process releases a number of heavy metal ions, such as Mg, Ca, and Nickel (Ni), which lead to an increase in water conductivity (Xia *et al.*, 2015).

According to Xia et al., 2015, the quality of rivers is highly affected by changes in precipitation. Both soil and water erosion elute contaminants from the soil and ground surface that exist as precipitants stored in the soil into the different water bodies resulting in poor water quality. Also, the increase in temperature as the result of climate change have the ability to induce the release of other pollutants, such as Nitrogen (N) and Phosphorus (P) from the sediments in the water found in lakes and reservoirs.

2.6 Water treatment processes and removal of physico-chemical properties and heavy metals

For many years there has been efforts to deliver portable drinking water safe from waterborne disease with the focus of reducing contamination at the source while developing water treatment techniques to remove chemicals including heavy meals whilst rendering water fit for human consumption (Wołowiec *et al.*, 2019; Lisle, 2000). Methods that have been used to remove heavy metals from water include chemical precipitation, ion exchange, adsorption, membrane filtration, reverse osmosis, solvent extraction and electrochemical treatment that requires high capital and operational costs (Virgen *et al.*, 2018; Wołowiec *et al.*, 2019).

A number of treatment processes are designed to modify the chemical and physical properties of the water (Stanfield, Lechevallier and Snozzi, 2003). A water treatment process that involves chemical precipitation to dissolve inorganic substances as insoluble precipitates is carried out. The process separates substances from the water by softening the water with a coagulant to remove substances such as heavy metals that eventually settle to the bottom and get flushed away with the sludge in sedimentation tanks (Schutte, 2006).

South Africa has been faced by water shortage that is contributed by a mixture of factors such as rapid population growth, water quality issues, climate volatility, drought and rising water-related pollution risks and ageing of water infrastructure (Railoun, 2021). South Africa’s urban areas water infrastructure is well developed as opposed to rural areas where the water treatment plants are fraught with a lot of technical and management problems rendering the water unsafe for human consumption in different provinces (Momba, Obi and Thompson, 2008). In 2021, the Water Institute of South Africa (WISA) (2020) has revived the Blue Drop programme that was cancelled together with the Green Drop programme since 2014 due to 44% of municipal water treatment works that were found to be in poor and in critical condition that could raise serious concerns regarding the quality of potable water (Massyn *et al.*, 2020). The incorporation of water treatment technologies to remove chemical pollutants such as heavy metals sound impossible for most municipal water treatment plants in South Africa exposing the public to critical health risk associated with such pollutants.

It is therefore very important to remove chemical pollutants including heavy metals from water as they represent a risk to both public and environmental health, and the Environmental Protection Agency (EPA) have considered heavy metals as priority pollutants that must be eliminated or reduced from any water body (Virgen *et al.*, 2018).

2.7 Human health effects due to physico-chemical properties and heavy metals

Heavy metals are found in trace amounts in water sources, yet they are very toxic and can pose serious health problems to humans and the ecosystems (Masindi, 2018). Physico-chemical and heavy metals above set standards for human consumptions are considered grave pollutants as they are not easily decomposed to simpler and less toxic substances such as other materials like organic pollutants (Chopra, Pathak and Prasad, 2009; Fayiga, Ipinmoroti and Chirenje, 2018; Sall *et al.*, 2020).

Changes in the levels of physico-chemical properties such as, temperature, electrical conductivity (EC), pH, total dissolved solids, total suspended solids, alkalinity, sodium (Na), dissolved oxygen, chemical oxygen demand (COD) and salinity affect drinking water quality causing most water borne diseases like diarrhoea (Dhawde *et al.*, 2018). Mg increases alkalinity, which can cause gastrointestinal problems and skin irritations, whereas too much alkalinity can disrupt a person's pH, causing metabolic alkalosis, which can cause nausea, vomiting, tremors, muscle twitching, tingling in the extremities of the face, and confusion. (Bouaroudj *et al.*, 2019).

Literature has shown that heavy metals are capable of causing severe health risks to humans and can also have an impact on other life forms (Kobielska *et al.*, 2018; Salawu et al., Oloyede, 2018). Heavy metals have the ability to enter the food chain and cause health problems, their toxic properties are also associated with adverse effects on human health even in their smaller quantities (Christiana, 2012; Taufique Arefin *et al.*, 2016).

Most of the effects of exposure to heavy metals are well known, but the toxicity due to heavy metals could cause serious illness and reduced quality of life. Heavy metals are known for causing various human health-related problems such as, cancers, cardiovascular and neurological diseases and they also have effects on aquatic life (Christiana, 2012).

Exposure to too much chromium may cause lung and respiratory tract cancer as well as kidney diseases and over exposure to chromium may also cause gastrointestinal symptoms, such as diarrhoea and vomiting. (Sall *et al.*, 2020). Exposure to high levels of metallic, inorganic, or organic mercury can damage the brain, kidneys, and developing foetus. Such exposure also has effects on brain functioning and may result in irritability, tremors, changes in vision or hearing, and memory problems (Sall *et al.*, 2020).

With so many industries in the society we live in, the use of various goods involves an increase in the range of metallic products. Most areas surrounded by mining, refining, smelting, energy production, industrial emission, and agricultural operations, sewage discharge, and the disposal of waste show increasing pollution to water sources, either by heavy metals or physico-chemical properties or both. Sewage treatment works and agriculture are amongst major contributors to the pollution of water sources; introducing high levels of physico-chemical properties into the water bodies (Molale, 2012).

2.8 Tolerable amounts for human consumption of physico-chemical properties and heavy metals in drinking water

Any changes in the levels of physico-chemical properties such as, temperature, EC, pH, TDS, TSS, alkalinity, Ca, Mg, Na, dissolved oxygen, COD and salinity of water contribute to poor water quality (Faiza *et al.*, 2012). Exposures to high levels of heavy metals such as cadmium, chromium, mercury, zinc, lead, and copper is not tolerable to any form of life and the environment (Gupta, Bhatnagar and Bakre, 2016; Kobielska *et al.*, 2018). Metals such as lead, cadmium and mercury are not required by any organism even at small quantities. Tolerable amounts for human consumption of physico-chemical properties and heavy metals in drinking water are those that meet the standards provided by the World Health Organisation in the Guidelines for Drinking – Water Quality (WHO, 2012) and the South African Standard for Drinking Water (SANS 241: 2015) (Anugrah, 2015).

The tolerable amounts for physico-chemical properties as set out in the South African Standard for Drinking Water are as follows; pH at 25ºC ≥ 5.0 - ≤ 9.7 pH Unit, Turbidity ≤ 1 and ≤ 5 NTU, conductivity at 25ºC ≤ 170 mS/m, colour ≤ 15 mg/L, free chlorine ≤ 5 mg/L, nitrate ≤ 11 mg/L, nitrite ≤ 0.9 mg/L, sulfate ≤ 250 and ≤ 500 mg/L, fluoride ≤ 1.5 mg/L, chloride ≤ 300 mg/L, sodium

≤ 200 mg/L and total dissolved solids ≤ 1200 mg/L (Nitasha Khatri and Tyagi, 2015). According to the United States Environmental Protection Agency (EPA) secondary drinking water regulations, 500 mg/L is the recommended maximum amount of TDS for drinking water.

The tolerable amounts for heavy metals as set out in the South African Standard for Drinking Water are as follows; calcium ≤ 150 mg/L, magnesium ≤ 70 mg/L, potassium ≤ 50 mg/L, Zinc ≤ 5 mg/L, Iron ≤ 2.0 and ≤ 0.3 mg/L, manganese ≤ 0.1 and ≤ 0.4 mg/L, aluminium ≤ 0.3 mg/L, antimony ≤ 0.02 mg/L, arsenic ≤ 0.01 mg/L, cadmium ≤ 0.03 mg/L, chromium ≤ 0.05 mg/L, cobalt ≤ 0.5 mg/L, copper ≤ 0.002 mg/L, lead ≤ 0.01 mg/L, mercury ≤ 0.006 mg/L, nickel ≤ 0.07 mg/L, selenium ≤ 0.04 mg/L, vanadium ≤ 0.2 mg/L, and cyanide ≤ 0.2 mg/L (Nitasha Khatri and Tyagi, 2015). Human bodies need small amounts of some heavy metals such as zinc, copper, chromium, iron, and manganese to function normally. It should be taken into consideration that toxic amounts of the same essential heavy metals are still harmful and can cause some serious health problems. There is still a gap in literature as it does not indicate the provisional daily and weekly intakes for heavy metals in drinking water. There is also insufficient data related to tolerable daily or weekly intakes which estimate the amount per unit body weight of a potentially harmful substance or contaminant in drinking water that can be consumed over a lifetime without risk of adverse health effects.

2.9 Regulation of physico-chemical properties and heavy metals in drinking water

Potable water that is supposed to be used for personal hygiene, drinking and food preparation must meet the water quality standards at the point of supply to the users (Bhagwat, 2019). Access to water is one of the main goals of UN-MDGs and the UN-SDGs that has led to the South African constitution to declare “access to water and food for all” in the constitution following the 1998 National Water Act (Dinka, 2018). The National Water Act 36 of 1998 ensures that the nation’s water resources are protected, used, developed, conserved, managed and controlled in ways that take into account amongst other factors including protecting aquatic and associated ecosystems and their biological diversity, reducing, preventing pollution and degradation of water resources (Abdullah, Mawardi and Rashid, 2013). Regulations promulgated under Section 9 of the Water Services Act, 1997 (Act No. 108 of 1997), Norms and Standards for quality water services, consists of Regulation 5 (Quality of potable water) which refers to entities within local and provincial government that are responsible for water services to the standard for drinking water quality which is the South African National Standard for Drinking Water (SANS 241) (Republic of South Africa, 1997).

SANS 241 serves as a definitive reference for drinking water quality parameters, including both physico-chemical and heavy metal parameters. The standards provide acceptable limits for drinking water quality parameters in South Africa and guideline levels for a range of water quality characteristics (Anugrah, 2015). SANS for drinking water also specifies the quality of acceptable drinking water defined in terms of physical, aesthetic, microbiological and chemical determinants. Section 9 of the Water Services Act, 1997 (Act No. 108 of 1997) also requires that water services institution compare the results obtained from the samples with SANS 241 whereby water quality analysis of physico-chemical, heavy metals and biological properties in water are measured against a set of known standards to determine if the water is suitable for human consumption and safe to be discharged into the environment (Republic of South Africa, 1997; Nitasha Khatri and Tyagi, 2015).

The more stringent standards are recommended by the World Health Organisation (WHO) guidelines for drinking water quality, which their main aim are to protect public health (RS2, 2012; WHO, 2012). The WHO guidelines give recommendations that help in proper management of risk from hazards that have the potential to compromise the safety of drinking water. Even though the WHO guidelines give minimum requirements of safe practice to protect the health of consumers, the guidelines also give a provision that national authorities can develop their drinking water regulations and standards which will be more appropriate for their different national situations (RS2, 2012). There are challenges encountered in meeting these regulations and standards by water utilities all over the world.

The similar challenges faced by water utilities all over the world to deliver quality drinking water are climate change, water scarcity, aging infrastructure and the growing and increasing population (Ortega-Ballesteros, Manzano-Agugliaro and Perea-Moreno, 2021). In South Africa which is regarded as a developing country, studies have shown that non-metro South Africa has high incidence of poor drinking water quality with high recorded levels of physico-chemical, heavy metals and microbiological characteristics (Edokpayi, Odiyo and Durowoju, 2017).

There are possible solutions to ensure that the water utilities meet the current regulations and standards. The study conducted by Hodgson and Manus, 2006 highlighted that in order for water utilities to deliver quality drinking water they must have a good understanding regarding the requirements for effective drinking water quality management. There must be adequate management monitoring of drinking water services, adequate management of assets, adequate institutional capacity that includes, staffing, funding, expertise and education and proper interventions to address poor drinking water quality when detected (Hodgson and Manus, 2006).

2.10 Conclusion

Literature has shown that amongst the least, agricultural nutrients and farmlands are the top running contributors of water pollution. In addition, fertilizers and pesticides used in agriculture have also proven to be major contributors to poor water quality. Mining and industrial activities also have shown to be having significant impacts on water quality, resulting in increased metal content, salinity, and sediment load in water bodies. It is apparent that the most socio-economic activities play an indirect or direct role on water quality. A broader analysis will be beneficial in understanding all components of hydrological cycle, and the impact human activities have on it, to efficiently sustain the water resources.

CHAPTER 3 METHODOLOGY

3.1 Introduction

This first section of the chapter explains the research design and the second section of the chapter explains the data collection method. Sampling point selection is discussed under data collection section. The chapter further gives information on the description of the data collection points and the description of the study area. Data analysis/statistical analysis, issues on ethical considerations and methodological assumptions and limitations are also discussed in the same chapter.

3.2 Research Design

To analyse the physico-chemical properties as well as to determine the presence and concentrations of heavy metals of water from the Middleburg Dam, before and after treatment, quantitative research method was used. Quantitative design provides acceptable answers to the research problem or questions in this study, as it is regarded as a process that is systematic and objective in its ways of using numerical data (Mouton, 2001).

3.3 Data Collection

Sampling point selection:

Water quality monitoring reports from Steve Tshwete Local Municipality were utilized for this study.

Sampling point one_A on Figure 3 - 1 - Raw water from the Dam collected from the inlet at the Vaalbank Water Treatment Plant (WTP). Water from the Inlet at the WTP gives a correct representation of water from the dam since water is extracted from the dam before treatment and is received in the WTP through the inlet for purification.

Sampling point two_B on Figure 3 - 1 - A sample collected from the outlet at the Vaalbank Water Treatment Plant. This sample represents water after purification at the WTP (The final product of the WTP). This sample will give an indication of whether there is an increase or decrease in the levels of physico-chemical properties and heavy metals after treatment as compared to the original sample, before treatment. Vaal bank Water Treatment Plant is surrounded by activities such as mining, agriculture, and industrial activities which according to Dhawde, et al., 2018 and Gyamfia, et al., 2019 are known to contribute to high levels of physico-chemical properties and heavy metals in water bodies affecting water quality.

Two (2) main reservoirs in the study area stated below were also selected:

- Graspan reservoir (**sampling point five _C** on Figure 3 - 1)
- Nazareth reservoir (**sampling point three _D** on Figure 3 - 1)

Reservoirs are contaminated by thermal, chemical, and physical changes that water undergoes when is stored, as well as the impact retention time has on water quality in reservoirs (Kobielska, et al., 2018). In addition, selected reservoirs needed to be evaluated for their water quality through the assessment of both their physico-chemical properties and heavy metal content, since industrial activities can increase metal, salinity, and sediment loading in water sources. (Gyamfia, et al., 2019).

There are pipelines in place to provide water from the Vaalbank Water Treatment Plant. Water is pumped over long distances to the households for domestic use. Data from different areas in Middelburg was also selected:

- Ext 4 (**sampling point three _E** on Figure 3 - 1)
- Eastdene (**sampling point three _F** on Figure 3 - 1)
- Groenkol (**sampling point three _G** on Figure 3 - 1)
- Rockdale (**sampling point three _H** on Figure 3 - 1)
- Rockdale 236 (**sampling point three _I** on Figure 3 - 1)
- Dennesig (**sampling point three _J** on Figure 3 - 1)

3.3.1 Description of the data collection points

Located on the Klein Olifants River, the Middelburg Dam forms part of the Olifants River basin, where mining, agricultural and conservation are the main activities around the dam. The dam's main purpose is to serve for water supply in the Steve Tshwete Local Municipality within Nkangala District Municipality. The Middelburg Dam catchment covers an area of 1 576km² (Tshwete, 2008). Figure 3 – 1; In this diagram, the various sampling points which samples were collected are shown in relation to each other, from water that enters the treatment plant from the Middelburg dam to the reservoirs, to the end-users in different residential areas and households.

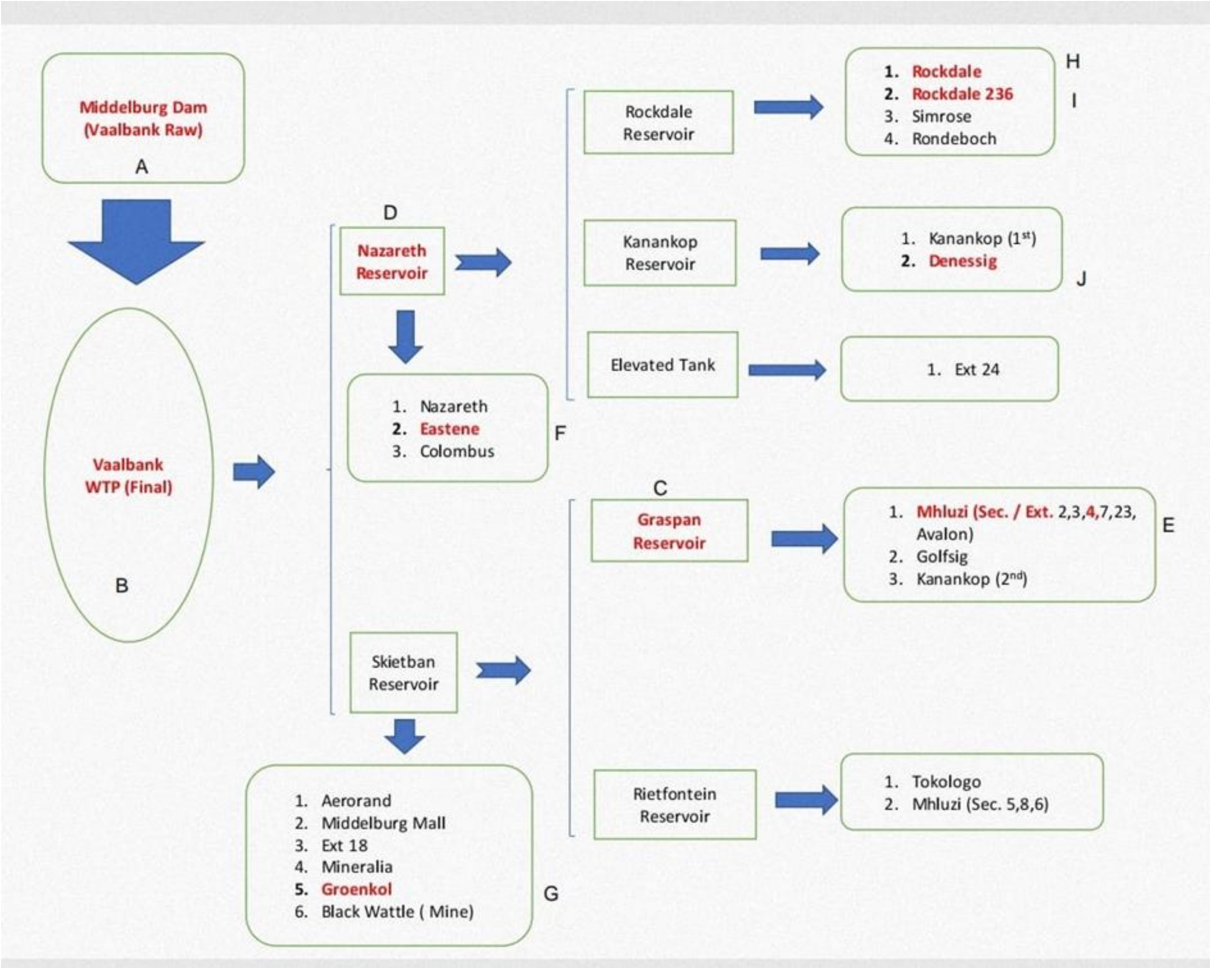

Figure 3-1: Data Collection Points

All sampling points were chosen to check for any possible contamination of water in the pipelines over distance travelled before water reaches the households. It is based on assumptions that poorly managed pipelines may erode and that may affect the quality of water carried by such pipes. So, it was important to select data for different residential areas and households and check for any possible increase or decrease in the levels of physico-chemical properties and heavy metal levels.

Sample Collection and Storage:

The sampling at all selected points was done by qualified Steve Tshwete Municipality technicians. Samples were collected following the protocol for water sampling as per APHA (American Public Health Association) to avoid cross contamination of the samples (Mosley et al., 2018). Sampling was done once in a month at the ten (10) sampling sites selected. The main aim was to obtain representative samples in the whole system, before and after treatment and that is the reason only ten (10) sampling points were chosen. Where sites are in proximity, a representative sample was taken from one point as they are all close to each other.

The municipality technicians do sampling once a month and analysis are done for both physicochemical and heavy metals to verify the quality of drinking water and that allows for quick intervention by the Municipality when required. Samples were collected for a period of thirteen (13) months, from March 2020 - March 2021 and a single sample was collected per sampling site. In a period of thirteen (13) months, a total of 13 samples were collected for each sampling point and a total of 130 samples were collected for all the ten sampling points chosen in the study area. Samples were analysed after sampling at Mpumamanzi Laboratory for both physico-chemical properties and heavy metals.

The sampling techniques are explained in detail:

- Step 1 - At the sampling point the cap of sample bottle was removed making sure that the inner surface of cap and neck of sample bottle was not contaminated with hands. 250 mL polypropylene sample bottles were used as the analysis required sterile samples.
- Step 2 - Samples were taken by holding bottle with hand near base of the sample bottle, and the neck of the sample bottle was plunged downward, below the water surface (gloves were used to protect hands from contact with the water).
- Step 3 - The bottle was turned until neck pointed slightly upward and mouth was directed toward the current.
- Step 4 -The sample bottle was filled without rinsing and the cap was replaced immediately. Before closing the sample bottle ample air space in the bottle (at least 2.5 cm) was left to facilitate mixing by shaking before examination.
- Step 5 - Complete labelling was done on the sample bottle and the sample sheet was completed.

At the Municipality Laboratory, the water for heavy metals sample analysis was immediately filtered using the 0.45µm pore diameter cellulose acetate (membrane) filter. After filtration, 10% concentrated nitric acid (HNO_3) of pH <2 was added to preserve the samples. The sample bottles with water were tightly sealed to avoid any form of contamination and taken to the fridge as per the procedure. The sampling operating procedure states that the water samples can be stored for 1 month at 1 – 4°C, and pH < 2 and for 6 months if frozen. The samples were stored in the Municipality laboratory before being transported to Mpumamanzi Laboratory for analysis. Dried ice was also used to keep the samples preserved in the stated temperature and stored in a laboratory certified cooler bag (Water Research Commission, 2000).

Preparation of water samples for heavy metal analysis:

The analysis were performed by SANAS accredited testing laboratory (T0786) for heavy metals. Preparation of all samples was done for determination of heavy metal concentrations as follows:

- A 100 mL aliquot of well-mixed sample was transferred to a beaker
- 2 mL of concentrated HNO_3 and 5 mL of concentrated HCl were added
- The sample was covered with a ribbed watch glass or other suitable covers and heated on a steam bath, hot plate, or other heating source at 90 to 95 ºC until the volume has been reduced to 15 - 20 mL.
- The beaker was removed and allowed to cool.
- The final volume was adjusted to 100 mL with reagent water

Heavy Metal Analysis of water samples by the laboratory:

Samples collected at all sampling points were analysed for the following parameters, Aluminium (Al), Iron (Fe), Manganese (Mn), Calcium (Ca), Magnesium (Mg), and Potassium (K) using Atomic Absorption Spectroscopy (AAS) method. AAS has always been the most reliable and most common technique for detecting heavy metals in water samples (Radulescu, et al., 2014; Department of Water Affairs and Forestry, 1996). This method was used as it is also regarded by DWAF as a reference method for detection of heavy metals in water samples (Department of Water Affairs and Forestry, 1996). A blank sample and standard solutions were used for the calibration of the equipment, and the method also requires that typical set of standard calibration curves with linear regressions and better relative standard deviations be achieved to measure the heavy metal concentrations. One reference material which is NIST SRM 1643e- Trace elements in water was also used to verify the validity of the measurements. Radulescu et al., (2014) used the same standard reference material to test the validity of the measurements in water and NIST SRM 4354 Lake sediment Powder and the results were accurate.

Physico-chemical Analysis of Water:

Water quality monitoring reports from Steve Tshwete Local Municipality were utilized for this study. Sampling at the same points mentioned above was done monthly and the analyses were carried out for the Municipality by SANAS accredited testing laboratory (T0786) in Middelburg called Mpumamanzi. The following physico-chemical parameters were considered for this study, pH, Turbidity, Electrical conductivity, True colour, Nitrate, Nitrite, Sulphate, Fluoride, Chloride, Sodium, TDS, Total Alkalinity and Total Hardness. The laboratory made use of SANAS accredited methods for all parameters indicated above except for the TDS (Non-SANAS accredited method was used).

To achieve the last objective of the study which is to check if either the water quality levels are within permissible limits, both physico-chemical properties and heavy metal concentrations were evaluated against the South African National Standard for drinking water (SANS 241:2015) as well as global drinking water quality standards. The guidelines were used as a source to make informed judgements about the water potability and use.

3.3.2 Description of the study area

Middelburg is an area located in the Nkangala District Municipality in the Mpumalanga Province of South Africa. The town is associated with large farming and industrial activities. It has an estimated population of 142 772 with a total area of 117.40 km2 (Tshwete, 2008).

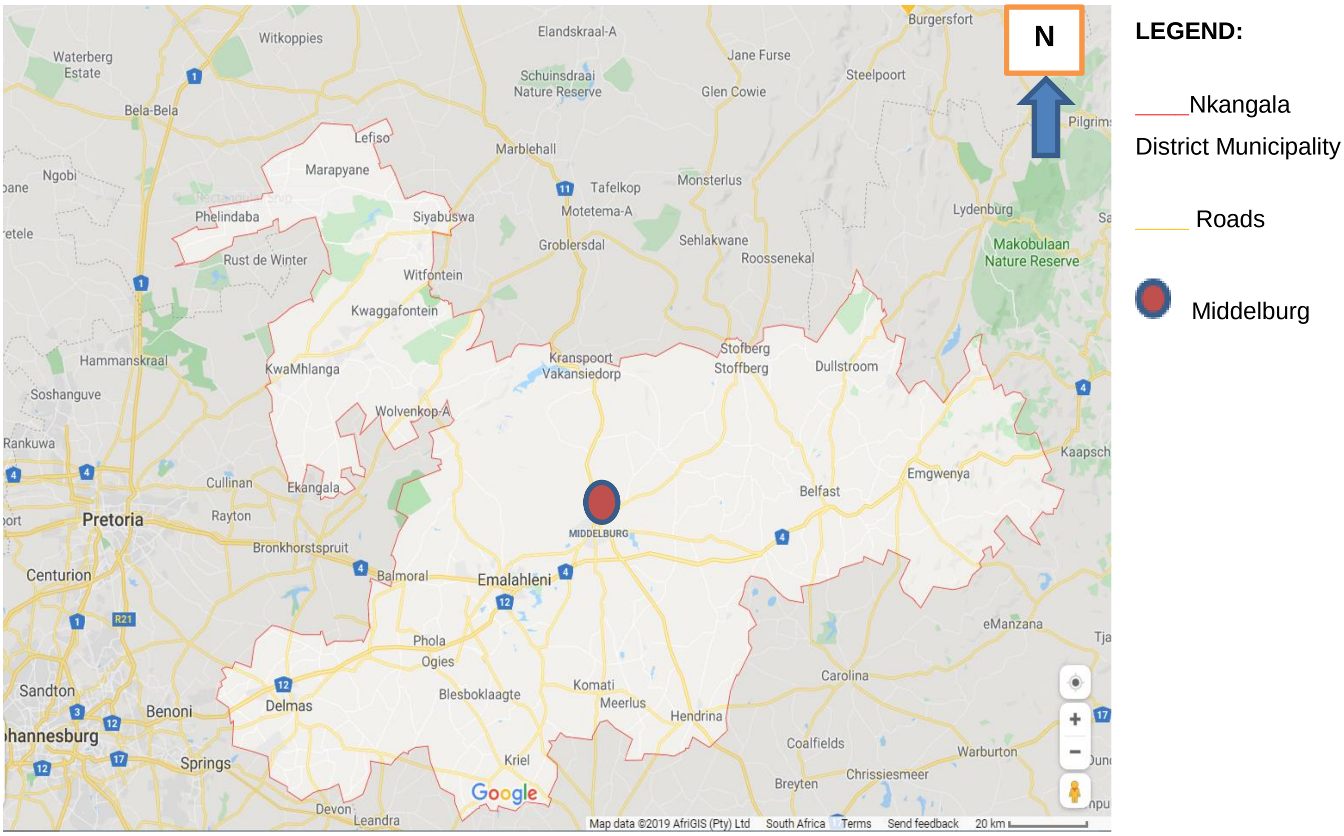

Figure 3-2: Location of Middelburg area in Nkangala District Municipality in Mpumalanga Province of South Africa (Google Maps, 2019)

3.4 Statistical data analysis

Microsoft Excel was used to tabulate all the secondary water quality monitoring data obtained from the Steve Tshwete Municipality. The quantitative data was analysed through OriginPro 8.5 which is a proprietary computer program for interactive scientific graphing and data analysis. Means and standard deviations of physico-chemical properties and heavy metal concentrations in water samples were calculated using Microsoft excel.

3.5 Ethical considerations

University of South Africa (UNISA) requires that ethical considerations should be acknowledged and taken into consideration during research. The research proposal was submitted to the Unisa-CAES Health Research Ethics Committee of the University of South Africa for consideration. The low-risk application was reviewed by the UNISA-CAES Health Research Ethics Committee on 02 July 2020, and it was found to be in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment. The research ethics clearance was granted by the Unisa-CAES Health Research Ethics Committee, REC Reference #: 2020/CAES_HREC/072_FR/RS2. Permission to use water quality monitoring results from the Municipality was also granted by the Steve Tshwete Local Municipality, their reference: 4/1/3/5/1.

3.6 Methodological Assumptions and Limitations

Secondary water quality monitoring data from the Steve Tshwete Local Municipality was used for this study. The data used is from March 2020 to March 2021 (A total of thirteen months), so there were challenges in having water quality monitoring results for other selected sampling points for some months in the following order: April 2020: Eastene, Groenkol, Rockdale, Rockdale 236 and Dennesig, June 2020: Ext 4, August 2020: Rockdale and November 2020: Ext 4. The missing data did not affect the statistical parameters.

Amongst other reasons, the Municipality has indicated challenges in meeting their monthly sampling targets due to the declaration of a state of national disaster, following an increase in confirmed cases of COVID-19 on the 15th of March 2020. The evolving COVID-19 pandemic caused the Municipality to have its staff working either on rotational basis or others working remotely affecting most of the Municipality’s operations.

3.7 Chapter summary

The chapter provided details of the quantitative research design used to address the research questions of the study. The secondary data used is from March 2020 to March 2021 (A total of thirteen months) for 10 (ten) sampling points in the Steve Tshwete Local Municipality. The quantitative data was analysed through OriginPro 8.5 which is a proprietary computer program for interactive scientific graphing and data analysis. Means and standard deviations of physico-chemical properties and heavy metals concentrations in water samples were calculated in Microsoft excel.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and discussion of the data collected to address the research aim and meet the objectives of the study. The physico-chemical properties and heavy metal concentrations for ten (sampling points) for a period of 13 months (March 2020 to March 2021) were averaged to obtain the mean values.

4.2 Physico-Chemical Parameters of Water Quality

According to (Anugrah, 2015), the standard limits for these physical determinants as set out in the South African Standard for Drinking Water are outlined as follows:

- pH at 25ºC ≥ 5.0 - ≤ 9.7,
- Turbidity ≤ 1 and ≤ 5 NTU,
- Conductivity at 25ºC ≤ 170 mS/m, and
- Colour ≤ 15 mg/L.

4.2.1 Physical determinants

4.2.1.1 pH

Figure 4-1 shows the pH mean values and standard deviations in the sampling area. The mean values of pH showed that there were slight changes of pH throughout the distribution system. The maximum mean pH value was at Ext. 4 (7,61) and the minimum mean values were at Middelburg Dam (Vaalbank Raw) (7.46) and Rockdale 236 (7.46). The mean values of pH were within permissible limits (pH at 25ºC ≥ 5.0 - ≤ 9.7) at all sampling points as set out in the South African Standard for Drinking Water (SANS 241: 2015).

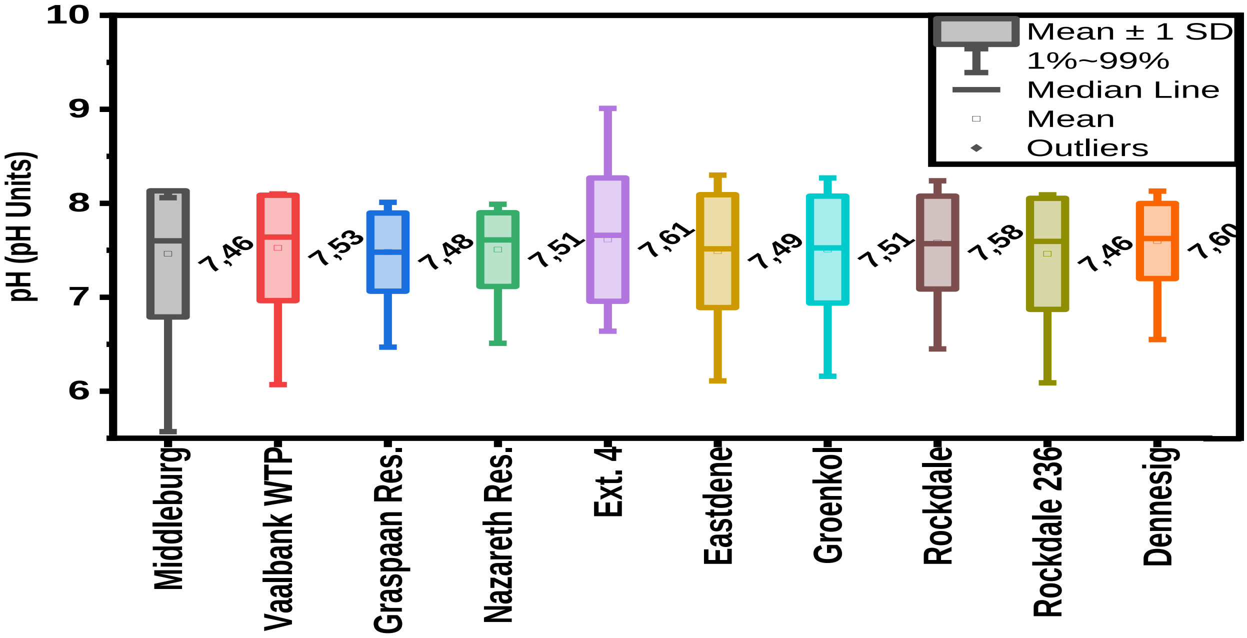

Figure 4-1: Box-whiskers plot of pH

pH is regarded as an important operation parameter, several studies have shown that unpolluted water has pH ranging from 6.5 – 8.5 (Molale, 2012; Kumar *et al.*, 2013; Dhawde *et al.*, 2018). Chemical and heavy metal pollution in water is indicated by either an extremely high or low pH. Polluted water normally has pH less than 6.5 which indicate that the water is acidic, corrosive to metal pipes and also rendered unsafe to drink. pH is the measure of the H^+ ion activity of the water system indicating if the water is neutral, acidic or alkaline (Kumar *et al.*, 2013).

4.2.1.2 Turbidity

Figure 4-2 shows the turbidity mean values and standard deviations in the sampling area. High mean value of turbidity was recorded at the Middelburg dam (Vaalbank raw). Higher turbidity is a result of clay, silt, very tiny inorganic and organic matter, algae, dissolved coloured organic compounds, plankton and other microscopic organisms from the dam, before water gets extracted into the water treatment plant. The mean values of turbidity change throughout the distribution system. The maximum mean value of turbidity was at Middelburg dam (Vaalbank Raw) (0.95 NTU) and the minimum mean value was at Eastdene (0.50 NTU). The mean values of turbidity were within permissible limits of less than 1 NTU with limits of greater than 1 to 5 NTU being allowed for a limited duration (DWA, 2005). There was also a greater standard deviation of turbidity at the Middelburg dam (Vaalbank Raw), this indicated a greater variation of the parameter over time. Different turbidity values were recorded at different months as per figure 4-3.

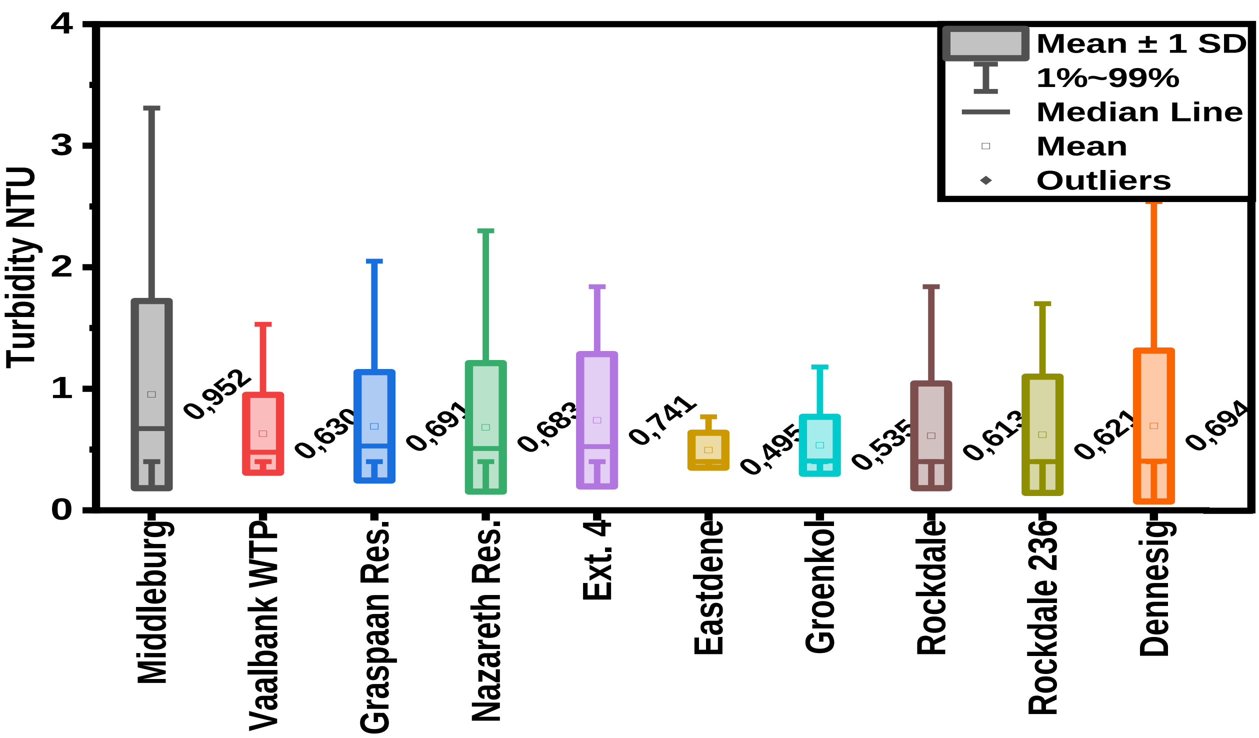

Figure 4-2 : Box-whiskers plot of turbidity

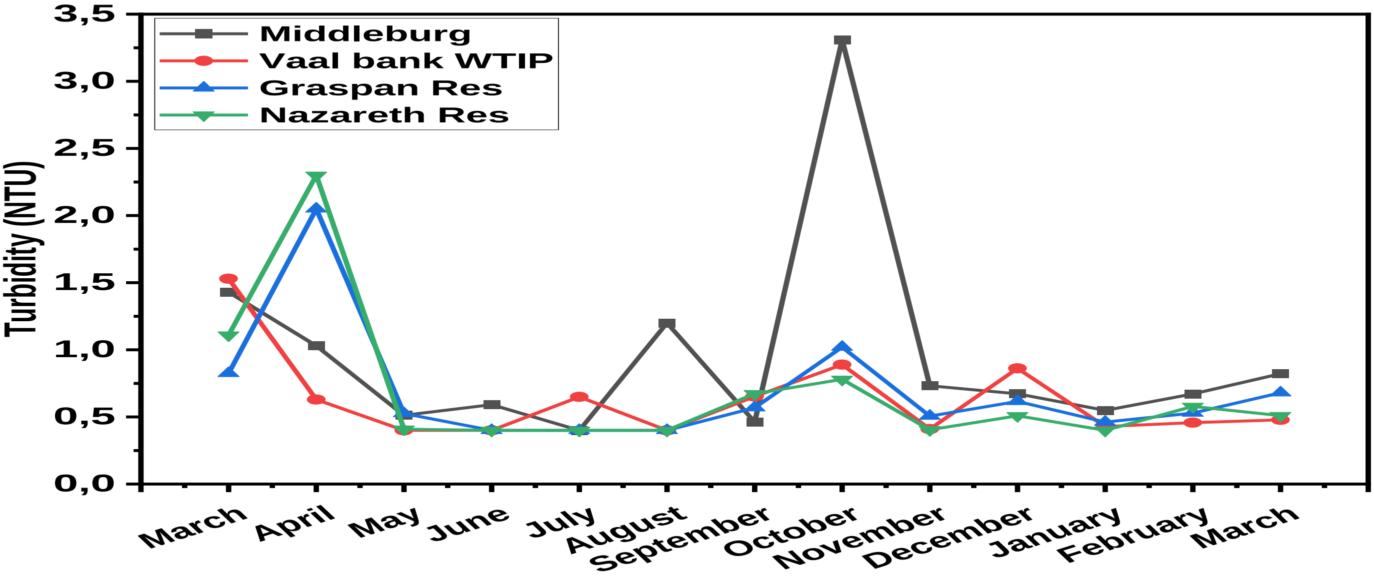

Figure 4-3 : A graph showing a variation of turbidity per month of sampling

To determine the aesthetic aspect of drinking water, the turbidity value is used. Water with high turbidity usually contains suspended solids, microorganisms, and colloidal substances (Edokpayi et al., 2016). High turbidity enables the presence of heavy metals as suspended solids and other colloidal substances absorb heavy metals leading to contamination of water (Yao et al., 2016; Edokpayi et al., 2016). Although the recommended limits are 0 NTU in drinking water, the results from this study showed that the average readings were below 1 as stated by DWA, (2005). Water from the sampling points may not pose danger due to contamination as the results were below 1 NTU.

4.2.1.3 Electrical Conductivity

Figure 4-4 shows the electrical conductivity mean values and standard deviations in the sampling area. The mean values of electrical conductivity indicated that there were slight changes in electrical conductivity throughout the distribution system. The maximum mean values of electrical conductivity were at Groenkol (103 mS/m) and Dennesig (103 mS/m) while the minimum mean value was at Eastdene (93 mS/m). The mean values of electrical conductivity were within permissible limit (conductivity at 25ºC ≤ 170 mS/m) at all sampling points.

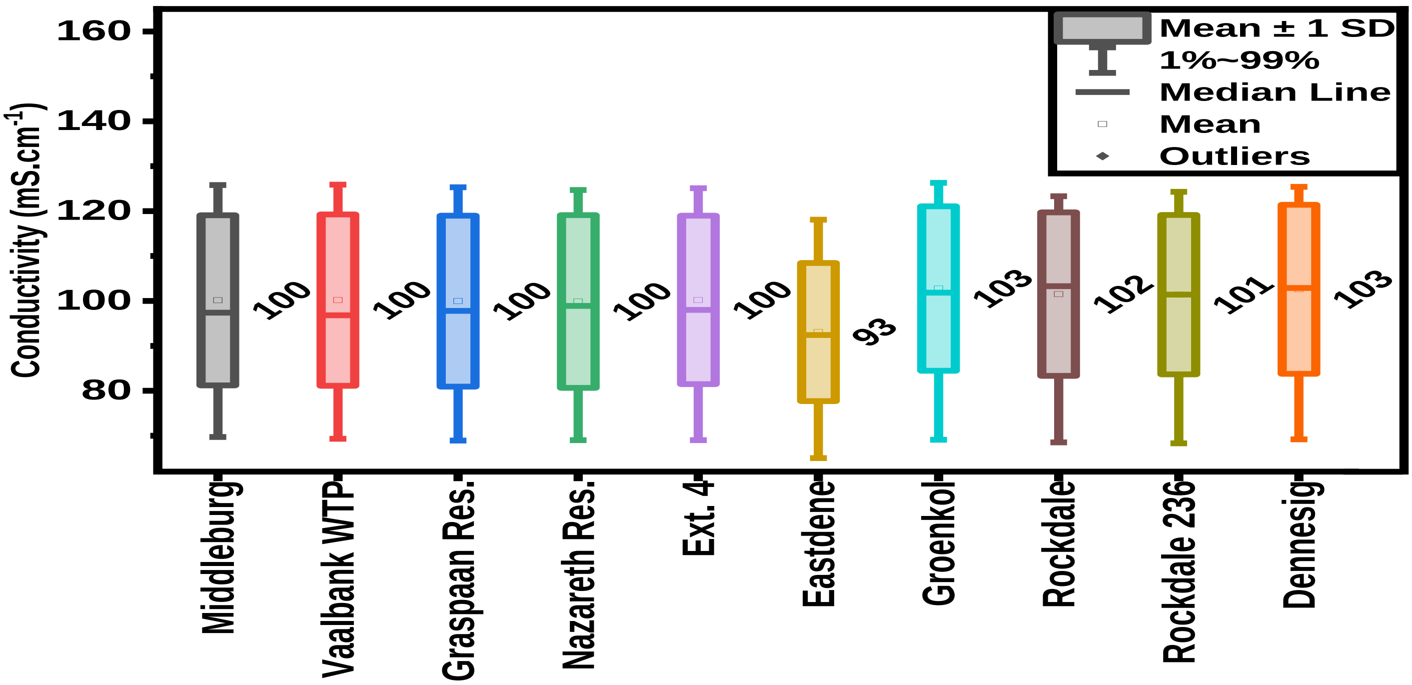

Figure 4-4: Box-whiskers plot of electrical conductivity

The measure of the ability of water to conduct an electrical current is referred to as electrical conductivity. It gives an indication of the number of dissolved substances or ions in water even though it does not give an indication of the exact minerals that are present. High levels of electrical conductivity are an indication that pollution has entered the water body. Electrical conductivity is altered by human activities that inorganic and charged chemical into the water bodies (Molale, 2012).

4.2.1.4 True Colour

Figure 4-5 shows the true colour mean values and standard deviations in the sampling area. Higher mean value of true colour was observed at the Middelburg dam (Vaalbank raw), that is due to elevated organic activity with algal growth and the presence of soluble minerals next to the dam. The mean values of true colour lowers after water was treated in the water treatment plant and distributed, then there were slight changes of true colour throughout the distribution system. The maximum mean value of true colour was at Middelburg Dam (Vaalbank Raw) (5.96 mg/L) and the minimum mean value was at Dennesig (2.82 mg/L). The mean values of true colour were within permissible limit (≤ 15 mg/L) at all sampling points. Higher standard deviations are observed in most sampling points, indicating fluctuations in the parameter in different months as per figure 4-6.

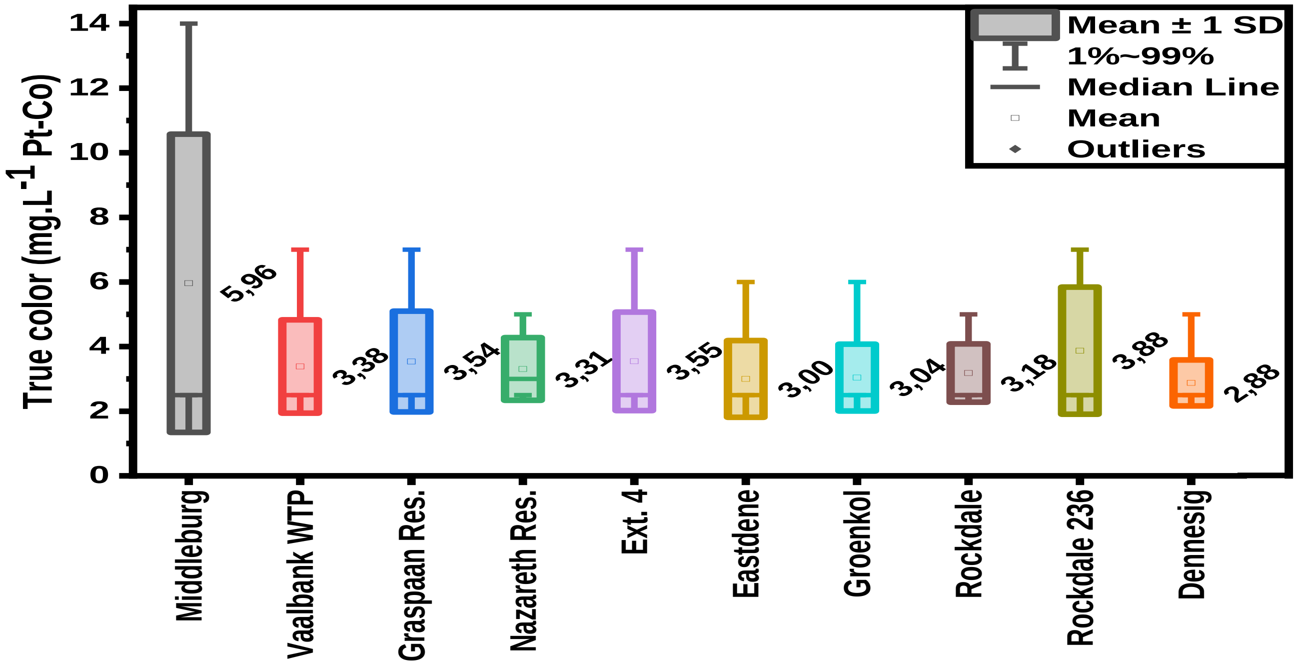

Figure 4-5: Box-whiskers plot of true colour

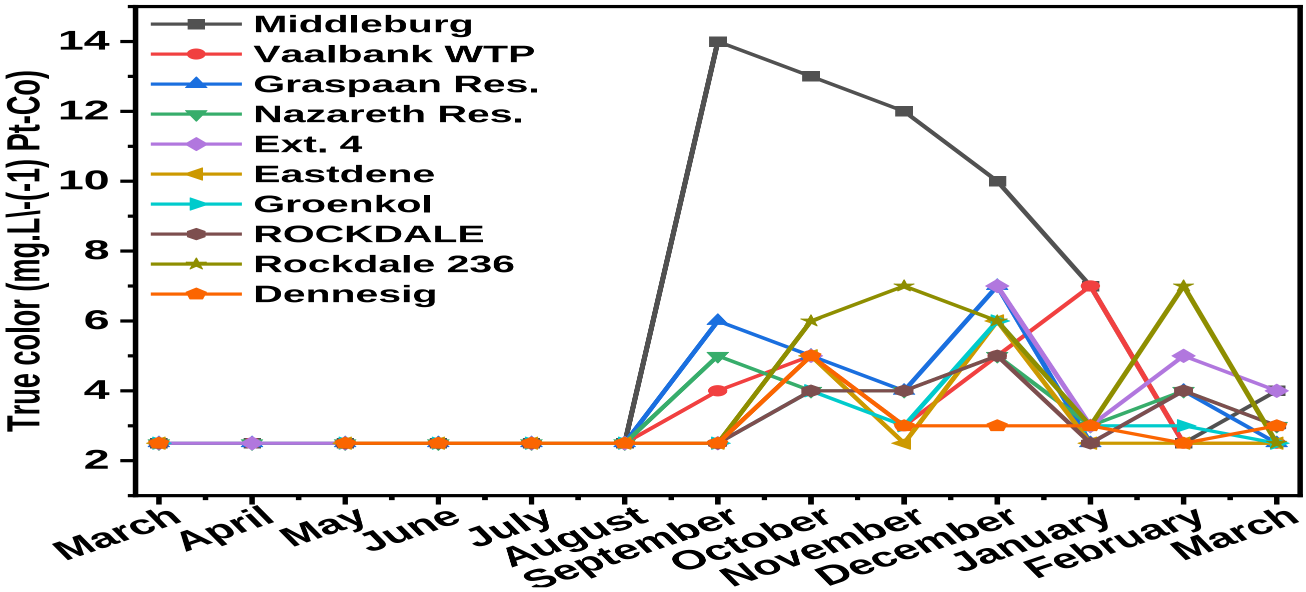

Figure 4-6: A graph showing a variation of true colour per month of sampling

The colour of water resulting from only dissolved substances is referred as true colour. This is only achieved after all suspended substances have been removed and cannot in any way influence the colour of the water. It is recommended that drinking water should have no colour and in drinking water colour is often influenced by iron and other metals (WHO, 2012).

4.2.2 Physico-chemical parameters (Alerts)

4.2.2.1 m-Alkalinity

Figure 4-7 shows the m-alkalinity mean concentrations and standard deviations in the sampling area. The mean concentrations of alkalinity indicated very slight changes to m-alkalinity throughout the distribution system. The higher standard deviations in most sampling points were an indication of greater variation of the parameter in different months. The maximum mean concentration of m-Alkalinity as $CaCO_3$ (mg/L) was at Middelburg Dam (Vaalbank Raw) (71.5 mg/L) and the minimum mean concentration was at Eastdene (64.7 mg/L).

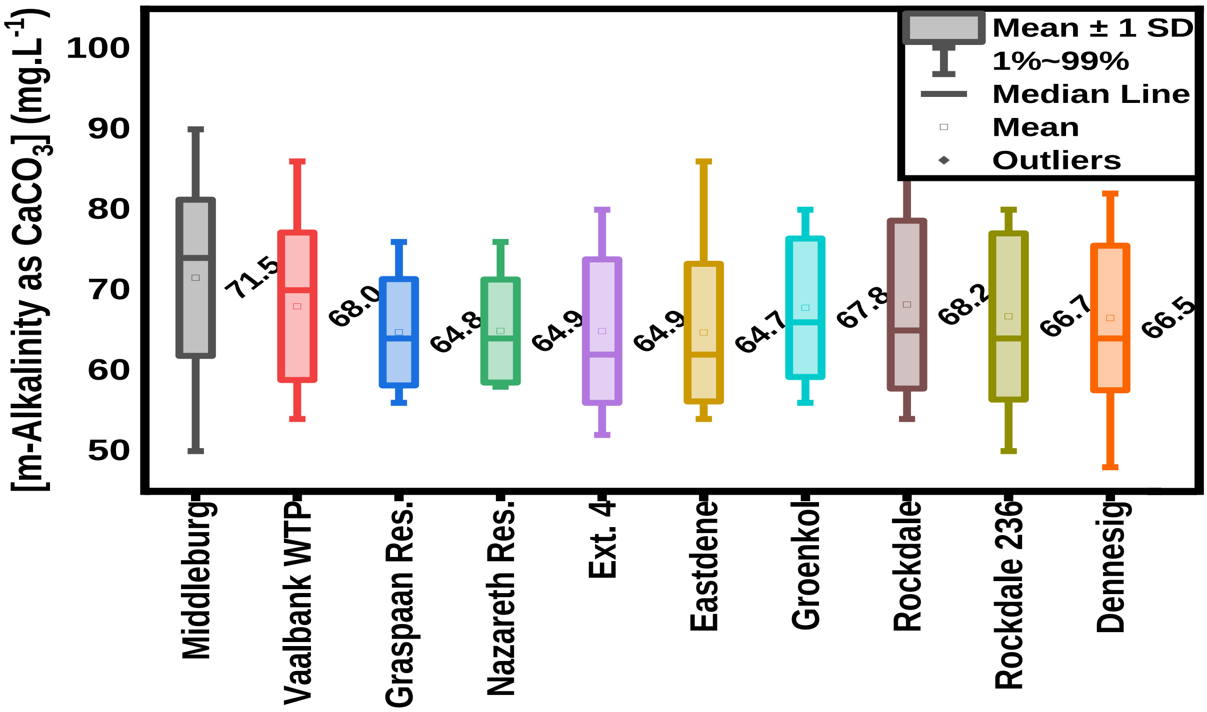

Figure 4-7: Box-whiskers plots of m-Alkalinity

Alkalinity is a measure of water's ability to neutralize acids. Water with low levels of alkalinity (less than 150 mg/L) is more likely to be corrosive when high alkalinity water (greater than 150 mg/L) may contribute to scaling. Most natural process such as weathering of rocks and leaching from soils causes changes in alkalinity (Nitasha Khatri and Tyagi, 2015).

4.2.2.2 Calcium hardness and magnesium hardness

Figure 4-8 shows the calcium hardness and magnesium hardness concentrations and their standard deviations in the sampling area. The mean concentrations for calcium hardness and magnesium hardness indicated that both parameters were consistent throughout the distribution system.

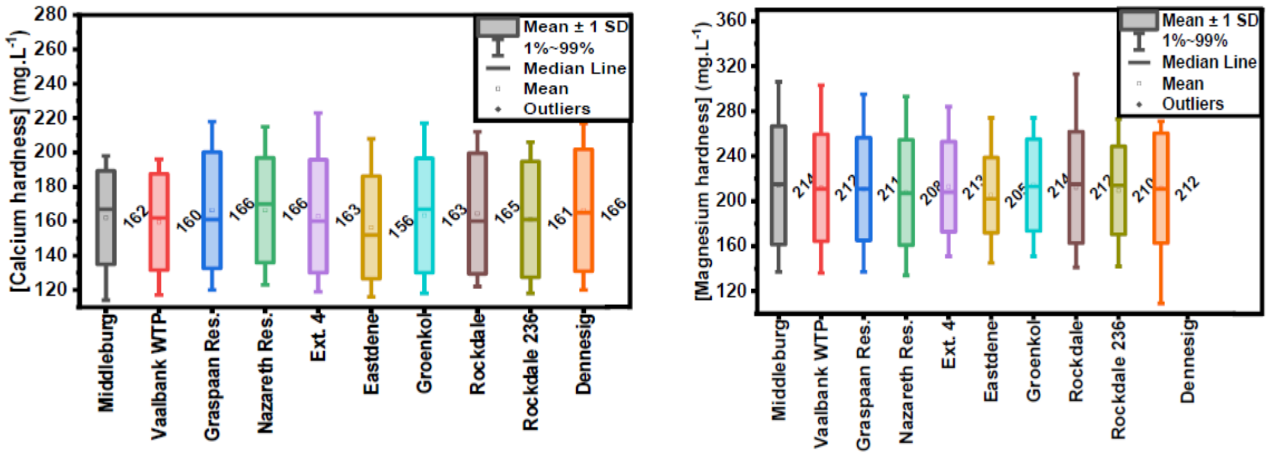

Figure 4-8: Box-whiskers plots of calcium hardness and magnesium hardness

Total Hardness (mg/L as $CaCO_3$) = Calcium Hardness (mg/L as $CaCO_3$) + Magnesium Hardness (mg/L as $CaCO_3$). Hard water is formed when water gradually filters through deposits of limestone, chalk or gypsum which are largely made up of calcium and magnesium carbonates, bicarbonates, and sulfate.

4.2.2.3 Total hardness

Figure 4-9 shows the total hardness concentrations and standard deviations in the sampling area. The mean concentrations of total hardness indicated that there were very slight changes to total hardness throughout the distribution system. The maximum mean concentrations of total Hardness as $CaCO_3$ (mg/L) were at Groenkol (378 mg/L) and Dennesig (378 mg/L). The minimum mean concentration was at Eastdene (361 mg/L). The average value of m-Alkalinity as $CaCO_3$ (mg/L) was almost 17% to 100% of the total hardness average value and this is a similar situation in all the sampling points.

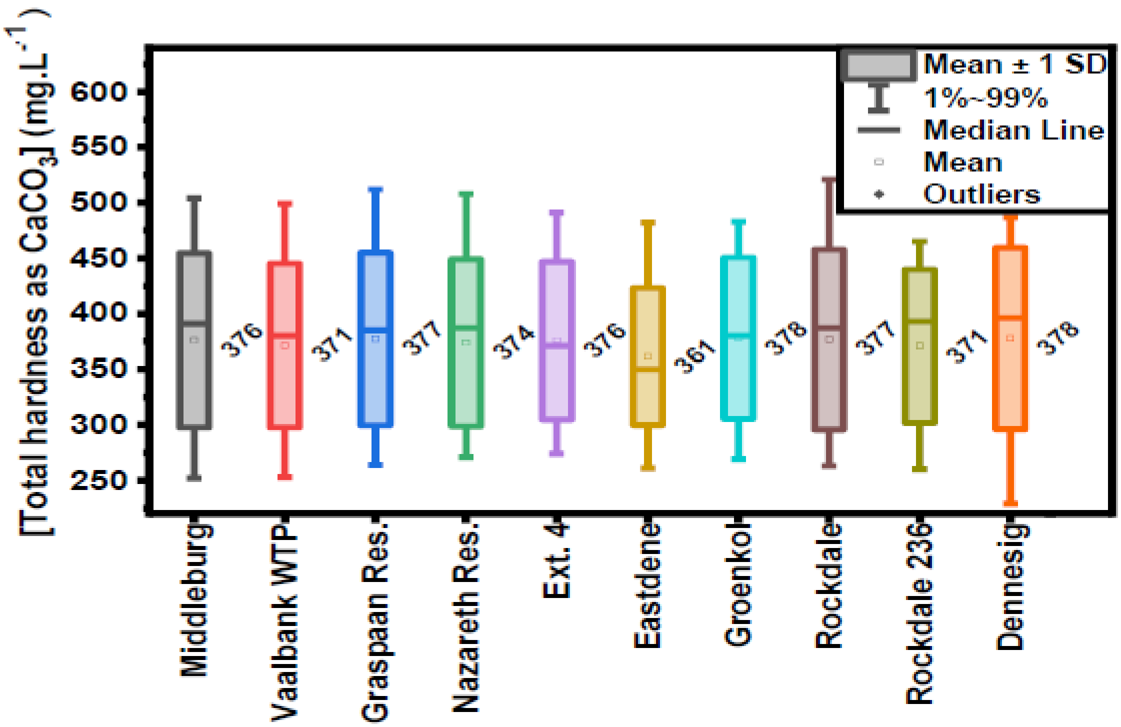

Figure 4-9: Box-whiskers plots of total hardness

The value for m-Alkalinity should be roughly 75% to 100% of the total hardness value in an unsoftened sample. Both total alkalinity and total hardness are used to test for overall water quality. In all the sampling points the mean concentrations of m-alkalinity were much less than the mean concentrations of total hardness and this was clear indication of elevated levels of chloride, nitrate, or sulfate. Concentrations for total hardness near 150 mg/L are generally ideal from an aesthetic viewpoint. Water less than 150 mg/L is considered soft water while water with concentrations greater than 200 mg/L is considered hard water and may cause scale deposition in treatment plants and pipes in buildings (WHO, 2012). The water from the Middelburg dam has shown to be hard.

The tolerable amounts as set out in the South African Standard for Drinking Water are outlined as follows:

- Calcium ≤ 150 mg/L,
- Magnesium ≤ 70 mg/L, and
- Potassium ≤ 50 mg/L.

4.2.2.4 Calcium and magnesium

Figure 4-10 shows calcium and magnesium concentrations and standard deviations in the sampling area. The mean concentrations of calcium and magnesium indicated very slight changes in both calcium and magnesium throughout the distribution system. The maximum mean concentrations for calcium were at Graspan reservoir (66.70 mg/L) and Nazareth reservoir (66.70 mg/L), while the minimum mean concentration was at Eastene (62.6 mg/L). The mean concentrations for calcium were within permissible limit (≤ 150 mg/L) at all sampling points. The maximum mean concentration for magnesium was at Middelburg dam (Vaalbank Raw) (52.00 mg/L) and the minimum mean concentration was at Eastdene (49.86 mg/L). The mean concentrations for magnesium were within permissible limit (≤ 70 mg/L) at all sampling points

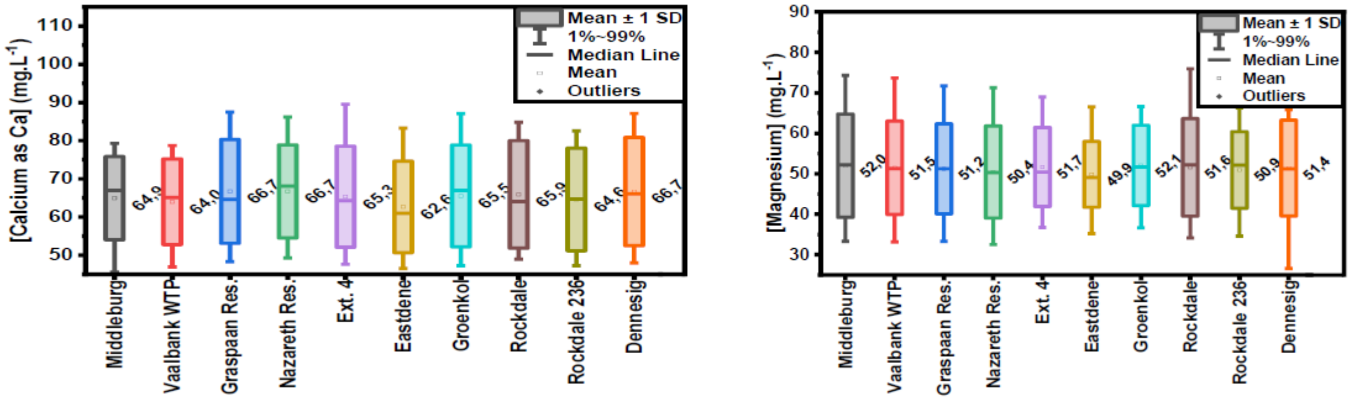

Figure 4-10: Box-whiskers plots of calcium and magnesium

The two main cations that cause water hardness are calcium (Ca^{2+}) and magnesium (Mg^{2+}). Water carries calcium as it passes through limestone deposits and magnesium is dissolved into the water as it passes through dolomite and magnesium bearing materials (Taufique Arefin *et al.*, 2016).

4.2.2.5 Potassium

Figure 4-11 shows potassium concentrations and standard deviations in the sampling area. The mean concentrations of potassium indicated very slight changes in potassium throughout the distribution system. The maximum mean concentration for potassium was at Rockdale 236 (10.6 mg/L) and the minimum mean concentration was at Eastdene (9.1 mg/L). The mean concentrations for potassium were within permissible limit (≤ 50 mg/L) at all sampling points.

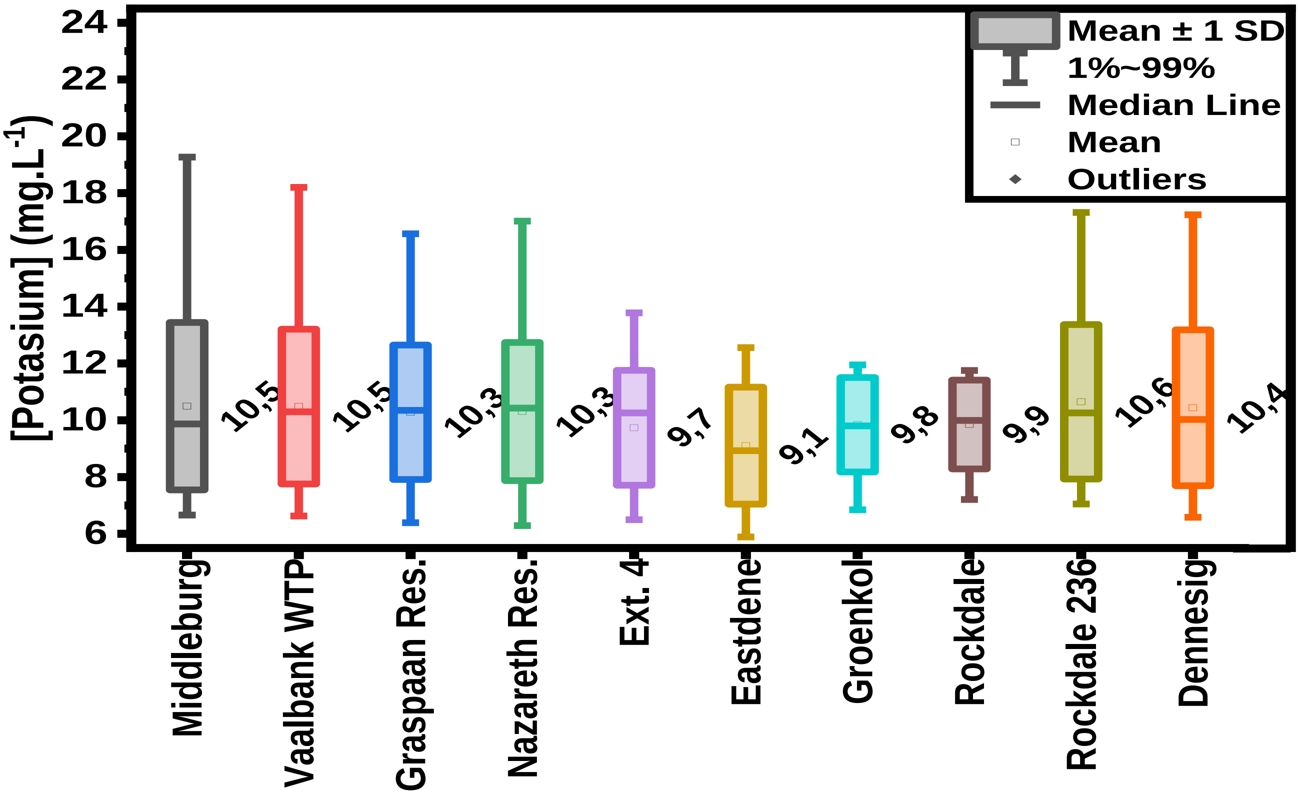

Figure 4-11: Box-whiskers plot of potassium

Potassium is one of the essential elements in humans. It occurs widely in the environment and natural waters. In water treatment works, potassium occurs in drinking-water as a result of applying potassium permanganate as an oxidant in water treatment (Zhou, Huang, Pontius, *et al.*, 2016).

4.2.3 Physicochemical parameters (Chemical Macro Determinants)

The tolerable amounts for the chemical macro determinants as set out in the South African Standard for Drinking Water are outlined as follows:

- Free chlorine ≤ 5 mg/L,
- Nitrate ≤ 11 mg/L,
- Nitrite ≤ 0.9 mg/L,
- Sulfate ≤ 250 and ≤ 500 mg/L,
- Fluoride ≤ 1.5 mg/L,
- Chloride ≤ 300 mg/L, sodium ≤ 200 mg/L and
- Total dissolved solids ≤ 1200 mg/L (Nitasha Khatri and Tyagi, 2015).

4.2.3.1 Free Chlorine

Figure 4-12 shows free chlorine concentrations and standard deviations in the sampling area. High mean concentration of free chlorine was noted at the Vaalbank WTP, which was an indication of the addition of chlorine (chlorination) to drinking water to kill parasites, bacteria, and viruses. There was also a greater standard deviation of free chlorine resulting from higher variation of the parameter in different months at the WTP. This indicated that different dosages of chlorine were added at different months as confirmed by the Municipal technicians. Free chlorine concentrations lowered throughout the distribution system; however, concentrations of free chlorine were still noted in the distribution system to ensure that final water is microbiologically safe. The maximum mean concentration for free chlorine was at Vaalbank Water Treatment Plant (Final) (2.21 mg/L) and the minimum mean concentration was at Rockdale 236 (0.05 mg/L). The mean concentrations of free chlorine were within permissible limit (≤ 5 mg/L) at all sampling points.

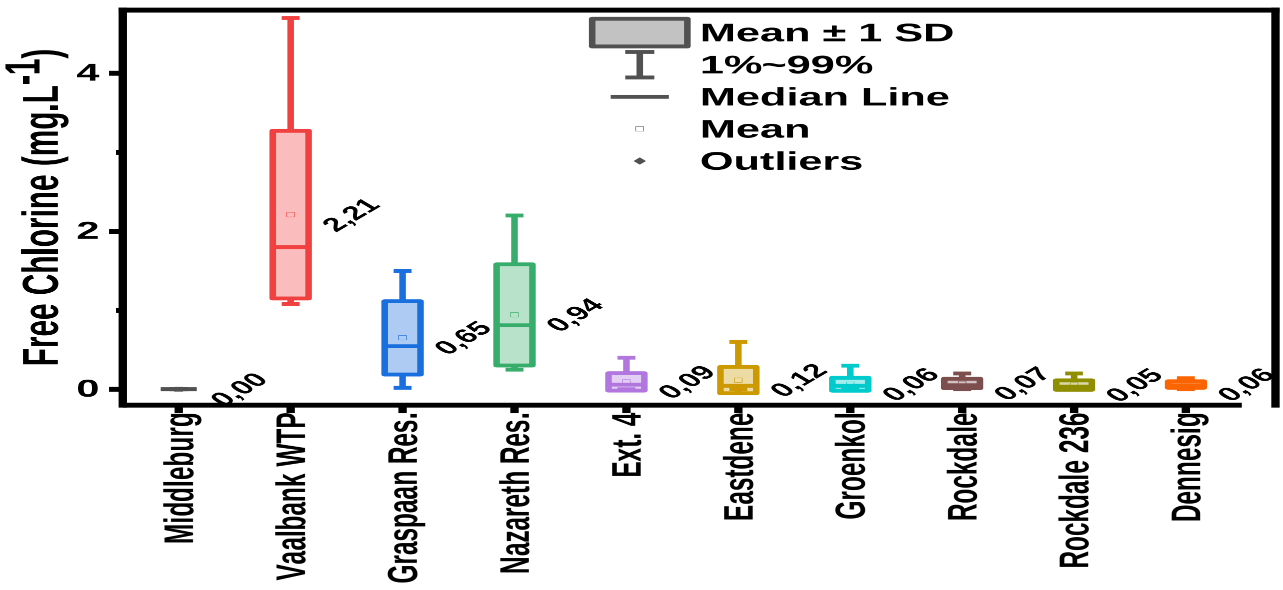

Figure 4-12: Box-whiskers plot of free chlorine

Due to the lack of chlorination at the Middleburg Dam, the free chlorine concentration will be equal to that of the chlorine initially added; thus, the Middelburg Dam (Vaalbank Raw) is not tested for free chlorine.

4.2.3.2 Nitrate and nitrite

Figure 4-13 shows nitrate and nitrite concentrations and standard deviations in the sampling area. The mean concentrations of nitrate indicated very slight changes in nitrate while the mean concentrations of nitrite indicated that nitrites remained the same throughout the distribution system. The maximum mean concentration for nitrate was at Vaalbank Water Treatment Plant (Final) (0.68 mg/L) and the minimum mean concentration was at Groenkol (0.57 mg/L). The mean concentrations for nitrate were within permissible limit (≤ 11 mg/L) at all sampling points. The mean concentrations for nitrite at all sampling points were 0.05 mg/L. The mean concentrations for nitrite were within permissible limit (≤ 0.9 mg/L) at all sampling points.

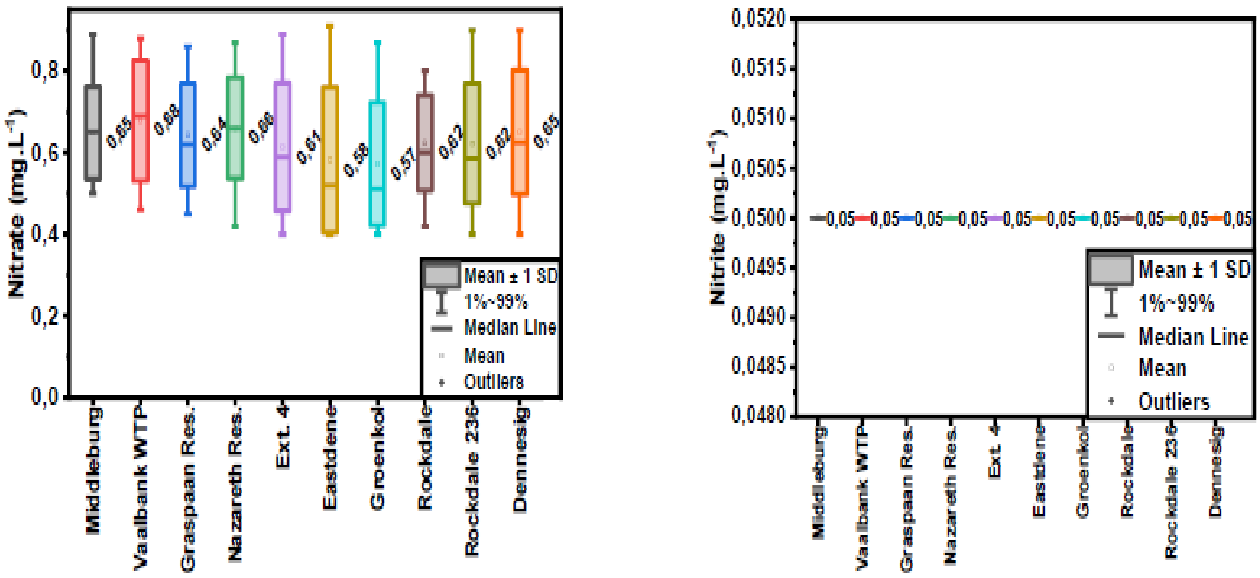

Figure 4-13: Box-whiskers plot of nitrate and nitrite

Nitrate and nitrite are naturally occurring and both form part of the nitrogen cycle. Nitrates and nitrate and reach the surface drinking water as the result of agricultural activities such as the fertilizer and manures through run-off, and other sources like sewage and mineral deposits (Oluyemi *et al.*, 2010; Kumar *et al.*, 2013; Zhou, Huang, Pontius, *et al.*, 2016).

4.2.3.3 Sulfate

Figure 4-14 shows sulfate concentrations and standard deviations in the sampling area. High mean concentration of sulfate was noted at the Middelburg dam (vaalbank raw), which was an indication of serious pollution of the dam by coal mining. There is also a high standard deviation of sulfate at the Middelburg dam (vaalbank raw) which indicates a greater variation of the parameter in different months. The mean concentrations of sulfate also indicated that the sulfate lowered after the water was treated at the WTP and then slight changes in sulfate were noticed throughout the distribution system. The maximum mean concentration for sulfate was at the Middelburg Dam (Vaal bank Raw) (579 mg/L) and the minimum mean concentration was at Eastdene (339 mg/L). The mean concentrations of sulfate at all sites were above 250 mg/L, associated with aesthetic risk while a mean concentration above / > 500 mg/L was found at the Middelburg Dam (Vaal bank Raw), suggesting serious health effects.

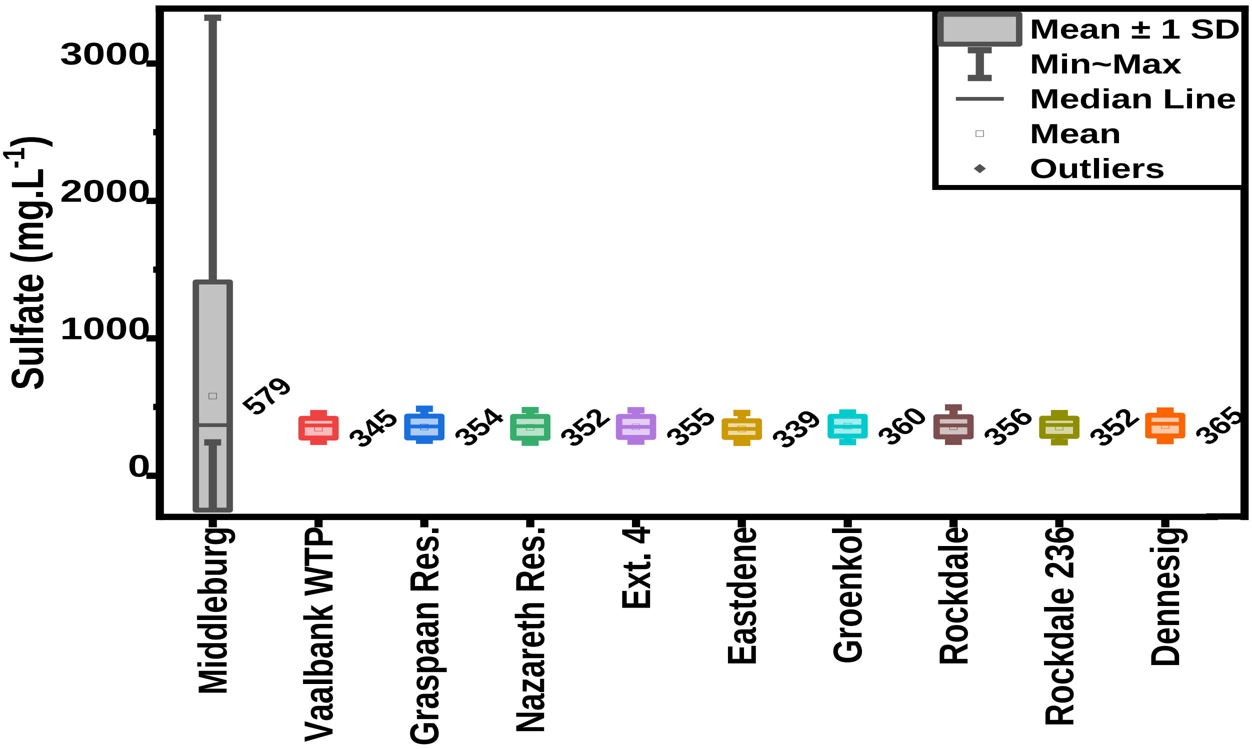

Figure 4-14: Box-whiskers plot of sulfate

The high levels of sulfate suggest pollution of water by activities such as coal mining. Sulfate concentrations above 250 mg/L are associated with aesthetic risk while concentrations above 500 mg/L suggest serious health effects (Su *et al.*, 2017; Edokpayi *et al.*, 2018).

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4.2.3.4 Fluoride

Figure 4-15 shows fluoride concentrations and standard deviations in the sampling area. High mean concentrations of fluoride were noted at Vaalbank WTP, Middelburg dam (Vaalbank raw), and the two reservoirs (Graspan and Nazareth Reservoirs). There were also high standard deviations of fluoride at Vaalbank WTP, Middelburg dam (Vaalbank raw), and the two reservoirs (Graspan and Nazareth Reservoirs), respectively which indicated a greater variation of the parameter in different months at these sampling points. The variation was caused by accidental contamination of water by fires and explosions. The mean concentrations of fluoride also indicated that the fluoride lowered after the water was supplied to the residential areas/ households and then only slide changes in fluoride were noticed throughout the distribution system. The maximum mean concentration for fluoride was at Vaalbank Water Treatment Plant (Final) (0.53 mg/L) and the minimum mean concentration was at Ext. 4 (0.42 mg/L). The mean concentrations for fluoride were within permissible limit (≤ 1.5 mg/L) at all sampling points.

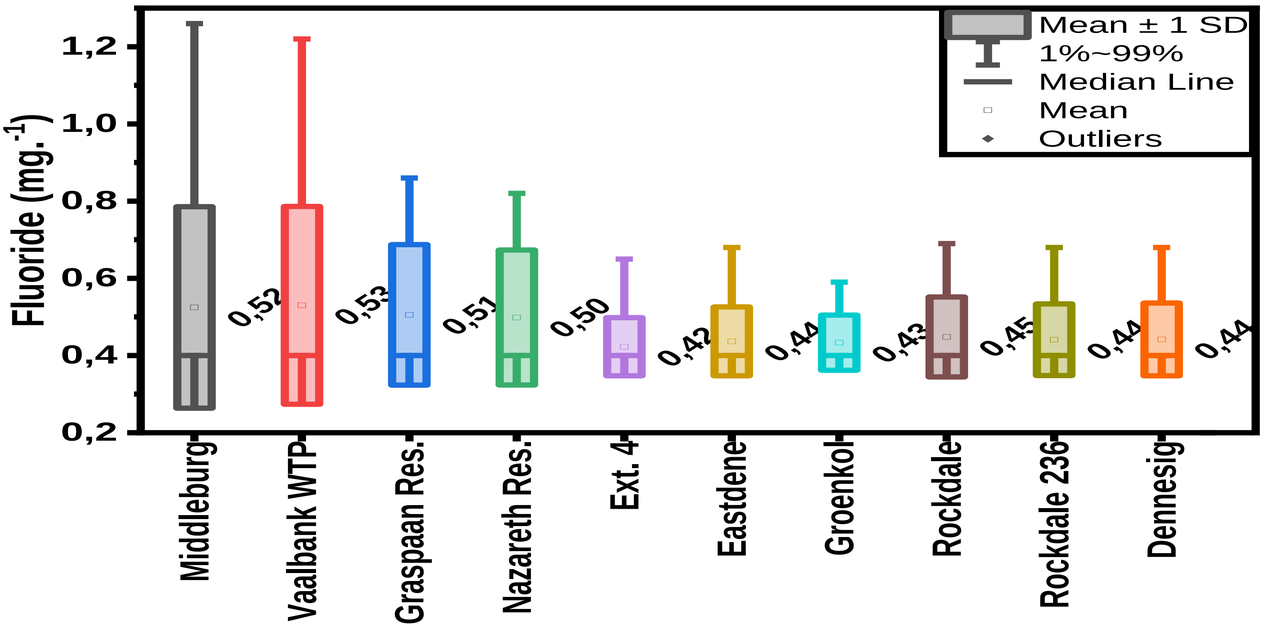

Figure 4-15: Box-whiskers plot of fluoride

Fluoride is a naturally occurring mineral that is released into the water, soil, and the air. So, water will naturally contain fluoride (Nitasha Khatri and Tyagi, 2015).

4.2.3.5 Chloride

Figure 4-16 shows chloride concentrations and standard deviations in the sampling area. The maximum mean concentration for chloride was at Vaalbank Water Treatment Plant (Final) (25.5 mg/L) and the minimum mean concentration was at Middelburg dam (Raw) (21.8 mg/L). The mean concentrations for chloride were within permissible limit (≤ 300 mg/L) at all sampling points. The mean concentrations of chloride indicated very slight changes of chloride throughout the distribution system.

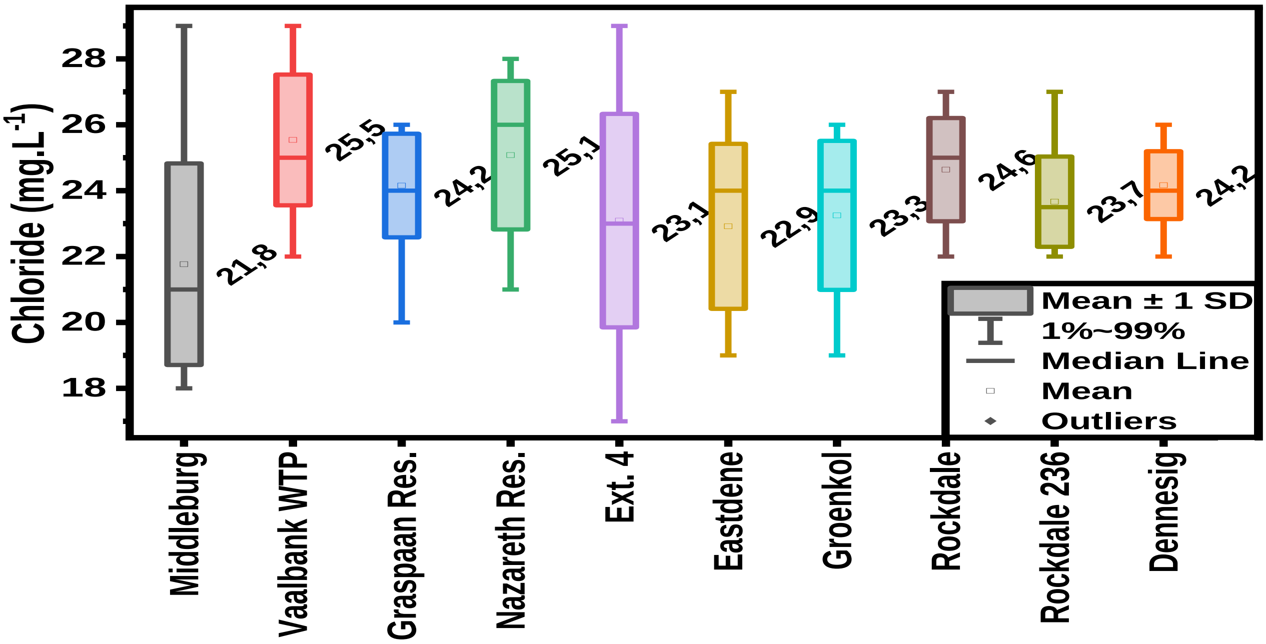

Figure 4-16: Box-whiskers plot of chloride

Chloride is common in natural waters and a naturally occurring element that is found as a component of salt (sodium chloride) or in some cases in combination with potassium or calcium (Oluyemi *et al.*, 2010; Bhat *et al.*, 2014; Sajitha and Smitha, 2016; Alam *et al.*, 2017; Bouaroudj *et al.*, 2019).

4.2.3.6 Sodium

Figure 4-17 shows sodium concentrations and standard deviations in the sampling area. The mean concentrations of sodium indicated very slight changes of chloride throughout the distribution system. The maximum mean concentration for sodium was at Dennesig (28.7 mg/L) and the minimum mean concentration was at Eastdene (24.11 mg/L). The mean concentrations for sodium were within permissible limit (≤ 200 mg/L) at all sampling points.

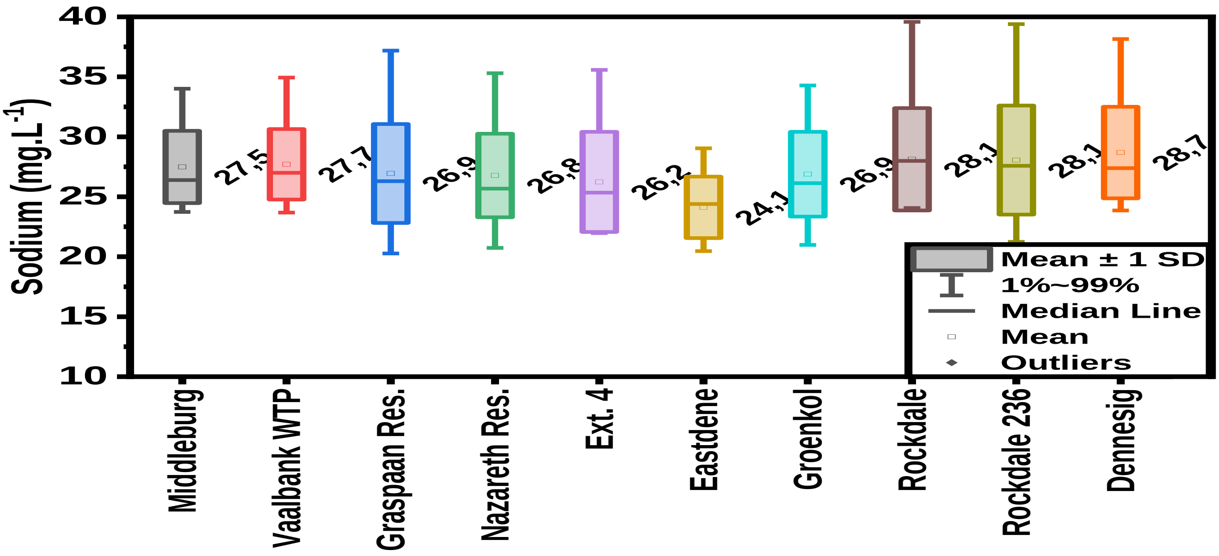

Figure 4-17: Box-whiskers plot of sodium

While sodium is a naturally occurring element that can be found in water, there are some other anthropogenic activities that elevate sodium levels in surface water such as sewage effluents, the chemicals that are used to treat the water, road salt and domestic water softeners (Sajitha and Smitha, 2016; Taufique Arefin *et al.*, 2016).

4.2.3.7 Total dissolved solids/ TDS

Figure 4-18 shows TDS concentrations and standard deviations in the sampling area. The mean concentrations of TDS indicated slight changes of TDS throughout the distribution system. The maximum mean concentration for total dissolved solids was at Dennesig (629 mg/L) and the minimum mean concentration was at Eastdene (587 mg/L). The mean concentrations for total dissolved solids were within permissible limit (≤ 1200 mg/L) at all sampling points as per the South African Standard for drinking water (SANS 241:2015).

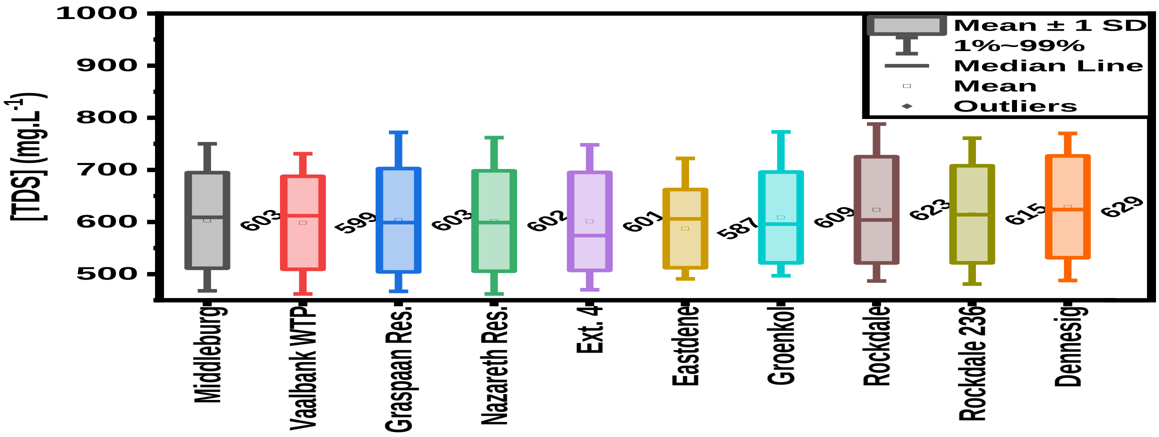

Figure 4-18: Box-whiskers plot of total dissolved solids/ TDS

TDS contain small amounts of organic matter and consist of mainly magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates. Salinity also gives a measurement of the amount of TDS that are present in the water. According to the United States Environmental Protection Agency (EPA) secondary drinking water regulations, 500 mg/L is the recommended maximum amount of TDS for drinking water. Any measurement higher than 1000 mg/L is an unsafe level of TDS. If the level exceeds 2000 mg/L, then a filtration system may be unable to properly filter TDS.

4.2.4 Heavy metals (Micro-determinants)

The tolerable amounts for heavy metals/micro–determinants of interest as set out in the South African Standard for Drinking Water are outlined as follows:

- Aluminium ≤ 0.3 mg/L,
- Iron ≤ 2.0 and ≤ 0.3 mg/L, and
- Manganese ≤ 0.1 and ≤ 0.4 mg/L.

4.2.4.1 Aluminium

Figure 4-19 shows aluminium concentrations and standard deviations in the sampling area. The mean concentrations of aluminium indicated that aluminium remained very low with slight changes throughout the distribution system. The maximum mean concentration for aluminium was at Ext 4 (0.144 mg/L) and the minimum mean concentration was at Middelburg Dam (Vaalbank Raw) (0.044 mg/L). The mean concentrations for aluminium were within permissible limit (≤ 0.3 mg/L) at all sampling points. Drinking water with slightly higher aluminium is associated with operational risk (Anugrah, 2015).

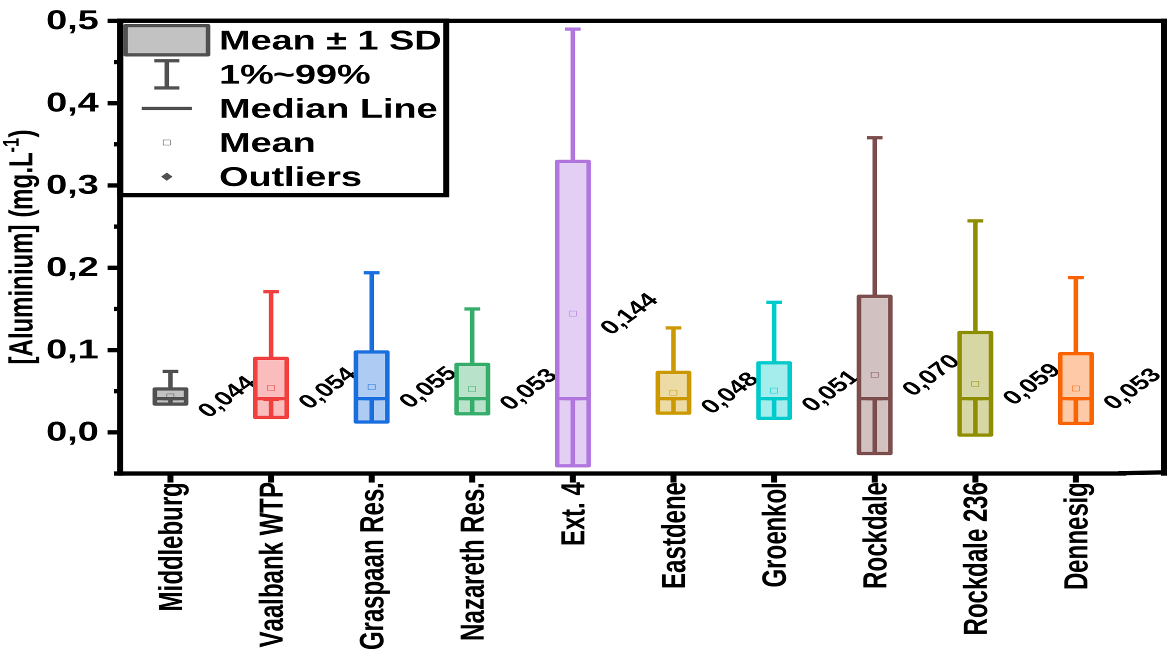

Figure 4-19: Box-whiskers plot of aluminium

Aluminium may be present in water due to natural sources and other human activities like aluminium production and mining activities. Aluminium in water is a result of aluminium salts that are commonly added as coagulants during water treatment to remove turbidity, organic matter, and microorganisms. Aluminium is found in other water treatment chemicals and has the ability to leach into drinking water from cement mortar pipes or linings (Maharaj, 2003; O'REILLY and Dissertation, 2012; WHO, 2012; Ncube, 2014; Prasad and Danso-Amoako, 2014).

4.2.4.2 Iron

Figure 4-20 shows iron concentrations and standard deviations in the sampling area. The mean concentrations of iron indicated that iron remained low and with slight changes throughout the distribution system. The maximum mean concentration for iron was at Groenkol (0.07 mg/L) and the minimum mean concentration was at Denessig (0.046 mg/L). The mean concentrations for iron were within permissible limits (≤ 2.0 and ≤ 0.3 mg/L) at all sampling points.

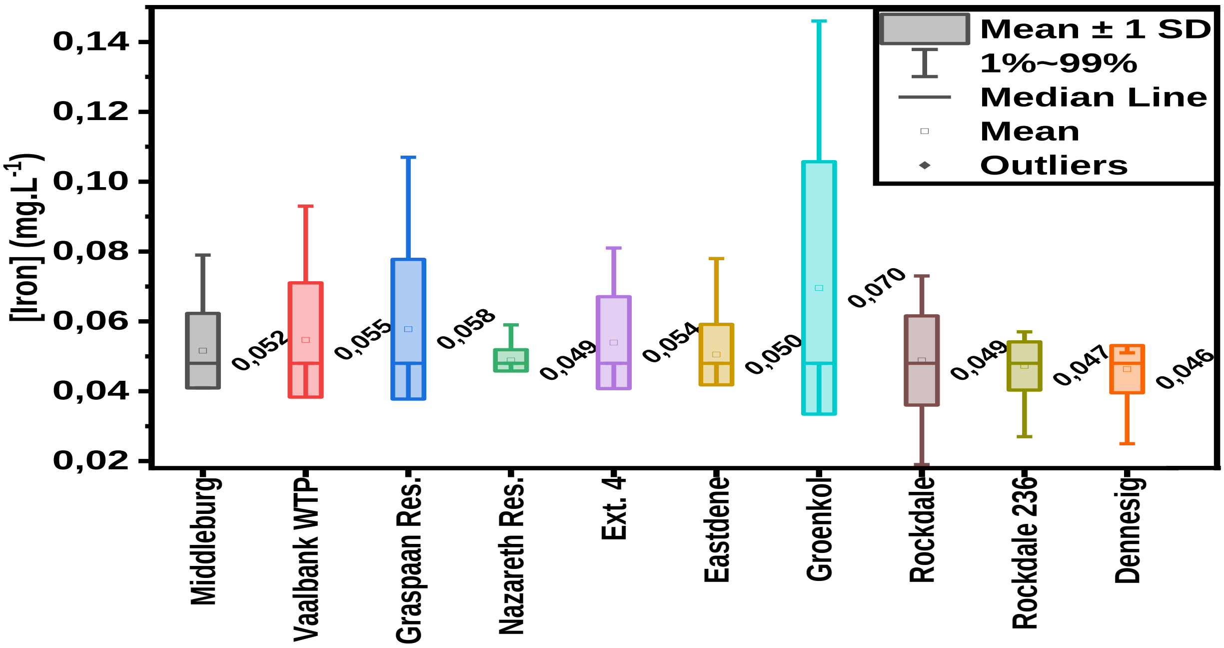

Figure 4-20: Box-whiskers plot of iron

The body needs iron to transport oxygen in the blood. Most iron comes from food since the body cannot easily absorb iron from water. Iron may present some concern if harmful bacteria have entered a water body as it speeds the growth of some harmful organisms. It has always been difficult to get rid of harmful bacteria if there is iron in water (Kumar *et al.*, 2013; Ma *et al.*, 2020).

4.2.4.3 Manganese

Figure 4-21 shows manganese concentrations and standard deviations in the sampling area. The maximum mean concentration for manganese was at Vaalbank Water Treatment Plant (Final) (0.34 mg/L) and the minimum mean concentration was at Dennesig (0.08 mg/L). Higher mean concentrations of manganese were also noticed at Graspan reservoir (0.28 mg/L) and Nazareth reservoir (0.32 mg/L). There was a considerable pollution of the water treatment plant and the reservoirs because of steel production and mining activities. The mean concentrations of manganese at most sampling points were above the limit of ≤ 0.1 mg/L, associated with aesthetic risk.

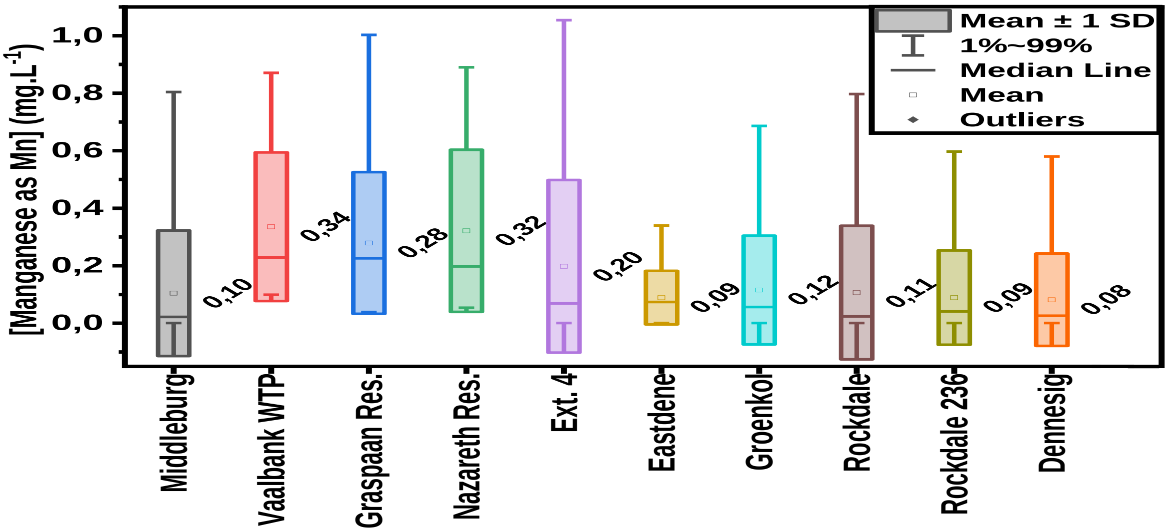

Figure 4-21: Box-whiskers plot of manganese

Manganese is a mineral like iron. Adults and babies drinking water containing manganese above certain levels may suffer harmful health effects. Drinking water with high concentrations of manganese is associated with a nervous system disease with symptoms like Parkinson's disease (Prasad and Danso-Amoako, 2014, 2014; Taufique Arefin *et al.*, 2016).

4.3 Chapter summary

Throughout the period, the pH remained within the range of SANS, which is ≥ 5 - ≤ 9.7 with the highest pH measured in Ext 4 in December 2021 (and the lowest in Middleburg dam in March 2021). Throughout the distribution system, pH also remained within range. In all the sampling points in the sampling period, electrical conductivity was below SANS 241 2015 threshold; it remained lower than 170 mS/m throughout the sampling period. These results indicated that the ions responsible for electrical conductivity also remained within a consistent range and were not affected by the treatment system. The consistency of electrical conductivity suggested that electrical conductivity and concentrations of the ions had a relatively strong correlation. Such correlations have been demonstrated in previous studies. For example, Zaharin *et al* demonstrated that bottled water had a sizeable presence of Na and K and that these ions were contributing to the electrical conductivity of the water while remaining within the WHO threshold for drinking water quality. It is also worth noting that these ions, Na^{+}, K^{+} and Cl^{-} were also way below the SANS threshold for their respective concentrations of which these thresholds are 200, 50 and 300 mg/L for each ion respectively.

CHAPTER 5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The chapter provides the summary, conclusions and recommendations which relate to the three research questions:

- What are the physico-chemical properties and heavy metal concentrations of water from the Middelburg Dam, before and after treatment? (RQ1)
- Do these concentrations change from raw water that flows into the water treatment plant, from the dam to the water stored in reservoirs and supplied to households after treatment? (RQ2)
- Are both physico-chemical properties and heavy metal concentrations within permissible limits? (RQ3)

The chapter also provides recommendations for improving water quality.

5.2 Summary

Potable drinking water is essential for domestic, industrial, and agricultural purposes yet the major environmental pollution is related to the pollution of water and the depletion of freshwater (Oluyemi *et al.*, 2010; Alam *et al.*, 2017). Despite strides being made in the world to have about 89% better drinking water sources that may include treated drinking water as stated by the World Health Organization (WHO), water obtained from improved drinking sources may still contain contaminants such as heavy metals (Alam *et al.*, 2017).

The average pH values ranged from 7.46 – 7.58 amongst the sampling points. The level of pH signifies that all the water samples were within the set limits as recommended by SANS 241-1, (2015). Turbidity was found to be less than 1 NTU in all the sampling points which is within the recommended limits by DWA, (2005). The water was found to be within the aesthetic total dissolved solids (TDS) levels as it was below the 1200 mg/L as stated by (SANS 241-1, 2015) with readings of 587 to 629 mg/L. Colour was also found to be within the permissible limit (≤ 15 mg/L) at all sampling points SANS 241-1, (2015). Alkalinity poses no health effect, therefore a reading of between 75% and 100% is acceptable (Islam & Majumder, 2020). In this study, the mean levels ranged from 64.7 to 71.5. Water hardness is determined by the concentrations of calcium and magnesium. In this study, magnesium ranged from 20.5 to 21.4 mg/L which was below the recommended limits of less than 70 mg/L, while calcium was slightly higher as it ranged from 156 to 168mg/L above the recommended limits of less than 150 mg/L (DWA, 2005). The maximum allowable concentrations for a limited period range from 150 – 300 mg/L, although with long exposure can lead to laxative effects (Sengupta, 2013). Potassium read between 9.1 and 10.6 in average was below the standard limits (SANS 241-1, 2015). The aesthetic limit for sulfate must be less than 250 mg/L and the acute health chemical presence is at 500 mg/L and above (SANS 241-1, 2015). Samples collected from Middleburg had a mean value of 579 mg/L indicating an acute health problem and can also have laxative effects mostly to people not used to the water (Sengupta, 2013). Sulfate concentrations are linked to coal mine water as stated by Gyamfi, Appiah-Adjei and Adjei, (2019), and the study area is close to coal mines indicating contribution of pollution from the mines. Fluoride, Chloride and Sodium were also within the recommended limits of 1.5 mg/L, 300 mg/L and 200 mg/L respectively (SANS 241-1, 2015). The other heavy metals tested were aluminium (0.044 – 0.144 mg/L) and iron (0.046 – 0.070 mg/L) and were also within the recommended limits of ≤ 0.3 mg/L and ≤ 0.3 mg/L respectively (SANS 241-1, 2015). The mean concentrations of manganese at most sampling points were above the limit of ≤ 0.1 mg/L, associated with aesthetic risk.

The levels detected from aluminium indicate possible pollution from wastewater and industrial processes dealing with aluminium processes (Anugrah, 2015). Drinking water had high concentrations of manganese associated with aesthetic risk. The levels of manganese suggested a considerable pollution of water with steel production and mining activities. The heavy metals concentrations showed to be of concern and a public health risk.

5.3 Conclusions

It is observed that water collected from the sources supplying the study area do contain concentrations of heavy metals although at lower ranges and manganese and sulfate at a slightly higher than acceptable. Consumptions of water with recorded concentrations overtime can be detrimental overtime due to accumulations. Findings of this study demonstrated that physico-chemical parameters such as pH, EC, m- alkalinity, total hardness, calcium hardness, magnesium hardness, calcium, magnesium, potassium, nitrate, nitrite, fluoride, chloride, sodium, and TDS were consistent throughout the distribution system and within the set limits were within the acceptable limits of South African Standard for drinking water by SANS 241: (2015) and DWA, (2005). Calcium, magnesium, and potassium mean concentrations for all the sampling points were also within the acceptable limits set by SANS 241: (2015) and DWA, (2005). Aluminium and iron mean concentrations for all the sampling points were within the acceptable limits recommended by DWA, (2005), while the mean concentrations of manganese were higher at the water treatment plant and the reservoirs and slightly higher at most sampling points (above the limit of ≤ 0.1 mg/L), associated with aesthetic risk as mentioned in the SANS 241-1, (2015). The high levels of sulfate suggest pollution of water by activities such as coal mining. The levels of manganese suggest a considerable pollution of water with steel production and mining activities.

5.4 Recommendations for improving water quality

The study recommends an in-depth analysis of the impacts of mining and other anthropogenic activities on the Middelburg dam and Olifants river catchment and the associated human health problems of the people living around the study area.

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APPENDICES

Appendix 5-1: Mean values of physical determinants (March 2020 – March 2021)

	pH (pH Units)	Turbidity (NTU)	EC (mS/m)	True colour (mg/L Pt-Co)
Middelburg dam (vaalbank raw)	7,46	0.95	100	5.96
Vaalbank WTP (final)	7,53	0.63	100	3.38
Graspan reservoir	7,48	0.69	100	3.54
Nazareth reservoir	7,51	0.68	100	3.31
Ext 4	7,61	0.74	100	3.55
Eastdene	7,49	0.50	93	3.00
Groenkol	7,51	0,54	103	3.04
Rockdale	7,58	0,61	102	3.18
Rockdale 236	7,46	0.62	101	3.88
Dennesig	7,60	0.69	103	2.82

Appendix 5-2: Mean concentrations of physico-chemical parameters (Alerts) (March 2020 – March 2021)

	m-Alkalinity as $CaCO_3$ (mg/L)	Total Hardness as $CaCO_3$ (mg/L)	Calcium Hardness as $CaCO_3$ (mg/L)	Magnesium Hardness as $CaCO_3$ (mg/L)	Ca as Ca (mg/L)	Magnesium as Mg (mg/L)	Potassium as K (mg/L)
Middelburg dam (vaalbank raw)	71,5	376	162	214	64,9	52.0	10,5
Vaalbank WTP (final)	68,0	371	160	212	64.0	51,5	10,5
Graspan reservoir	64,8	377	166	211	66,7	51,2	10,3
Nazareth reservoir	64,9	374	166	208	66,7	50,4	10,3
Ext 4	64,9	376	163	213	65,3	51,7	9,7
Eastdene	64,7	361	156	205	62,6	49,9	9,1
Groenkol	67,8	378	163	214	65,5	52,1	9,8
Rockdale	68,2	377	165	212	65,9	51,6	9,9

Rockdale 236	66,7	371	161	210	64,6	50,9	10,6
Dennesig	66,5	378	166	212	66,7	51,4	10,6

Appendix 5-3: Mean concentrations of physicochemical parameters (Chemical Macro Determinants) (March 2020 – March 2021)

	Free Chlorine as Cl (mg/L)	Nitrate as N (mg/L)	Nitrite as N (mg/L)	Sulphate as SO4 (mg/L)	Fluoride as F (mg/L)	Chloride as Cl (mg/L)	Sodium as Na (mg/L)	TDS Measured / Calculated (mg/L)
Middelburg dam (vaalbank raw)	**x**	0,65	0,05	579	0,52	21,8	27,5	603
Vaalbank WTP (final)	2,21	0,68	0,05	345	0,53	25.5	27,7	599
Graspan reservoir	0,65	0,64	0,05	354	0,51	24,2	26,9	603
Nazareth reservoir	0,94	0,66	0,05	352	0,50	25,1	26,8	602
Ext 4	0,09	0,61	0,05	355	0,42	23,1	26,2	601
Eastdene	0,12	0,58	0,05	339	0,44	22,9	24,1	587
Groenkol	0,06	0,57	0,05	360	0,43	23,3	26,9	609
Rockdale	0,07	0,62	0,05	356	0,45	24,6	28,1	623
Rockdale 236	0,05	0,62	0,05	352	0,44	23,7	28,1	615
Dennesig	0,06	0,65	0,05	365	0,44	24,2	28,7	629

Appendix 5-4: Mean concentrations of heavy metals (Micro-determinants) (March 2020 – March 2021)

	Aluminium as Al (mg/L)	Iron as Fe (mg/L)	Manganese as Mn (mg/L)
Middelburg dam (vaalbank raw)	0,044	0,05	0,10
Vaalbank WTP (final)	0,054	0,05	0,34
Graspan reservoir	0,055	0,06	0,28
Nazareth reservoir	0,0053	0,05	0,32
Ext 4	0,144	0,05	0,20
Eastdene	0,048	0,05	0,09
Groenkol	0,051	0,07	0,12
Rockdale	0,070	0,05	0,11
Rockdale 236	0.059	0,05	0,09
Dennesig	0.053	0,05	0,08