

**THE ASSESSMENT OF WATER SUPPLY SYSTEM EFFICIENCY AND
WATER QUALITY IN STANDERTON, LEKWA MUNICIPALITY,
MPUMALANGA, SOUTH AFRICA**

By

Shikwambana Pamleh Patience

Student Number: 11541666

Supervisor: Prof Makungo Rachel

Co-Supervisor: Mr Sengani Ben

**A dissertation submitted to the Department of Earth Science, Faculty of
Science, Engineering and Agriculture at the University of Venda in fulfilment
of the requirements for Master of Earth Science in Hydrology and Water
Resources**

August 2025

Dedication

This research is also dedicated to all those who believe in the pursuit of knowledge for the betterment of society. This work is dedicated to my family, whose unwavering support, encouragement, and prayers have been a source of strength throughout this academic journey.

Acknowledgements

I extend my deepest gratitude to God Almighty for the strength, guidance, and perseverance granted to complete this research. I am sincerely thankful to Professor Makungo for her mentorship, encouragement, and academic guidance throughout the study period. Special thanks go to Mr. Sengani for his unwavering support, patience, and valuable contributions that motivated me to complete this work. I am profoundly grateful to my husband, Tinyiko Stanley Mabasa, and our four children Ntsako, Kulani, Kurisani, and Ripfumelo Mabasa for their constant support and understanding during my academic commitments. I am thankful to my mother, Tintswalo Shikwambana, for her continuous prayers and spiritual guidance, and I honour the memory of my late father, Grafton Shikwambana, whose belief in the value of education continues to inspire me. Appreciation is also extended to my siblings Isabel, Eschel, and Frederick Shikwambana and my devoted friend, Khuliso Mubva, for their ongoing encouragement. Institutional acknowledgements go to the Department of Water and Sanitation (Mpumalanga and Polokwane offices) for providing water quality data and study support, especially Mr. Hlabane Pat. I also thank the Lekwa Local Municipality for granting research access and the process operators for their assistance during site visits. Lastly, I gratefully acknowledge the Department of Water and Sanitation for the financial support that made this study possible.

ABSTRACT

Most municipalities in South Africa face significant challenges in managing their water treatment plants effectively, often due to a lack of technical expertise, insufficient staffing and poor maintenance planning. These result in poor water quality, frequent supply interruptions and failure to comply with regulatory standards. Furthermore, difficulties in retaining skilled personnel and misallocation of resources exacerbate the problem, exposing communities to health risks and unreliable water services that undermine sustainable water supply efforts. This study evaluated the efficiency of the water supply system and assessed water quality at the Standerton Water Treatment Plant (SWTP) in Lekwa Local Municipality, Mpumalanga, South Africa. The assessment focused on operational performance, distribution effectiveness and compliance with national and international water quality standards. Data were collected through field observations, water meter readings and five years of water quality data obtained from the Department of Water and Sanitation (DWS) Mpumalanga from 2016 to 2020. Efficiency analysis involved comparing water quantity against demand, quantifying water losses and assessing distribution reliability. Water quality was evaluated by comparing measured parameters to guidelines set by the World Health Organization (WHO), South African National Standard (SANS-241), and Department of Water Affairs (DWA). Parameters analyzed included microbiological indicators such as *Escherichia coli* and total coliforms, as well as physicochemical variables like pH, turbidity, free chlorine, electrical conductivity (EC), total dissolved solids (TDS), manganese (Mn), and iron (Fe). The results showed that pH, EC, and TDS consistently met the acceptable limits throughout the five-year period, indicating stable performance in these aspects. However, free chlorine, turbidity, manganese and iron persistently exceeded regulatory limits, signaling systemic issues within the treatment process. These ongoing exceedances point to challenges such as inadequate chemical dosing, poor filtration, ineffective disinfection and possible contamination within the distribution network. Of particular concern was the detection of *E. coli*, suggesting faecal contamination and increased risk of waterborne diseases. The elevated turbidity, Mn and Fe levels also affected water aesthetics, leading to consumer complaints and diminished trust in the municipal water supply. Operational challenges identified include aging infrastructure, poor maintenance practices, inaccuracies in chemical dosing and delayed responses to equipment failures such as

malfunctioning pumps and burst pipelines. The plant operates beyond its designed capacity; although licensed for 27 ML/day with a design capacity of 37 ML/day, SWTP treated 43 ML/day while the estimated demand was approximately 45 ML/day. This overcapacity strains the plant, contributing to the suboptimal treatment performance. Additionally, the plant did not comply with regulatory requirements mandating the measurement of critical parameters pH, turbidity and EC at two-hour intervals, due to a lack of necessary analytical equipment. Staffing issues were prevalent, with many process controllers lacking formal training and qualifications necessary for effective plant management. The study also highlighted real-world impacts on local businesses, such as Goldie Chicken, which experiences water outages lasting up to two days per week. These interruptions have resulted in reduced production, workforce retrenchment and the inability to meet market demand. To improve water service delivery, it is imperative for the municipality to invest in upgrading water treatment infrastructure, ensure that plant personnel meet minimum qualification standards and implement continuous training programs to build technical capacity. Strengthening operational management and maintenance practices is essential to achieving regulatory compliance, safeguarding public health and securing a sustainable water supply for the Standerton community.

Keywords: Surface Water, Water Quality, Efficiency, Sustainability, Water Balance, Water loss

Table of Contents

Dedication	I
Acknowledgements	II
ABSTRACT	III
Table of Contents	V
LIST OF FIGURES.....	IX
LIST OF TABLES	X
LIST OF SYMBOLS	XI
LIST OF ACRONYMS.....	XII
Chapter 1	1
Introduction	1
1.1 Background	1
1.2 Statement of the problem	3
1.3 Justification of the study	5
1.4 Objectives of the study.....	6
1.4.1. The main objective of the study.....	6
1.4.2 Specific objectives	7
1.5 Research Questions	7
1.6 Characteristics of the study area	7
1.6.1 Location	7
1.6.2 Topography and Geology	10
1.6.3 Climate.....	10
1.6.4 Land Use	10
1.6.5 Mining.....	11
1.6.6 Dams	12
Chapter 2	13
Literature Review	13
2.1 Preamble.....	13
2.2 Water resources availability in South Africa	13

2.3 Water supply efficiency	14
2.3.1 Link between water supply efficiency and Integrated water resource management (IWRM)	15
2.3.2 Water governance theory	17
2.3.4 Global and South African perspectives on best practices in water supply efficiency ..	17
2.4 Overview of South Africa's water supply system and infrastructure.....	19
2.5 Water Quality in South Africa	20
2.5.1 Linkages between water supply efficiency and water quality	20
2.6 Chemical properties of water	21
2.6.1 Free chlorine	21
2.6.2 Iron (Fe)	22
2.6.3 Manganese (Mn)	23
2.7 Physical properties of water	24
2.7.1 Total dissolved solids (TDS)	24
2.7.2 Turbidity	24
2.7.3 Electrical Conductivity (EC).....	25
2.8 Microbiological Properties of Water.....	25
2.8.1 Escherichia Coliform (E-coli).....	25
2.8.2 Total coliform	26
2.9 Water Supply in South Africa	27
2.10 Layout of Water Treatment Supply Processes	28
2.10.1. Feed Water for Municipal Water Treatment.....	28
2.10.2. Screening	28
2.10.3. Chemical Pre-treatment	28
2.10.4. Flocculation.....	29
2.10.5. Sedimentation.....	30
2.10.6. Filtration.....	31
2.10.7. Disinfection.....	32
2.11 Water Supply Efficiency Measures in South Africa	33
2.12 Sustainability of Water Resources in South Africa.....	33
2.13 Assessing efficiency of Domestic Water Supply in South Africa	34
2.14 Water Legislation in South Africa	35
2.14.1 Water Services Act (108) of 1997.....	35

2.15.2. National Water Act (36) of 1998	36
2.15.3 Municipal Structures Amendment Act (3) of 2021	36
2.15.4 Free Basic Water Policy (FBW), April 2007	37
2.15.5 National Water Resource Strategy (NWRS) March (2023).....	38
Chapter 3	40
Research Methodology	40
3.1 Preamble.....	40
3.2 Data Collection.....	40
3.2.1 Field observations	40
3.2.2 Water Sampling	41
3.3 Data Analysis	41
3.3.1 Water Quality.....	41
3.3.2 Water Quantity.....	42
3.4 Water Supply Efficiency and Water Balance for Standerton.....	43
3.5 Limitations and Challenges Encountered During Data Collection	44
Chapter 4.....	46
Results and Discussion.....	46
4.1 Preamble.....	46
4.2 Water Supply in Standerton	46
4.2.1 Raw Water Supply from Vaal River	46
4.2.2 Layout of the Standerton Water Supply System and Distribution Network Diagram ..	47
4.3 Water Quality Results for Raw, Final and Sasol Garage	54
4.4 Summary of the Relationship of Parameters Beyond Water Quality Guidelines	65
4.5 The Impact of Overflow of Water from the Flocculation Channels on a Daily Basis in SWTP	66
4.6 Results on Water supply efficiency and Water balance	67
4.7 Water Supply Sustainability in Standerton	71
Chapter 5	73
Conclusion and Recommendations	73
5.1 Conclusion.....	73
5.2 Recommendations	76
References	79
APPENDICES.....	91

APPENDIX A: STANDERTON WATER TREATMENT WORKS DATA RESULTS FROM 2016 TO 2020	91
Appendix B: Monthly Meter Reading.....	99
Appendix C: Observation and Tools used for Field Research	100

LIST OF FIGURES

Figure 1.1: Map of the study area.....	9
Figure 2.1: Indicate the typical water supply treatment processes.	33
Figure 4.1: PH of raw and final water.....	47
Figure 4.2: Chlorine for raw and final water.....	48
Figure 4.3: Electrical conductivity for raw and final water.....	49
Figure 4.4: Turbidity for raw and final water.....	50
Figure 4. 5: Total dissolved solid for raw and final water.....	52
Figure 4.6: <i>E-Coli</i> counts for raw and final water.....	53
Figure 4. 7: Total coliform for raw and final water.....	55
Figure 4. 8: Manganese for raw and final water.....	56
Figure 4.9: Iron for raw and final water.....	57
Figure 4.10: Electrical Conductivity for raw, final water and sasol garage.....	58
Figure 4. 11: Pump 1 and Pump 2.....	60
Figure 4.12: Standerton Water Treatment Works.....	61
Figure 4.13: E-Coli counts for raw, final water and sasol.	62
Figure 4.14: Standerton Water Supply Scheme.	63
Figure 4.15: 2 Concor Reservoir.....	65
Figure 4.16: Fe raw, final water and sasol garage.....	66
Figure 4.17: Water loss due to overflow from flocculation channels daily.	68
Figure 4.18: Diagrams of water balance of water supply in standerton.	70

LIST OF TABLES

Table 4.1: Water Balance Based on the Demand Supply Scenario and the Diagram of Water Balance of Water Supply in Standerton	69
Table 5.1: Results of the Monitoring Sites.....	92
Table 5.2: Shows the Results of the Monthly Meter Reading	100

LIST OF SYMBOLS

% - percent

= - equal to

> - greater than

± - plus, or minus

≤ - less than or equal to

μm -micrometres

cm - centimetres

cm³ - cubic centimetres

g/m³ - grams per cubic metres

km - kilometres

km² - square kilometres

Mℓ - mega litres

mL - millilitres

mm - millimetres

ML/d- megalitre per day

mM - millimolar

mS - millisiemens

N - normality

nm - nanometres

pg/dm³ - picogram per cubic decimetres

ppb - parts per billion

ppm - parts per million

μg/dm³ - microgram per cubic decimetres-

LIST OF ACRONYMS

APHA – American Public Health Association

CBD – Central Building District

CDC – Centers for Disease Control

CFU – Colony forming units

COD – Chemical oxygen demand

CMS – Catchment Management Structures

DL – Detection limit

DMAs – District Metered Areas

DO – Dissolved oxygen

DOC – Dissolved organic carbon

DWA – Department of Water Affairs

DWAF – Department of Water Affairs

DWS – Department of Water and Sanitation

EC – Electrical Conductivity

E-Coli – Escherichia Coli

EPA – Environmental Protection Agency

FAO – Food and Agriculture Organization

Fe – Iron

FBW – Free Basic Water

GIS – Geographic Information System

IWRM – Integrated Water Resource Management

OECD – Organisation for Economic Co-operation and Development

N – Nitrogen

ND – Not detected

NDP – National Development Plan

NTU – Nephelometric turbidity unit

NWA – National Water Act

NRW – Non Revenue Water

NWRS – National Water Resource Strategy

Mn – Manganese

TC – Total Coliform

TDS – Total dissolved solids

TSS – Total suspended solids

TWA – Total Water Available

TWS – Total Water Supply

SALGA – South African Local Government Association

SANS-241 – South African National Standard

SCADA – Supervisory Control and Data Acquisition

SANBI – South African National Biodiversity Institute

SDG – Sustainable Development Goal

SWTP – Standerton Water Treatment Supply

UNESCO– United Nations Educational, Scientific and Cultural Organization

WB– World Bank

WHO – World Health Organisation

WTWs – Water Treatment Works

WSA– Water Service Authority

WSDPS – Water Services Development Plan System

WSE – Water Supply Efficiency

WSP –Water Service Provider

RSA – Republic of South Africa

Chapter 1

Introduction

1.1 Background

Water supply system efficiency refers to the effectiveness of treatment and distribution systems in delivering water to end-users while minimizing losses, optimizing operational performance and ensuring resource sustainability (United Nations, 2015; Lockwood and Smits, 2011). Molobela (2011) highlighted that water supply efficiency is a critical global challenge linked to water scarcity and environmental issues. As a developing nation with rising water demand, South Africa must manage this vital resource effectively to promote sustainable development and enhance quality of life (Nkonsi et al., 2018). Water is essential for human health, socio-economic progress and environmental sustainability (WHO, 2017). Access to clean and reliable drinking water is enshrined as a basic human right under Section 27 of the South African Constitution (RSA, 1996). In response, South Africa has established an advanced legal and policy framework governing water management, including the Water Services Act (No. 108 of 1997) and the National Water Act (No. 36 of 1998), which mandate municipalities to provide safe, efficient and sustainable water services to all residents.

Despite this framework, many municipalities continue to face significant challenges concerning the efficiency of water supply systems and the quality of treated water (Ekdopayi et al., 2018). South Africa is classified as a water-scarce country, ranking among the 30 driest globally. Its water resources are unevenly distributed, with 60% of river flow concentrated in only 20% of the land area (DWAF, 2004; DWS, 2018). These geographical limitations, compounded by climatic variability, aging infrastructure, governance deficits and increasing demand, pose serious obstacles to ensuring a reliable potable water supply (DWS, 2018; Muller et al., 2009; World Bank, 2018). The government has delegated water supply responsibilities to local governments, designating municipalities as Water Services Authorities (WSAs) tasked with ensuring access to potable water across the country (RSA, 1997; DWS, 2018). According to DWS (2023), South Africa continues to face substantial challenges regarding the efficiency of its water supply systems. Rapid urbanisation has driven increased water demand alongside significant alterations in land use, which have intensified surface runoff, reduced groundwater recharge and exacerbated the urban heat

effect factors contributing to localized climate change and placing additional stress on already strained water resources (Mthembu, 2022).

Urbanisation has further escalated water consumption across domestic, commercial and industrial sectors. The influx of populations into urban centers intensifies pressure on existing water infrastructure, often outstripping municipalities' capacity to expand or upgrade services (UN-Habitat, 2020; World Bank, 2018; DWS, 2018). Ferdowsi et al. (2024), emphasize that evaluating water supply system efficiency is a complex, multifaceted process that necessitates thorough assessment of infrastructure conditions, water consumption patterns and community behavior. Addressing challenges related to the efficiency of water supply systems is essential for the sustainable management of water resources; however, aging infrastructure within water treatment plants continues to pose a significant problem across the country (Mokoena, 2022). Water supply systems are frequently outdated and susceptible to recurrent failures, including leaking pipes, antiquated distribution networks, malfunctioning water meters, and insufficient maintenance. These issues cause substantial water losses before reaching consumers, thereby intensifying supply constraints and raising concerns within communities (Dlamini, 2023). In numerous South African cities, these challenges contribute to water shortages, service delivery backlogs and declining water quality. These issues stem largely from the combination of aging infrastructure, insufficient maintenance, limited municipal capacity and increasing demand driven by urban growth (DWS, 2018; Muller, 2016; World Bank, 2018).

WTWs are essential for delivering potable water to communities; however, many municipalities face challenges including frequent supply interruptions, low water pressure, discolored water and chlorine odor (Nkosi, 2023). These issues raise serious concerns regarding both the operational efficiency of treatment plants and the quality of water delivered to end-users (DWS, 2023). Such problems affect public health and undermine consumer confidence in municipalities' ability to provide essential services (Muller, 2016; DWS, 2018). Infrastructure degradation including aging asbestos cement pipes, malfunctioning pumps and poorly maintained reservoirs further exacerbates inefficiencies. This degradation delays fault detection and repairs compromising the continuity and reliability of supply (DWS, 2018; Momba et al., 2016; World Bank, 2018). Aging and poorly maintained infrastructure frequently lead to increased water losses from leaks and

bursts, service interruptions and elevated operational costs, all of which undermine water supply system sustainability (World Bank, 2018; DWS, 2018; Mekonnen and Hoekstra, 2016).

The South African National Standard (SANS-241:2015) establishes minimum requirements for the microbiological, chemical, and physical properties of drinking water. Non-compliance with these standards poses significant health risks, particularly for vulnerable populations. Most municipalities face challenges with irregular water quality monitoring and poor record-keeping, complicating efforts to consistently meet SANS-241 standards. The Blue Drop Programme, a government initiative to monitor and rate municipal water quality compliance, has highlighted numerous municipal shortcomings (DWA, 2013; DWS, 2018). These deficiencies largely arise from technical, managerial, and institutional weaknesses, including limited staff capacity, inadequate training, and insufficient investment in infrastructure upgrades. With ongoing pressures from climate change, population growth and increasing water demand, continuous assessment and improvement of municipal water system efficiency and quality are imperative (DWS, 2018; World Bank, 2018; Ekdopayi et al., 2018).

1.2 Statement of the problem

Numerous studies have shown that municipal water treatment facilities across South Africa face substantial operational challenges in meeting consumer demands for safe and reliable drinking water (Momba and Makala, 2017; Auditor-General South Africa, 2022; DWS, 2018). These challenges are compounded by financial constraints, aging infrastructure, frequent pipe bursts and increasing pressure to deliver high-quality water. Consequently, many municipalities are unable to meet the rising demand for potable water (DWS, 2018; Momba and Makala, 2017; Auditor-General South Africa, 2022). Approximately 85% of municipalities struggle to provide consistent access to safe drinking water, posing a serious threat to public health and service delivery (DWS, 2018; Auditor-General SA, 2022; Momba and Makala, 2017). Municipalities, acting as Water Services Providers (WSPs), are legally responsible for ensuring the provision of clean and safe water. While many treatment plants were originally designed or upgraded to meet existing demands, the widening gap between water supply and demand necessitates urgent reassessment of system efficiency, infrastructure renewal and long-term resource planning to secure sustainable water access for all communities (DWS, 2018; World Bank, 2018; Momba and Makala, 2017).

Molobela (2011) emphasized the importance of evaluating the efficiency of water supply systems such as that of Standerton as a prerequisite for sustainable water management.

Several factors hinder efficient service delivery in municipalities, including outdated infrastructure, high water losses due to leaks, inefficiencies in water distribution systems and the absence of reliable data to inform water management decisions (DWS, 2023). Haigh et al. (2010) argued that public awareness and participation in water conservation are critical, yet often lacking, which further impedes efforts to improve water use efficiency. Financial limitations also restrict the ability of municipalities to perform essential maintenance and infrastructure upgrades. These limitations directly undermine sustainable water management and contribute to inconsistent service delivery. Edokpayi et al. (2018), noted that inefficiencies within water supply systems compromise both water quality and resource sustainability, despite the essential role of water in supporting public health and socio-economic development. The reliable supply of clean and safe drinking water is a fundamental human right and an essential public health requirement. In South Africa, especially in smaller towns such as Standerton, many communities continue to face persistent challenges related to intermittent water supply, poor water quality and deteriorating water infrastructure. The Standerton Water Treatment Plant (SWTP), managed by the Lekwa Local Municipality, has experienced increasing concerns from residents regarding water quality, irregular supply, low pressure and frequent system breakdowns. These issues indicate inefficiencies within the supply system and potential non-compliance with national drinking water standards (SANS-241, 2015).

According to DWS (2023), municipal water systems in South Africa suffer from significant water losses within WTWs. A lack of routine maintenance worsens existing infrastructure problems, leading to frequent service disruptions, reduced system performance and diminished water availability for end users (Bhandari et al., 2023). Neglecting preventive maintenance tasks such as pipeline inspections, reservoir cleaning and pump servicing allows minor issues to escalate into major operational failures. This contributes to water contamination risks, increased losses, burst pipes and intermittent supply, particularly in older or overburdened systems (UNESCO, 2019; WB, 2016; Bhandari et al., 2023). As water demand continues to increase due to urbanisation and the impacts of climate change, the inability to proactively maintain and upgrade infrastructure has become a critical barrier to achieving universal access to safe and reliable water (DWS, 2018;

UNESCO, 2019; World Bank, 2018). Promoting water use efficiency can help address these challenges by reducing losses in the distribution network, alleviating pressure on existing water resources and extending the functional life of infrastructure (World Bank, 2018; DWS, 2018; UNESCO, 2019). For example, the town of Standerton could enhance its long-term water security by implementing measures that prevent losses and safeguard ecological systems, thereby protecting biodiversity and maintaining natural hydrological cycles (DWS, 2022). Hutton and Varughese (2016), highlighted the broad benefits of water use efficiency, including lower operational costs for municipalities, reduced household water bills and improved resource allocation for other essential services.

1.3 Justification of the study

This study is justified by the urgent need to critically assess the efficiency and effectiveness of the water treatment and distribution system by identifying technical and operational weaknesses and providing evidence-based recommendations for improvement. Evaluating parameters such as water losses, treatment plant functionality, infrastructure condition and the quality of the treated water is essential to inform sound decision-making. This research addresses a significant knowledge gap concerning the extent and impact of inefficiencies within the water supply system. A comprehensive assessment is necessary to tackle water scarcity, upgrade infrastructure, inform policy development, and promote sustainable water-use practices by pinpointing areas requiring improvement. Moreover, efficiency supports compliance with regulatory frameworks such as the National Water Resource Strategy (NWRS), which promotes sustainable water management through improved system performance (DWAF, 2008). Thus, assessing and enhancing water use efficiency is not merely a technical necessity it is a strategic investment in the health, development and resilience of communities.

This study therefore, aims to address the critical knowledge gap by investigating the operational inefficiencies and water quality issues at the Standerton Water Treatment Works. The objective is to identify the root causes of these challenges and to propose evidence-based, sustainable interventions that can improve the overall efficiency and reliability of water service delivery in the Standerton and to contribute to the effective management and long-term sustainability of the Standerton water supply system, ensuring that community water demands are met in a manner that is both environmentally sustainable and economically viable. Enhancing water supply efficiency

is critical for reducing losses and leaks while implementing sustainable water management strategies amid increasing resource constraints. Given the community's reliance on limited water sources, efficient utilization is imperative to prevent shortages and guarantee equitable access for all residents. Addressing these challenges is expected to significantly improve water supply efficiency, reduce losses and decrease operational costs for the municipality. These improvements are vital for developing a resilient water supply system capable of meeting Standerton's future water demands. Furthermore, the findings on water use efficiency can provide critical insights to inform policy decisions at both local and national levels. Detailed assessments will offer evidence-based data for policymakers to develop regulations and initiatives that promote sustainable water use. Infrastructure investments, water conservation, and demand management programs are essential for securing government and stakeholder funding, which supports long term solutions to water challenges.

Financial savings can be redirected to support other essential services and development projects, thereby enhancing the socio-economic well-being of the community. This study aligns closely with several United Nations Sustainable Development Goals (SDGs). It not only addresses local water scarcity issues but also contributes to global sustainability efforts. The 17 SDGs, established by the United Nations, aim to tackle a broad spectrum of global challenges and promote sustainable development across social, economic and environmental dimensions. By ensuring the availability and sustainable management of water resources for all, this study helps identify and mitigate water wastage, thereby supporting a more sustainable water supply. Implementing efficient water use practices reduces losses from leaks and inefficient operations, enhancing overall water availability. The National Development Plan (NDP) Goal 6 focuses on environmental sustainability and resilience. It emphasizes the sustainable use of natural resources and the necessity to protect the environment. Efficient water use directly supports these objectives by reducing wastage, conserving water resources and securing their long-term availability.

1.4 Objectives of the study

1.4.1. The main objective of the study

- To assess water supply system efficiency and water quality.

1.4.2 Specific objectives

- To determine the quantity of raw and final water supply from Vaal River.
- To analyse the layout of the Standerton water supply system.
- To compare the water quality results for raw, final and furthest point (Sasol garage).
- To examine the level of compliance of the treated water with the water quality standards recommended for domestic water use.
- To determine the efficiency based on water supply and demand, water quality and water balance.
- To assess the water supply sustainability in STWP.

1.5 Research Questions

- What is the quantity and quality of water available for domestic supply in Standerton?
- What are the main users in Standerton and their water demands?
- What is the efficiency of available water to meet the demand?
- What is the current state of water infrastructure in Standerton and what improvements are needed?
- Does the treated water meet the South African National Standards (SANS 241) or WHO guidelines for domestic water use?
- What are the key components and flow structure of the Standerton water supply system from source to consumer?

1.6 Characteristics of the study area

1.6.1 Location

Standerton is a large commercial and agricultural town lying on the banks of the Vaal River in Mpumalanga, South Africa with a population of 119 669 (Census, 2022) and specialises in cattle, dairy, maize and poultry farming. Standerton is part of the Lekwa Local Municipality. Standerton is in Mpumalanga Province of South Africa which constitutes 6.5% of South Africa's land area. It shares borders with the South African provinces of Limpopo to the north, Gauteng to the west, the

Free State to the southwest, and KwaZulu-Natal to the south. Mpumalanga was part of the now defunct Transvaal Province before 1994. The province's name was Eastern Transvaal from its initial establishment in 1994 until 24 August 1995. Prior to the establishment of the province, the term "Eastern Transvaal" was used to refer to the eastern part of Transvaal Province or to the scenic tourist area around the Escarpment and Mpumalanga Lowveld bordering the Kruger National Park (Wikipedia, 2010). Figure 1.1 shows location of the study area.

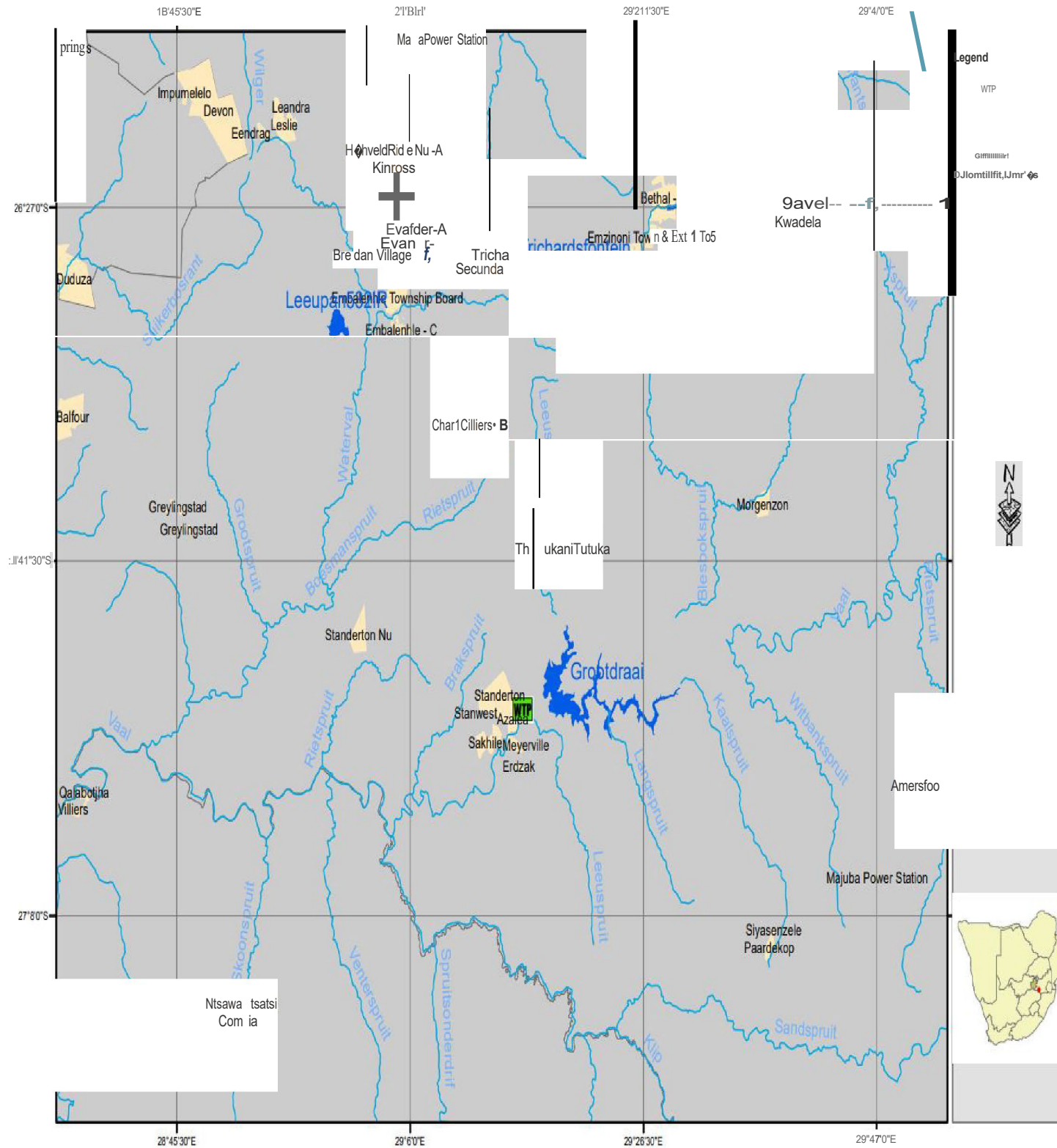


Figure 1.1: Map of the study area

1.6.2 Topography and Geology

The Drakensberg escarpment divides Mpumalanga into a westerly half consisting mainly of high-altitude grassland called the Highveld and an eastern half situated in low-altitude subtropical Lowveld/Bushveld, mostly savanna habitat. The southern half of the Kruger National Park is in the latter region. The Drakensberg exceeds heights of 2000m in most places, with this central region of Mpumalanga being very mountainous. These regions have alpine grasslands and small pockets of Afromontane forest. The Lowveld is relatively flat with interspersed rocky outcrops. The Lebombo Mountains form a low range in the far east, on the border with Mozambique. Some of the oldest rocks on earth have been found in the Barberton area; these ancient greenstones and metamorphosed granites form the Crocodile River Mountains in the southeast of the province. The Lowveld is underlaid by African Cratonic Basement rocks of ages in excess of 2 billion years. The Highveld is mostly Karoo Sequence sedimentary rock of a younger, Carboniferous to Permian age. Mpumalanga is the only South African province to border two provinces of Mozambique (Gaza Province to the northeast and Maputo Province to the east), as well as all four regions of Eswatini (Lubombo, Hhohho, Manzini, and Shiselweni Districts) (Great Escarpment, 2010).

1.6.3 Climate

The Lowveld is subtropical, due to its latitude and proximity to the warm Indian Ocean. The Highveld is comparatively much cooler, due to its altitude of 2300m to 1700m above sea level. The Drakensberg escarpment receives the most precipitation, with all other areas being moderately well-watered by mostly summer thunderstorms. The Highveld often experiences severe frost, while the Lowveld is mostly frost-free. Winter rainfall is rare, except for some drizzle on the escarpment. The differences in climate are demonstrated by the capital, Mbombela, which is in the Lowveld, an hour from Belfast on the Highveld (Great Escarpment, 2010).

1.6.4 Land Use

The area around promotes mixed agriculture with crops such as maize, sunflower seeds, ground nuts and potatoes. Poultry and dairy farming are also conducted in the region. Although some irrigated commercial agriculture does occur to the south of Ermelo and to the north and east of Manzana, most of the commercial crops are grown on dryland. In total 23% of the district's land surface is under cultivation of which approximately 99% constitutes commercial dry land under

grains. Significantly, the area between Carolina, Bethal and Ermelo produces the most sheep and wool in South Africa. The Standerton area is known for its large dairy industry and maize agriculture. Most of the cattle farming activity occur within the Dr Pixley ka Isaka Seme and Mkhondo Local Municipalities. Other types of crops grown in the district include potatoes, sweet potatoes, groundnuts, and soybeans. A small measure of bee keeping and honey harvesting also occurs within the forests. Apart from commercial agriculture, subsistence farming plays an important part in the livelihoods of many of the district's communities, especially those in the Manzana and Lochiel areas.

The climatic contrasts between the drier Highveld region, with its cold winters, and the hot, humid Lowveld allow for a variety of agricultural activities. About 68% of the Standerton land is used for agriculture. Crops include maize, wheat, sorghum, barley, sunflower seed, soybeans, macadamia, groundnuts, sugar cane, vegetables, coffee, tea, cotton, tobacco, citrus, subtropical and deciduous fruit. Forestry is extensive around Sabie in the far northeast of the province. Located near the forests, Ngodwana is the site of one of South Africa's largest paper mills (Sappi). Natural grazing covers approximately 14% of Mpumalanga. The main products are beef, mutton, wool, poultry and dairy (Great Escarpment, 2010).

1.6.5 Mining

Extensive mining is done and the minerals found include gold, platinum group metals, silica, chromite, vanadiferous magnetite, argentiferous zinc, antimony, cobalt, copper, iron, manganese, tin, coal, andalusite, chrysotile asbestos, kieselguhr, limestone, magnesite, talc and shale. Gold was first discovered in Mpumalanga province in 1883 by Auguste Roberts in the mountains surrounding what is now called Barberton. Gold is still mined in the Barberton area today. Mpumalanga accounts for 83% of South Africa's coal production. 90% of South Africa's coal consumption is used for electricity generation and the synthetic fuel industry. Coal power stations are in proximity to the coal deposits. A coal liquefaction plant in Secunda is one of the country's two petroleum-from-coal extraction plants, which is operated by the synthetic fuel company Sasol. The highveld region is the most polluted of the world due to the mine industry and plant power stations and the lowveld near the famous Kruger Park is under threat of new mines as well (Great Escarpment, 2010).

1.6.6 Dams

Grootdraai Dam is situated in the upper reaches of the Vaal River less than 10 km upstream of Standerton. It has a catchment area of 8,195 km², a mean annual precipitation of approximately 750 mm, a mean annual potential evaporation at the dam site of 1,400 mm and a natural inflow of 580 million m³/a. The full supply capacity of the reservoir is 364 million m³. The Grootdraai dam was completed in 1982 (Great Escarpment, 2010).

Chapter 2

Literature Review

2.1 Preamble

This chapter reviewed literature on water resource availability, water quality, water supply, water supply efficiency measures, sustainability of water resource, water treatment plant, national water act, water supply, infrastructure conditions, public awareness, policy effectiveness, and technological solutions. This review aims to identify areas for improvement and propose actionable strategies for enhancing water efficiency and the drivers of water management in the community as whole that uses water.

2.2 Water resources availability in South Africa

South Africa's average annual surface water supply is approximately 49,200 million cubic meters, of which about 4,800 million cubic meters originate from Lesotho (DWAF, 2004). A designated portion of this runoff must be maintained within rivers as an ecological reserve to preserve natural habitats along the watercourses (DWA, 2020). The required ecological reserve varies by river, depending on the specific environmental and socio-economic activities within each catchment area (DWA, 2020). Additionally, a significant amount of South Africa's rainfall evaporates and returns to the atmosphere before reaching rivers or streams, reducing the effective water yield (DWA, 2012). Anthropogenic factors such as air and water pollution from manufacturing and petrochemical industries negatively affect agricultural productivity (Sutton et al., 2013). Moreover, natural grasslands are increasingly being replaced by commercial monoculture plantations of fast-growing, non-native tree species including pine, wattle, blue gum, and Australian eucalyptus, which consume substantially more water than indigenous vegetation (Le Maitre et al., 1999).

Water resources in the country are often utilized inefficiently and are not equitably allocated (DWA, 2012). The Department of Water Affairs (DWA) oversees approximately 250 programs responsible for regulating and monitoring South Africa's vital water resources (DWA, 2022). The current replacement value of the country's water resource infrastructure is estimated at R139 billion, with an additional land valuation of R7.3 billion (DWA, 2022). Furthermore, the DWA is

actively involved in transboundary water projects, such as those involving water resources from neighbouring countries like the Lesotho Highlands (DWA, 2022). South Africa's water infrastructure has a weighted average age of 39 years and is susceptible to deterioration due to insufficient maintenance, lack of capital renewal, and stresses induced by internal and external pressures (DWS, 2020). Severe capacity and financial constraints hinder adequate infrastructure upkeep, with the DWA estimating that annual investments of approximately R1.4 billion are necessary to maintain the system's current state (DWS, 2020).

Additionally, the department faces a shortage of skilled personnel to perform and supervise maintenance activities, a situation exacerbated by the loss of institutional knowledge as experienced staff retire or move to the private sector in search of better opportunities (DWS, 2020; National Treasury, 2019). Land use practices and climate change significantly influence the proportion of rainfall that reaches surface streams or recharges groundwater, thereby affecting water supply availability (Hyandye et al., 2018). Activities such as afforestation, invasion by alien vegetation species, dry land crop farming, overgrazing, urbanisation, and soil erosion causing reservoir sedimentation alter water availability (Le Maitre et al., 1999). Evidence indicates that global temperatures are rising, and climate models predict a potential decline in South Africa's runoff over the coming decades, accompanied by a gradual shift in precipitation patterns from west to east (Engelbrecht et al., 2015).

2.3 Water supply efficiency

Water supply efficiency refers to a system's ability to provide clean, safe and sufficient water to consumers while minimizing losses, resource use and service interruptions (DWAf, 2008). In a Water Treatment Plant (WTP), efficiency ensures treated water reaches users with the correct quantity and good quality, while optimizing resources like energy, chemicals, labor and finances (WHO, 2017). Efficient systems promote operational reliability, sustainability and protect public health (GWP, 2000). Key indicators of efficiency include non-revenue water (NRW), plant uptime, equipment performance, chemical and energy use and customer satisfaction (DWS, 2023). High NRW can be due to aging infrastructure, illegal connections and faulty meters requires urgent leak detection and meter audits (DWAf, 2008). The plant being overloaded beyond its design capacity, risking treatment quality and supply consistency (WHO, 2011). Equipment breakdowns and understaffing also reduce efficiency and increase costs (DWS, 2023). Water supply efficiency

directly affects water quality, pressure drops and pipe bursts can cause microbial contamination, while incorrect chemical dosing harms disinfection effectiveness (SANS-241, 2015). Intermittent supply fosters biological growth like *Escherichia coliform* (*E. coli.*) and algae, posing health risks (WHO, 2011). Challenges in Standerton include outdated infrastructure, power outages, limited monitoring and community misuse (GWP, 2000). Improving efficiency demands modernizing equipment, training staff, adopting smart metering and control systems and enhancing community awareness (DWS, 2023). Using energy-efficient technologies and solar backups can mitigate power disruptions (GWP, 2000). Overall, boosting efficiency goes beyond increasing output it means delivering safe, reliable and cost-effective water sustainably (WHO, 2017). A strategic resource efficient and well-governed approach is critical to meeting national standards like SANS-241, reducing costs and maintaining public trust in Standerton's water services (SANS-241, 2015; DWS, 2023).

2.3.1 Link between water supply efficiency and Integrated water resource management (IWRM)

An integrated and sustainable approach to water resource management requires the adoption of several key principles. A participatory approach involving local communities, municipalities, water boards, farmers and industrial stakeholders is essential in decision making and implementation processes to achieve equitable and sustainable outcomes (ICWE, 1992). This fosters accountability and ensures that water supply strategies are responsive to local socio-economic and environmental realities. Recognizing water as an economic good facilitates the implementation of pricing policies that incentivize conservation and support cost recovery, thereby promoting the long term sustainability of water services (ICWE, 1992; Vawda et al., 2010). Such policies also help address challenges related to NRW, including losses from leaks and illegal connections. Intersectoral coordination is crucial for aligning water supply planning with the needs of other sectors such as mining, agriculture, energy and sanitation to ensure holistic resource management (Steyn, 2022; FAO, 2016). This is particularly relevant in provinces like Mpumalanga, where intensive mining operations have the potential to degrade water quality. Ecosystem protection must be integrated into water management strategies, acknowledging the ecological importance of rivers such as the Komati, Crocodile and Olifants along with wetlands. This integration includes implementing comprehensive water quality monitoring programs and

enforcing pollution control measures to safeguard aquatic ecosystems and ensure long-term sustainability of water resources (McLoughlin et al., 2021; SANBI, 2019).

An IWRM framework provides a comprehensive approach to addressing water supply and quality challenges. Key performance indicators for assessing water supply efficiency include household access to potable water, percentage of treated water lost before reaching consumers, the operational condition of infrastructure such as pipelines and treatment works and response time to system failures (DWAF, 2004). However, several challenges hinder efficiency aging infrastructure, poor intergovernmental coordination, inadequate funding for infrastructure upgrades and disparities between urban and rural service delivery (DWS, 2020). Assessing water quality efficiency requires monitoring compliance with South African National Standard (SANS) 241 for drinking water, particularly the levels of electrical conductivity (EC), *E. coli*, nitrates, sulphates and heavy metals especially in mining affected areas. Blue Drop and Green Drop reports serve as essential tools to monitor potable and wastewater quality respectively. Mpumalanga faces significant threats such as acid mine drainage (AMD) from coal mining, leading to acidic water and elevated sulphate levels (McCarthy, 2011; Hobbs and Cobbing, 2007). Acid Mine Drainage (AMD) severely impacts aquatic ecosystems and poses risks to human health. Additionally, wastewater treatment inefficiencies in the region result in partially treated effluent being discharged into rivers, further degrading water quality (DWA, 2012; Ntuli and Mafereka, 2020). These failures highlight the need for improved monitoring and rehabilitation efforts to ensure sustainable water management. Agricultural runoff further compounds the problem by increasing nutrient pollution, particularly nitrates and phosphates, while poor maintenance of rural wastewater infrastructure undermines system reliability (Smith et al., 2018; Xu et al., 2021).

To improve water use efficiency and promote long term sustainability, a range of IWRM aligned strategies should be adopted. These include leveraging real-time data on water quality and quantity to guide informed decision-making and investing in capacity building of local water professionals through training in IWRM principles (UNESCO, 2009; Jonker, 2007; Muller, 2012). Targeted infrastructure development especially in underserved rural and mining affected communities is also essential (GWP, 2000; Schreiner & van Koppen, 2018). Furthermore, fostering public-private partnerships can mobilize both financial resources and technical expertise while stronger

regulatory enforcement is critical to ensuring compliance and holding polluters accountable (World Bank, 2017; Movik et al., 2016). These strategies collectively contribute to resilient and equitable water governance systems. Incorporating scientific data, ecosystem protection, economic instruments and participatory governance. IWRM offers a holistic pathway toward sustainable and equitable water resource management in Mpumalanga (DWAF, 2004; Global Water Partnership, 2000).

2.3.2 Water governance theory

Water governance theory provides a multidimensional framework for assessing water management by integrating institutional, regulatory and participatory aspects alongside technical performance (Schreiner and van Koppen, 2018). In the case of SWTP, this theory highlights governance challenges such as unclear institutional roles, procurement delays and poor enforcement of regulations (Muller, 2012). The Organisation for Economic Co-operation and Development (OECD) principles of effectiveness, efficiency and trust provide a structured framework for evaluating water management operations by emphasizing clear service delivery standards, cost-effective resource use and active public engagement (OECD, 2015).

Despite the presence of legal frameworks like the National Water Act (1998) and Water Services Act (1997), implementation remains weak due to limited capacity and underfunded operations (Movik et al., 2016). Gaps in daily monitoring, reporting and stakeholder participation further compromise compliance with SANS-241 standards (Ntuli and Mafereka, 2020). To address these issues, recommendations include improved staff training, digital monitoring tools, public forums for engagement and stricter enforcement of maintenance and compliance protocols (Jonker, 2007). Integrating Water Governance Theory into the assessment of Standerton Water Treatment Plant (SWTP) allows for a more holistic understanding of systemic inefficiencies, supports the development of targeted interventions to ensure equitable and sustainable water service delivery (Schreiner and van Koppen, 2018; Jonker, 2007; Movik et al., 2016).

2.3.4 Global and South African perspectives on best practices in water supply efficiency

Water service providers worldwide adopt innovative strategies to improve water supply efficiency by minimizing losses, optimizing energy use and ensuring sustainable delivery of quality water (PUB, 2021). Singapore's Public Utilities Board maintains non-revenue water (NRW) below 5%

through active leak detection, real-time monitoring, district metered areas (DMAs), smart meters and pressure management techniques (PUB, 2021). SWTP could adopt similar DMA zoning and advanced leak detection to reduce losses from aging infrastructure and illegal connections. Denmark's utilities use IoT sensors, GIS mapping and predictive analytics integrated with SCADA systems to optimize pump operations and reduce downtime, offering a model for Standerton's operational improvement (Danish Water Sector, 2019). Globally, energy efficiency is a critical focus. In German water plants deploy energy-efficient motors, solar power and biogas recovery to reduce grid dependence and carbon footprints (German Water Partnership, 2020). SWTP could explore solar energy to mitigate frequent power outages and load shedding impacts. The Netherlands employs automated real-time water quality monitoring and public dashboards for transparency and rapid response, a practice Standerton could emulate by continuously monitoring key parameters to meet SANS-241 guidelines (Dutch Ministry of Infrastructure, 2018).

Within South Africa, water sector frameworks emphasize efficiency amid challenges such as scarcity, aging infrastructure and financial constraints (DWS, 2022). The Department of Water and Sanitation's Blue Drop certification evaluates drinking water quality and treatment performance, while Green Drop focuses on wastewater treatment efficiency (DWS, 2022). SWTP should aim for Blue Drop compliance through improved operations, frequent testing and accurate reporting (DWS, 2022). Nationally, NRW averages around 41%, but municipalities like eThekweni and Cape Town have reduced NRW using pressure management, leak detection and meter audits, strategies that Standerton could adopt to enhance reliability (DWAF, 2019). Water Services Development Plans (WSDPs) require clear efficiency targets and infrastructure upgrades, Lekwa Local Municipality could integrate these best practices into its WSDP to prioritize pump station refurbishment and reduce wastage (DHS, 2020). Integrating global best practices with South African water governance frameworks and the OECD Water Governance Principles, SWTP can significantly improve water supply efficiency and quality outcomes (OECD, 2015). Adoption of smart monitoring, renewable energy solutions, systematic NRW management and enhanced training will collectively foster a sustainable, reliable and safe water supply system that meets regulatory standards and community needs (OECD, 2015).

2.4 Overview of South Africa's water supply system and infrastructure

South Africa's water supply system is an integrated network of surface water, groundwater, treatment facilities and bulk distribution managed primarily by municipalities under the Department of Water and Sanitation (DWS, 2020). Key infrastructure includes major dams like the Vaal River System, water boards such as Rand Water and Umgeni Water and municipal providers responsible for treatment and distribution (DWS, 2022). The system complies with national standards, including SANS-241 for drinking water quality (DWS, 2022). However, challenges such as aging infrastructure, high non-revenue water (around 41%), frequent Blue Drop non-compliance and climate pressures persist (WRC, 2018).

Regionally, Standerton in Mpumalanga relies on Grootdraai Dam as its main water source, with water supplied by the Standerton WTW to urban and peri-urban areas (Lekwa Local Municipality, 2022; DWS, 2019). The treatment process includes raw water abstraction, coagulation, sedimentation, filtration, chlorination and storage before distribution (Edokpayi et al., 2018). Distribution infrastructure consists of pump stations, reticulation pipes and meters monitoring supply and consumption (Lekwa Local Municipality IDP, 2023).

Standerton's WTW infrastructure faces challenges such as aging and poorly maintained equipment leading to frequent breakdowns (Mokhobo et al., 2019; Ntombela et al., 2016). The distribution network relies on old asbestos cement and steel pipes prone to leaks, contributing to high non-revenue water losses (Mokhobo et al., 2019). Load shedding causes electrical interruptions and plant shutdowns, while storage capacity is inadequate and occasionally compromised (BDR, 2021; DWS, 2021). Monitoring is largely manual with limited automation, hindering timely decision-making (DWS, 2021). Institutional weaknesses include poor technical capacity, insufficient maintenance and delayed infrastructure repairs, resulting in recurring non-compliance with Blue Drop standards (DWS, 2022). Opportunities for improvement include renewing pipelines, pumps and chlorination units to boost reliability and water quality (Mokhobo et al., 2019). Implementing SCADA systems and smart metering can enhance operational control, leak detection and supply management (Gul et al., 2020). Proactive maintenance and rapid response teams can reduce downtime and water losses (Jordaan and Bezuidenhout, 2019). Enhancing energy reliability through backup generators or solar power will help mitigate load shedding impacts (WRC, 2019).

Automated water quality monitoring of turbidity, pH, chlorine residuals and microbial indicators like *E. coli* is essential for compliance and public health protection (WRC, 2019). SWTP operates within South Africa's broader water supply framework but faces constraints from aging assets, operational inefficiencies and institutional challenges. Modernizing and maintaining treatment and distribution systems, alongside improved monitoring and governance are crucial to enhancing efficiency and meeting SANS-241 and Blue Drop requirements for a sustainable and safe water supply (DWS, 2022).

2.5 Water Quality in South Africa

Water is essential, but only a relatively small amount of high-quality water is needed specifically for drinking purposes (Van Dijk et al., 2019). This drinking water could be stored separately with communities provided necessary chemicals or tools to maintain its quality (Van Dijk et al., 2019). In many developing countries, although water treatment ensures initial quality, transport and storage often contaminate the water again (Zinn et al., 2018). Point of use treatments like boiling or filtration can be more effective in guaranteeing drinking water quality (Van Koppen et al., 2006). Early water supply development prioritized high-quality water provision over larger quantities of average quality water (Van Koppen et al., 2006). The choice of water source is often influenced by ease of access or the absence of costs related to domestic water use (Moriarty and Butterworth, 2003). Large surface water systems supplying major urban, mining, and industrial centers are sophisticated and well managed (Moriarty and Butterworth, 2003). However, delays in adopting new water resource innovations are sometimes due to insufficient institutional capacity (Moriarty and Butterworth, 2003). This study conducted a comprehensive analysis of physicochemical parameters including pH, electrical conductivity, turbidity and total dissolved solids and biological variables such as free chlorine, manganese, iron, *E-coli* and total coliform bacteria to assess the water quality at SWTP.

2.5.1 Linkages between water supply efficiency and water quality

In municipal water treatment systems, water supply efficiency and water quality are closely linked (Edokpayi et al., 2018). Efficient infrastructure and operations ensure reliable delivery while maintaining microbiological safety and chemical quality throughout distribution (Edokpayi et al., 2018). Inefficiencies such as pipe leaks and irregular disinfection directly affect water quality and

pose health risks (DWAF, 2013). Leakages in old pipes can allow contaminants to enter through backflow during low pressure or intermittent supply (Kumpel and Nelson, 2013). Frequent pump failures and power outages due to load shedding lead to distribution of partially treated water (WHO, 2011). Poorly calibrated chlorine dosing can result in inadequate disinfection or harmful residuals (WHO, 2011; SANS-241, 2015). Overloaded treatment units reduce sedimentation and filtration effectiveness, while stagnant water in reservoirs promotes microbial growth like *E. coli* (WHO, 2011).

Standerton's specific challenges include corroded pipes, failing filters and neglected reservoirs that increase non-revenue water losses and microbial regrowth (Mokhobo et al., 2019). Operational issues like untrained staff, lack of automation and absent backup systems limit compliance with water quality standards (Edokpayi et al., 2018). Blue Drop reports cite microbiological non-compliance and communities complain about foul-smelling, discolored water, especially after pipe repairs or outages (DWS, 2023; Municipal IQ, 2022). Addressing these requires integrated interventions including leak detection, pipe replacement, SCADA automation, automated chlorination and backup power for load shedding resilience (GWP, 2000; WHO, 2017). Continuous staff training on water quality monitoring and system calibration is also essential (WHO, 2017). Inefficiencies in the SWTP undermine both the reliability and safety of drinking water (Edokpayi et al., 2018). Enhancing operational, technical and infrastructure efficiency is vital to protect public health and meet South Africa's SANS 241 standards (SANS-241, 2015). A comprehensive, targeted approach will improve service delivery and restore public trust in municipal water governance (DWS, 2023).

2.6 Chemical properties of water

2.6.1 Free chlorine

In chlorine chemistry, hypochlorous acid (HOCl) and hypochlorite ions (OCl⁻) form when sodium hypochlorite, calcium hypochlorite or chlorine gas dissolve in water. For example, chlorine gas rapidly dissolves in water to produce hydrochloric acid (HCl) and hypochlorous acid (HOCl) (WHO, 2017).



- **HOCl** is **hypochlorous acid**, a weak acid.
- **HCl** is **hydrochloric acid**, a strong acid.
- This equilibrium reaction represents the formation of **chlorine gas (Cl₂)** and **water (H₂O)** when hypochlorous acid reacts with hydrochloric acid and typically occurs in acidic conditions and is relevant in disinfection and water treatment processes where chlorine is generated in situ. Hypochlorous acid partially dissociates to provide the hydrogen ion (H⁺) and the hypochlorite ion (OCl⁻).

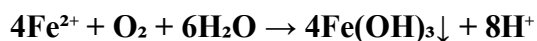
2.6.2 Iron (Fe)

Iron (Fe) is the fourth most abundant element in the Earth's crust, making up about 5% by weight (WHO, 2011). It is commonly found in various minerals, with haematite (FeO) being the most extensively used iron ore in metallurgy (WHO, 2011). The reddish colour of soil is primarily due to iron, with an average content of about 4.0% (m/m) (DWAF, 1996). In uncontaminated surface water, dissolved iron concentrations typically range between 0.001 and 0.5 mg/L (WHO, 2017). Iron precipitates in water distribution systems over time, which reduces flow rates (DWAF, 1996). Standard water treatment techniques coagulation with lime or alum, sedimentation and filtration are effective for iron removal (Edokpayi et al., 2018). Iron can also be removed through oxidation, converting it into insoluble hydroxide or hydrated oxide for easy filtration (WHO, 2011). Before filtration, ferrous iron (Fe²⁺) must be oxidised to ferric iron (Fe³⁺), which forms the insoluble Fe(OH)₃ complex (DWAF, 1996). Oxidation involves electron transfer from substances like Fe and Mn to an oxidising agent such as chlorine or oxygen (WHO, 2011). Reduced manganese (Mn²⁺) is oxidised to Mn⁴⁺, forming insoluble MnO₂ (WHO, 2017). Jar tests are used to determine the appropriate contact time and chlorine dosage for oxidation (DWAF, 1996). Potassium permanganate (KMnO₄), although more expensive than ozone or chlorine, is effective for iron and manganese removal with lower equipment requirements (WHO, 2017). Aeration using oxygen in the air through devices like tray aerators is a cost-effective oxidation method (DWAF, 1996). Tray aerators work by circulating water over porous trays to facilitate air-water contact and promote oxidation (WHO, 2011).

2.6.3 Manganese (Mn)

Mn is a relatively abundant element, constituting approximately 0.1 % of the earth's crust. Commonly occurring minerals which contain manganese include pyrolusite (MnO), manganite (MnOH), rhodochrosite (MnCO) and rhodonite (MnSiO). Mn is found in solution predominantly as the manganous Mn (II) ion which may be stabilised by complexation to humic acids. On oxidation to the manganic, ion, Mn (IV), Mn tends to precipitate out of solution to form a black hydrated oxide which is responsible for the staining problems often associated with manganese-bearing waters. According to Casey (2009), it is challenging to mitigate against the aesthetic impacts of Mn because treatment procedures should ideally eliminate it. Safe and clean water will result from the proper oxidation of manganous ions to manganic ions which will be sufficiently removed for filtering, if chlorine is added in sufficient amounts during the pre-chlorination stage or phase. Two steps make up the removal of iron and manganese: (a) An oxidation process that turns the soluble forms of the elements into insoluble precipitates and (b) A solid separation process that extracts the precipitated material from the water stream.

Here is the chemical formula added, based on common water treatment practices for iron and manganese removal when organic materials or iron/manganese bacteria are present: According to McFarland and Dozier (2004), the following technique is especially useful when iron is mixed with organic materials or when Fe/Mn bacteria are present:



This reaction represents the oxidation of ferrous iron (Fe^{2+}) by oxygen (O_2) in water to form ferric hydroxide [$\text{Fe}(\text{OH})_3$], which precipitates out of solution. This is a key step in removing iron from water in treatment systems, especially when iron is complexed with organic matter or bacteria and Mn were discovered to have been largely eliminated after standard treatment and they showed up in treated water that became yellowish to brown red. It was established that the presence of Fe and Mn is what gives the water its hue. It was shown that the high chlorine dosage (15 mg/L) combined with an excessive addition of lime resulted in the significant removal of Fe and Mn.

2.7 Physical properties of water

2.7.1 Total dissolved solids (TDS)

High salt concentrations in drinking water can give it an unpleasant taste and may negatively affect kidney function (WHO, 2017). Sodium sulphate and magnesium sulphate at high concentrations can have laxative effects, while sodium can worsen conditions in individuals with heart disease or hypertension (DWAF, 1996). Pregnant women suffering from toxemia are particularly vulnerable to elevated sodium levels in water (WHO, 2011). High salt intake can also impair kidney function over time (WHO, 2017). Bathing or washing in water with high Total Dissolved Solids (TDS) concentrations can lead to skin dryness and irritation (DWAF, 1996). High levels of calcium and magnesium in water interfere with soap lathering, making cleaning difficult (DWAF, 1996). Alkalinity in water can contribute to chemical corrosion of plumbing and fixtures (WHO, 2011). Low levels of hydroxide, bicarbonate, and carbonate in water can affect buffering capacity, increasing corrosion risk (DWAF, 1996). A low pH combined with high TDS, particularly elevated chloride and sulphate levels, indicates aggressive water that may corrode metal surfaces (WHO, 2017). High TDS levels can damage household appliances and pipes, increasing maintenance and replacement costs (DWAF, 1996).

2.7.2 Turbidity

Turbidity is a measurement of water's ability to scatter light and indicates the presence of suspended materials (WHO, 2017). It is also associated with clarity, which refers to the transparency of water and the amount of settleable material (DWAF, 1996). Turbidity is often linked to microorganisms; thus, reducing turbidity lowers the risk of waterborne disease transmission (LeChevallier et al., 1981; WHO, 2017). Raw water turbidity can range from below 1 NTU in very clear water to over 1,000 NTU in highly turbid conditions (EPA, 2006). Sewage and industrial discharges into rivers can significantly increase turbidity levels (DWAF, 1996). There is a known relationship between turbidity, taste and odour in both raw and treated water (WHO, 2011). However, these taste and odour issues can still occur even when turbidity is not visibly high (EPA, 2006). Turbidity should ideally be measured on the day of sample collection to ensure accuracy (WHO, 2017). If immediate testing is not possible, samples can be stored in the dark for up to 24 hours, though turbidity may irreversibly change (APHA, 2012). Adding

flocculants helps neutralize the charge on suspended particles, allowing them to aggregate and settle out (DWAF, 1996). Effective turbidity removal from residential or commercial water requires well-designed treatment systems (WHO, 2011). Although turbid water does not directly cause health problems, it can carry pathogens or harmful substances attached to particles (LeChevallier and Norton, 1992). Turbidity significantly affects the microbiological quality of water (WHO, 2017). The greatest microbial growth often occurs within natural flocs or on particle surfaces (LeChevallier et al., 1981). Silt in rivers can absorb bacteria and viruses, increasing contamination risk (WHO, 2011). During treatment, coagulation traps microorganisms in flocs, and any floc escape could indicate microbial breakthrough (APHA, 2012). Highly turbid chlorinated water can still pose a health risk due to inadequate disinfection (WHO, 2017). Particles can shield microbes from disinfectants, reducing the effectiveness of chlorine and other agents (LeChevallier and Norton, 1992).

2.7.3 Electrical Conductivity (EC)

Electrical conductivity, which ranges from 0 to 50,000 $\mu\text{S}/\text{cm}$, is a measurement of water salinity (Hem, 1998). Microsiemens per centimetre ($\mu\text{S}/\text{cm}$) is the standard unit used to express electrical conductivity (APHA, 2012). Freshwater typically has conductivity values ranging from 0 to 1,500 $\mu\text{S}/\text{cm}$, whereas seawater generally measures around 50,000 $\mu\text{S}/\text{cm}$ (EPA, 2001). Natural waterways contain small amounts of salts essential for aquatic plant and animal life (DWAF, 1996). However, high salt concentrations in freshwater can damage aquatic ecosystems and limit its suitability for human use (WHO, 2011). Drinking water with low conductivity is usually safe for human consumption as long as there is minimal organic or suspended contamination (WHO, 2017). It is generally suitable for irrigation purposes, though care is required at levels above 300 $\mu\text{S}/\text{cm}$ especially with overhead sprinklers, which may burn foliage (Ayers and Westcot, 1995).

2.8 Microbiological Properties of Water

2.8.1 *Escherichia Coliform (E-coli)*

Escherichia coli (E-coli) and faecal coliforms are the most widely used bacterial indicators of faecal contamination (WHO, 2017). These indicators are employed to evaluate the quality of drinking water, river and seawater, recreational water, aquaculture and irrigation sources and wastewater effluents (EPA, 2003). The presence of *E-coli* confirms pollution from warm-blooded

animal faeces and although often attributed to human sources, it can originate from other animals as well (Leclerc et al., 2001). Natural aquatic processes such as flocculation, coagulation, adsorption, and sedimentation can physically remove microorganisms without necessarily inactivating them, and sometimes even protect them from disinfection (Bitton, 2005). Faecal coliforms are commonly used as indicators of bacterial pathogens including *Salmonella* spp, *Shigella* spp, *Vibrio cholerae*, *Campylobacter jejuni*, *Campylobacter coli*, *Yersinia enterocolitica*, and pathogenic *E-coli* (WHO, 2011). These pathogens are transmitted mainly through the faecal-oral route by consuming contaminated or improperly treated water, leading to diseases such as cholera, typhoid, dysentery, salmonellosis and gastroenteritis (Ashbolt, 2004). The risk of infection depends on both the level of water contamination and the volume of water consumed (Haas et al., 1999). Even ingestion of small amounts of highly contaminated water poses a high risk of illness (WHO, 2017). Anyone suspected of having a waterborne disease should receive prompt medical treatment (CDC, 2020).

2.8.2 Total coliform

Total coliform bacteria are a group of generally harmless microorganisms found in the intestines of both warm- and cold-blooded animals, as well as in soil and on plants (EPA, 2009). Coliforms assist in food digestion in animals and humans (Leclerc et al., 2001). The total coliform group includes species that can survive or naturally exist in soil, vegetation, and aquatic environments (WHO, 2011). They are often associated with disease outbreaks and are commonly detected in water that has been polluted by faecal matter (Ashbolt, 2004). Although total coliforms are not usually pathogenic, their presence in drinking water suggests possible contamination with disease-causing microorganisms (WHO, 2017). *E-coli*, a species within the coliform group, is a more specific indicator of faecal pollution and potential enteric pathogens, as it is always found in faeces (Edberg et al., 2000). Some strains of *E-coli* are pathogenic and can cause serious illness (Nataro and Kaper, 1998). There are at least sixteen types of coliform bacteria that occur in soil, plants, and the faeces of both humans and animals (Leclerc et al., 2001). Faecal coliforms, a subgroup of total coliforms, differ in that they grow at elevated temperatures and originate exclusively from the faeces of warm-blooded animals (WHO, 2011).

2.9 Water Supply in South Africa

District municipalities have the authority to establish water supply systems under Schedules 4 and 5 of the Constitution of the Republic of South Africa (Act 108 of 1996), with the province government's responsibility being to monitor, assess, and assist. Furthermore, "everyone has the right to have access to sufficient water and sanitation," according to Section 27 of the Republic of South Africa's 1996 Constitution. In addition to providing provinces, districts and local municipalities with sanitation services, the National Department of Water and Sanitation (DWS) is tasked with providing communities with equal and consistent access to water of acceptable quality and quantity.

According to WHO (2014), international and state laws in many nations, including South Africa, access to water is a fundamental human right. About 884 million people worldwide still rely on unprotected and frequently tainted water sources, like springs, fountains, wells and rivers to exist. WHO (2015) and Rodrigues et al. (2015), report that over a billion people worldwide suffer from waterborne illnesses because of using unprotected sources of water due to insufficient availability. According to Matchawe et al. (2022), population growth, drought and global warming are the main causes of Sub-Saharan Africa's shortage of drinkable water supplies. Most rural populations in Africa still struggle to obtain clean water, despite attempts by several countries to enhance the quality of the potable water supply (Matchawe et al., 2022).

According to Renwick (2019), an assessment of the current water delivery infrastructure, which includes pipes, treatment plants, and reservoirs, is necessary. Regular maintenance and upgrades can help alleviate the issues of leaks and inefficiencies caused by older or failing infrastructure. Water losses from leaks in the distribution system must be measured and tracked using leakage management. High levels of leakage point to possible infrastructure upgrade opportunities and inefficiencies. According to Argent (2004), stresses that to determine if the water supply can satisfy the population's demand it is necessary to evaluate the water supply's existing capacity. Van Schalkwyk (1996) said over-extraction of resources or insufficient water availability during peak seasons might result from an imbalance between supply and demand. Reservoirs and tanks are examples of storage structures that need to be assessed for efficiency and sufficiency. Appropriate

storage helps control supply and demand swings and guarantees water availability during dry spells.

2.10 Layout of Water Treatment Supply Processes

2.10.1. Feed Water for Municipal Water Treatment

Water is transported to the treatment facility through a system of pipelines and pumps. In cases where elevation gain is required, high-capacity pumps are utilized to lift the water to the treatment plant. To optimize operational efficiency and reduce energy and infrastructure costs, it is recommended that treatment plants be strategically located in topographical areas that facilitate gravity fed flow wherever possible. In the water treatment sector, multiple raw water sources typically a combination of surface water and groundwater are often integrated to improve the quality and reliability of the treated output (Spellman, 2018).

2.10.2. Screening

The amount of dissolved and suspended particles in water sources including lakes, rivers and reservoirs varies. These solids could include things like flavour, turbidity, colour, microorganisms, odour and undesirable pollutants. It can be inert or physiologically active, organic or inorganic and range in size from tiny particles to massive rocks. Some of these larger objects, like plastic and sand can clog the water pumps and impede the treatment apparatus. The larger particles are first screened or strained out in a typical water treatment procedure (Spellman, 2018). A bar screen is a huge metal screen that is frequently used. There are mechanical and manual versions of these screens. They are frequently positioned in front of the feedwater pump to carry out this function. Water flows across the huge screen as its items are separated from the water. It is essential to routinely scrape, rake or clean these screens (Spellman, 2018).

2.10.3. Chemical Pre-treatment

Chemicals are now added to the treatment plant once the source water has been screened and the sludge. Chemicals are added during this procedure to create precipitates that will not dissolve in water. These processes use a variety of chemicals on the market. Chemicals such as these are called coagulants. Aluminium sulphate or alum has been used for many years as one of the most common chemical coagulants. Another extremely popular coagulant is ferrous sulphate combined with

ferric chloride, sodium aluminate, activated silica and compounds called polymers which are low molecular weight compounds composed of dozens of small molecules combined into exceptionally large molecules. Catalytic polymers (positively charged), anionic polymers (negatively charged) and non-ionic polymers (neutrally charged) make up the three types of polymers. Coagulants must be mixed very well with water before heavy clumps can form, regardless of the coagulant or combination of coagulants used (Spellman, 2018).

After the sludge and source water have been screened, chemicals are now added to the treatment facility. During this process, chemicals are added to produce precipitates that are insoluble in water. A range of commercially available compounds are used in these procedures. These kinds of chemicals are known as coagulants. For many years, one of the most widely used chemical coagulants has been aluminium sulphate, also known as alum. Ferrous sulphate, ferric chloride, sodium aluminate, activated silica, and substances known as polymers low molecular weight compounds made up of dozens of tiny molecules joined to form excessively big molecules are other common coagulants (Spellman, 2018). The three categories of polymers are catalytic (positively charged), anionic (negatively charged), and non-ionic (neutrally charged) (Spellman, 2018). Coagulants must be mixed very well with water before heavy clumps can form, regardless of the coagulant or combination of coagulants used. With a rapid mix unit, the coagulant is added to the water for a quick and thorough mixing. When water mixing is slowed water encounters flocs as they form and enlarge. During the next mixing procedure, the mixing must continue gently so that the floc can grow and gain weight and remain suspended until the sludge is ready to settle in the clarifiers (Spellman, 2013).

2.10.4. Flocculation

The process of adding chemicals to destabilize and aggregate suspended particles into larger, settleable flocs is known as coagulation and flocculation. These processes are typically implemented in a treatment unit called a flocculator. Once flocculation is complete, water flows over a weir and into the central zone of a clarifier or sedimentation basin. In circular clarifiers, this movement typically occurs from the periphery toward the center, often guided by a sawtooth weir along the basin's edge. As the water moves slowly toward the weir, floc particles settle to the bottom by gravity. Mechanical rakes continuously sweep the settled floc, or sludge, toward the

center of the basin for removal. This sludge is typically pumped to a sludge disposal system or sedimentation pond. The clarified water is then transferred from the weir to the filtration units for further treatment (Tchobanoglous et al., 2014).

Clarifying before filtration eliminates most of the suspended material, which keeps the filters from overloading and enables a significantly higher volume of water to be filtered before they require backwashing. Fe and Mn removal plants are not necessary in systems that have a lime-soda ash softening plant. Rapid oxidation and precipitation of iron and manganese, as well as their integration into the calcium and magnesium precipitates, are made possible by the high pH during softening. Iron and manganese are also eliminated by surface water treatment facilities that use coagulation, flocculation, sedimentation, and filtration so long as they ensure that Fe and Mn undergo oxidation. Because organic materials are present, oxidation can occasionally be problematic. And lastly, biological therapy techniques are being pilot tested at various locations.

Biological treatment techniques are widely utilised in European nations including the Netherlands, France, and Germany. Fe, Mn and N work best when they are present in the water at the same time. Prior elimination through proper treatment and bituminous protection of iron/steel mains can reduce problems caused by Fe and Mn in distribution mains. process of flocculation and coagulation after settlement, or deep-bed or multimedia filtration if the particles are colloidal. Insignificant amounts of polyelectrolytes are typically added to coagulants, such as ferric chloride or aluminium sulphate to aid in flocculation. Small amounts of polyelectrolytes may be enough in many fluids to encourage the flocculation of the particles for their eventual removal by settling and filtering.

2.10.5. Sedimentation

Turbidity and suspended solids can be effectively reduced through simple sedimentation. Sedimentation tanks are designed to reduce the velocity of water flow, thereby allowing suspended particles to settle out under the influence of gravity. The selection of an appropriate tank design is often based on basic settling tests or informed by operational experience from similar treatment facilities. However, these systems primarily remove larger and heavier particulates and are generally insufficient for finer colloidal materials unless supplemented by coagulation. Due to the

relatively slow nature of the sedimentation process, storage tanks are typically required to buffer variations in water demand (Spellman, 2013).

2.10.6. Filtration

Manganese oxidation is generally more challenging than iron oxidation due to its slower reaction rate. To facilitate complete oxidation, a detention time of 10 to 30 minutes after chemical addition is typically required before filtration. Various filtration media are employed to remove iron and manganese, including anthracite/sand also known as ironman sand, manganese greensand, ceramic media, and electro media. Among these, manganese greensand is the most commonly used pressure filtration medium for the effective removal of both iron and manganese from water (Crittenden et al., 2012). “Greensand” is a processed filtration media composed of nodular grains of the zeolite mineral glauconite. The ion exchange properties of glauconite facilitate the formation and maintenance of a catalytic coating on the media surface. This coating catalyzes the redox reactions essential for the effective removal of manganese and iron during the filtration process. Potassium permanganate dosing, applied either intermittently or continuously, helps sustain this catalytic layer (Crittenden et al., 2012). Other media used for manganese and iron removal include Iron-man sand, anthracite/sand blends, and chemically bonded manganese oxide media. These media typically consist of anthracite and sand chemically bonded to manganese oxide. Unlike manganese greensand, these media require conditioning within the filter after installation to develop their catalytic properties (AWWA, 2012). Compared to manganese oxide-coated media, electro media offer an alternative filtration option. This proprietary multimedia formulation utilizes a naturally occurring zeolite and does not require regeneration with potassium permanganate. In contrast to the other media discussed, macrolite is not a naturally occurring material but a synthetic media specifically designed for the removal of iron and manganese (Tchobanoglous et al., 2014). This ceramic media is characterized by its rough texture and spherical shape. The removal of contaminants, such as iron and manganese, primarily occurs through physical filtration mechanisms rather than chemical processes like absorption or oxidation (Crittenden et al., 2012). Each filtration medium possesses its own set of advantages and limitations. Therefore, pilot testing is essential when selecting both the medium and oxidant, as it allows for the determination of all relevant design parameters under site-specific conditions. Physical straining is often the primary mechanism for contaminant removal, rather than contact

oxidation or adsorption. Conducting pilot studies ensures that the chosen treatment approach is optimized for efficiency and effectiveness (Tchobanoglous et al., 2014).

2.10.7. Disinfection

After the filtration process, water is clarified and purified as much as possible; however, viruses and bacteria may still be present. To ensure their complete destruction, a disinfection step is necessary. Chlorination is a widely used disinfection method in water treatment. Chlorine is applied in various forms, including chlorine gas, chlorine dioxide, and hypochlorite (bleach), with chlorine gas being the most common. Any chlorination process effectively eliminates pathogenic microorganisms. Water treatment plants continuously monitor and carefully control chlorine levels to ensure complete disinfection. It is essential to add sufficient chlorine to achieve microbial inactivation, but excessive chlorine can negatively affect the water's taste and odor when delivered to consumers (WHO, 2017).

Figure 2.1 below shows the diagram of the standard procedures for water treatment from the source to the distribution point. Water treatment is the process of purging home and wastewater water of impurities. Producing a fluid waste stream that is safe for the environment and a solid waste stream that can be disposed of or reused are its goals.

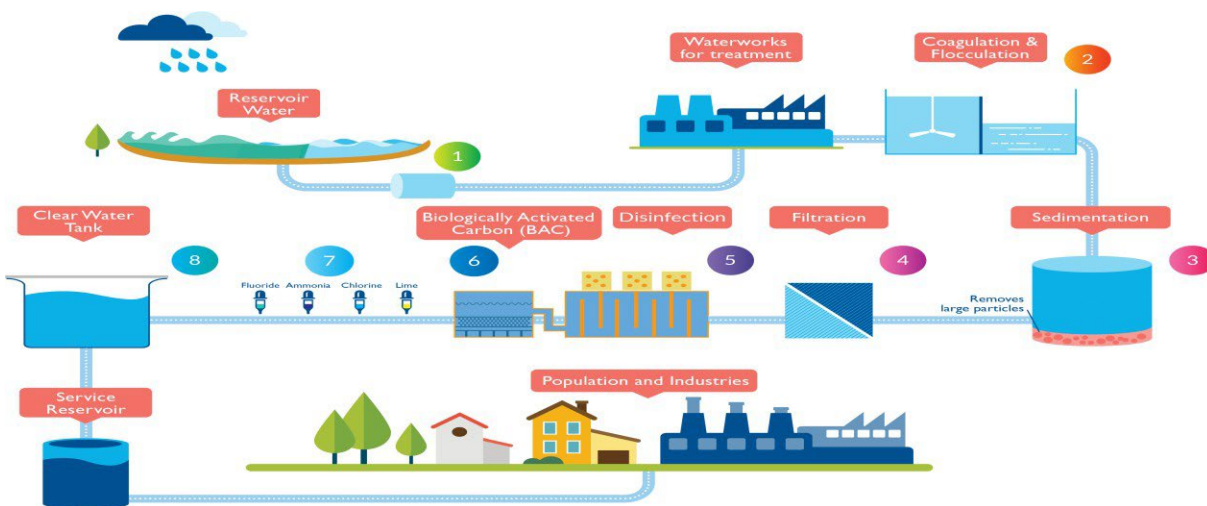


Figure 2.1: Indicate the typical water supply treatment processes

2.11 Water Supply Efficiency Measures in South Africa

Muller (2022) suggested that routine maintenance checks be carried out in addition to infrastructure enhancements to find and repair leaks in the water distribution system. Water loss could be significant if leaks are not immediately rectified. Modernise pipes and invest in replacing antiquated and inefficient water distribution infrastructure to reduce water loss and increase system efficiency (Tang, 2020). Moller (2003), asserts that one of the effective water usage technologies that can help detect patterns of excessive consumption and enhance water resource management is smart metering, which offers real-time data on water usage. Rainwater harvesting systems, which allow rainwater to be collected and used for non-potable purposes like landscaping, are one tool that must be encouraged. This will make it possible to implement a tiered pricing structure in which higher usage levels will result in a rise in the cost per unit of water. Smith (2023) emphasized that continuously collecting and analysing data alongside monitoring water usage assist to track changes over time and identify important patterns or trends in water management. Smith (2023) noted that data must be used to refine and adapt water efficiency approaches to provide exact performance indicators for assessing the effectiveness of water efficiency programs and efforts. Metrics can include reductions in the amount of water consumed per person and improvements in system efficiency. The community will learn how to use water if local groups, educational institutions, and environmental organisations collaborate to spread the word about water conservation and reach a larger audience, claims (DWS, 2020).

2.12 Sustainability of Water Resources in South Africa

Inadequate service delivery by municipalities and failure to perform basic maintenance on existing infrastructure cause many urban water systems in developing nations to suffer significant financial and physical water losses (Mckenzie et al., 2012). Water losses significantly affect the performance of water services in poor countries and many water service providers operate at technical efficiency levels far below best practices (Tremolet and Rama, 2012). With an average annual rainfall of approximately 450 mm well below the global average South Africa ranks among the driest countries globally (DWS, 2022). According to DWS (2022), this limited water availability makes it challenging to meet the needs of a growing economy and population. High water demand stems from agricultural, industrial, mining, and domestic sectors (DWS, 2022). Water resource management must be grounded in sound practices to ensure the sustainable

protection, use, and administration of South Africa's water resources (DWAF, 2004). There is an urgent need for effective water management and usage strategies to avoid severe water shortages on local, regional, and national scales that would reduce water availability (DWS, 2019). Compared to other sectors (85%), agricultural water supply is less assured (NWRS, 2013). Water is strategically vital for power generation, which has the highest supply assurance of 99.5%, equivalent to a failure rate of once every 200 years (DWS, 2022). Agriculture is the largest consumer of water, accounting for 66% of total usage, including afforestation and livestock watering (NWRS, 2013). Municipal and domestic use including industrial and commercial users supplied by municipalities follows at 27% (DWS, 2022). The remaining 12% of water use includes power generation, mining, bulk industry, livestock, conservation, and afforestation (DWS, 2022). Water scarcity is worsened by inefficient agricultural water use, which consumes the majority of available resources (Backeberg and Sanewe, 2010). Drought conditions are likely to intensify due to climate change, which is also expected to alter rainfall patterns and increase the frequency of extreme weather events (DEA, 2016). These climatic changes could aggravate water scarcity and reduce the availability of water resources (DWS, 2022).

2.13 Assessing efficiency of Domestic Water Supply in South Africa

Water resource assessment can be used to thoroughly examine all surface water resources to determine their capacity, current state, and river water quality (DWAF, 2004). Water use licensing and regulation will guarantee that all major water uses have the appropriate licenses and that the circumstances are in place to encourage water efficiency and conservation (DWS, 2013). Examine current licenses to make sure the act's standards for water efficiency are being followed (DWS, 2013). The National Water Resources Strategies (NWRS) and Catchment Management Structures (CMS) must describe the implementation of demand management and water conservation strategies (DWS, 2013). This includes actions like encouraging water efficiency and minimising water losses (DWS, 2013). The most crucial method for choosing the ideal chemical course for accomplishing certain water treatment objectives is the Jar Test (EPA, 2002).

Jar testing allows you to find the optimum chemicals for your application by testing how certain chemicals will work in your treatment system (EPA, 2002). In addition to saving time, the test also saves money (EPA, 2002). To make sure there is no overusing and overspending on chemicals, various therapy dosages can be tested using jar testing (EPA, 2002). Jar testing is particularly

helpful since it can help you identify the components of a particular waste stream and whether the wastewater sample will need a different chemical load than anticipated, filtration, or a pH correction (Tchobanoglous et al., 2014). Each wastewater sample has a unique composition, requiring a unique treatment (Tchobanoglous et al., 2014). Jar tests are the best and most efficient way to determine the best treatment system (EPA, 2002).

2.14 Water Legislation in South Africa

2.14.1 Water Services Act (108) of 1997

South Africa's Water Services Act (WSA) (Act No. 108 of 1997) encourages the efficient and sustainable use of water resources while providing the legal basis for the delivery of water services, such as sanitation and water supply (RSA, 1997). The WSA is relevant to evaluating how well Standerton's residential water supply is being used, and it includes. According to the WSA, everyone has the right to basic water supply and sanitation; everyone is entitled to these forms of services (RSA, 1997). This guarantees a minimum amount of clean water for basic needs for every resident (RSA, 1997). Water Services Authorities (WSAs) of municipalities oversee and making sure that water services are provided within their borders (RSA, 1997). To provide water services, WSAs must create a Water Services Development Plan (WSDP), which must include plans for infrastructure requirements, water demand assessment, and water-saving techniques (DWS, 2017). Regular updates to the WSDP are necessary to incorporate demand management and water saving strategies (DWS, 2017).

To ensure efficient and effective service delivery, the Water Services Providers (WSPs) and WSAs can contract to manage the provision of water services (RSA, 1997). They must also operate under the terms and conditions set by the WSAs (RSA, 1997). The Water Conservation and Demand Management Strategy highlights the necessity for WSAs to implement measures for water conservation and demand management to ensure sustainable use of water resources (DWS, 2004). Among them are reducing water losses, promoting efficient water use, and educating the public about water conservation (DWS, 2004). The Department of Water and Sanitation (DWS) is responsible for overseeing the implementation of the Act and monitoring the performance of WSAs and WSPs (DWS, 2013). The Community Participation Policy encourages the involvement of communities in the planning and management of water services (DWA, 2001). The WSDP

involves public consultations and participation (DWA, 2001). The Tariff Setting Guidelines require that water tariffs be set in a way that promotes the efficient and sustainable use of water (DWS, 2015). Tariffs must cover the cost of providing water services, including maintenance and infrastructure development (DWS, 2015).

2.15.2. National Water Act (36) of 1998

The National Water Act (NWA) (Act No. 36 of 1998) is South Africa's primary legislation for sustainable water resource management (RSA, 1998). It ensures protection, development, conservation, and equitable use of water resources (RSA, 1998).

I. The Act emphasizes protecting water quantity, quality, and ecological integrity by setting water reserves for both environmental and human needs (RSA, 1998; DWAF, 2004).

II. It promotes Integrated Water Resources Management (IWRM) by coordinating water, land, and related resource use, requiring water use authorizations for major uses including domestic supply to ensure sustainable and efficient water consumption (RSA, 1998; DWS, 2013).

III. The National Water Resource Strategy (NWRS) and Catchment Management Strategies (CMS) provide frameworks for demand management, conservation, and efficiency improvements, with public participation mandated to ensure community needs are incorporated in decision-making (DWS, 2013; DWAF, 2004). Monitoring, compliance, and enforcement mechanisms are in place to ensure adherence to water use permits and sustainable practices (RSA, 1998).

IV. Catchment Management Agencies (CMAs) manage water resources at the catchment level, tailoring management strategies to local conditions; Standerton falls within a CMA jurisdiction ensuring localized water resource governance (RSA, 1998; DWS, 2013).

2.15.3 Municipal Structures Amendment Act (3) of 2021

Municipal structures allow municipalities to be established in accordance with the requirements pertaining to categories and types of municipalities (RSA, 1998a). They also define criteria for deciding which category of municipality should be established in each area, as well as the types of municipalities that may be established within each category (RSA, 1998a). They also provide for an appropriate division of functions and powers between categories of municipalities, regulate the internal systems, structures, and office-bearers of municipalities, provide for elective systems that

are appropriate, and address matters related to these categories (RSA, 1998a). According to the Municipal Structures Act, a Water Services Authority (WSA) is any municipality with the executive authority to supply water services within its borders (RSA, 1998a). WSAs are mostly in charge of making sure that water services are provided, and they can be authorised local municipalities, districts, or metropolitan (DWS, 2003). It is the responsibility of WSAs to gradually supply at least basic water services to everyone under their jurisdiction (RSA, 1997). It does not require the provision of these essential water services at free expense (RSA, 1997). Higher service levels must be planned for and delivered by WSAs where feasible and sustainable (DWS, 2003). The Act states that in places where local capability is lacking, typically in rural areas, the district authority oversees providing services (RSA, 1998a). Through the creation of municipal integrated development plans (IDPs), which are essential to the planning, designing, and implementing of productive use systems, the Municipal Systems Act creates an environment for integrated planning (RSA, 2000). This act implies that the obligation lies with municipalities and is not facilitating (RSA, 2000).

2.15.4 Free Basic Water Policy (FBW), April 2007

The Free Basic Water (FBW) policy, introduced by the Department of Water Affairs and Forestry (DWAF) in 2007, provides every household with 6,000 litres of free clean water annually, equating to approximately 25 litres per person per day for an eight-member household (DWAF, 2007). The policy does not differentiate between household sizes or rural and urban areas, which results in urban households generally receiving more water per capita due to smaller family sizes compared to rural households (DWAF, 2007). Implementation has been more timely in larger urban areas, while rural communities face challenges such as long distances to water sources, low water demand, poor cost recovery, and limited municipal finances (DWAF, 2007). The policy delivers free water through piped reticulation systems, thus excluding those without existing infrastructure from accessing the benefit, further disadvantaging underserved communities (DWAF, 2007). This highlights the challenge where infrastructure development has not kept pace with water service needs (DWAF, 2007).

2.15.5 National Water Resource Strategy (NWRS) March (2023)

Information regarding the management of water resources and the establishment of institutions is provided by the NWRS (DWS, 2013). It demands input from municipalities that considers both present and future water needs (DWS, 2013). As part of a Catchment Management Strategy (CMS), municipalities are required to make sure that water allocation plans at the catchment level account for water distribution for various purposes (DWS, 2013). Linking the catchment-wide water distribution to small-scale household water users may prove challenging in practice (Movik, 2009). Therefore, research must be done to ascertain the water needs and uses of each community (Funke et al., 2007). The legislative framework system in South Africa is quite supportive of providing water for basic human needs (WSA, 1997). As mandated by the WSA (Act No. 108 of 1997), homes shall receive 6,000 litres of free basic potable water per month to fulfil basic human needs (WSA, 1997). To supply this water, the local government is in charge (DPLG, 2004). Instead of addressing productive water usage, this complies with the UNESCO minimum standard for fundamental human requirements (hygiene and health) (UNESCO, 2003). The provision of water for fundamental human needs is given more attention in South African laws and policies than productive water applications, even though water can promote social and economic growth (Backeberg and Sanewe, 2010). The definition or analysis of essential water requirements is limited and limited to drinking water requirements (Hope et al., 2008). The Act acknowledges that water may promote both social and economic advancement (NWA, 1998). The Act promotes useful, sustainable, and effective use for the general public's benefit (NWA, 1998). Although it is not stated explicitly, these are tasks that optimally utilise water (Schreiner & van Koppen, 2002). The definition of beneficial water use is vague (van Koppen & Schreiner, 2014). The distribution of water is the responsibility of the national government (NWA, 1998). However, there are no guidelines for local government on how to provide these potentially beneficial uses (Funke et al., 2005). Although the NWA places a lot of emphasis on water for economic hubs, including water for residential use by water companies such as Rand Water and Lepelle Northern Water Board, they are not connected to or aligned with the water supply for customers (DWS, 2017).

The Free Basic Water Supply (FBWS) should be covered by the cost of bulk water delivery rather than municipality-specific charges because the government is moving the burden of FBWS to municipalities, which is causing a major imbalance in cost recovery (RSA, 2002; SALGA, 2015).

This issue contributes to towns' inability to recoup their expenses (Auditor-General South Africa, 2022). The Strategic Framework for Water Services (2023) should support water programs that promote sustainable living and economic development (DWS, 2023). According to this structure, the local government oversees making provisions for this (DWS, 2023). However, Act No. 117 of 1998, the Municipal Structures Act, does not provide guidance on this and merely stipulates that fundamental services must be offered perhaps at a cost (RSA, 1998).

Chapter 3

Research Methodology

3.1 Preamble

This chapter outlines the methodology employed to evaluate the efficiency of Standerton's water supply system. The process involved several key stages, including collection of water quality and quantity data its analysis, field observations and assessment of the water treatment plant's performance. Each phase comprises specific actions and tasks designed to provide a comprehensive understanding of water consumption efficiency. The chapter also presents the data collected, identifies the sources of this data, and details the analytical techniques used to achieve the study's objectives.

3.2 Data Collection

Data collection is a systematic process that facilitates the acquisition of specific information relevant to a study. According to Chaleunvong (2009), structured data collection is essential as random or disorganized data gathering can make it difficult to provide clear and accurate answers to the research questions. A systematic approach, therefore, helps to ensure the reliability and validity of the findings. Creswell (2007) emphasizes that data collection involves more than simply obtaining data; it encompasses multiple tasks, such as identifying appropriate locations or participants, gaining contextual understanding, investigating issues in the field, and maintaining detailed records. Based on the research design adopted in this study, a range of data collection techniques were applied. Chaleunvong (2009), outlines several effective strategies, including the use of existing information, administration of instruments and direct observation methods that were employed in this study. These techniques supported the implementation of a mixed-methods approach, enabling an in-depth exploration of the research objectives and providing comprehensive insights into water supply efficiency and quality.

3.2.1 Field observations

The initial stage of the study involved a field visit to the SWTP to observe and gain a practical understanding of its operational procedures and challenges. Baseline data were collected on water

supply conditions, the general characteristics of the sampling locations, and the quantity and quality of water within the study area. The SWTP abstracts raw water from the Vaal River; therefore, field observations included an examination of the river's abstraction point. The tool used to guide the observations is in Appendix C. Process controllers were requested to provide periodic raw and final water meter readings. During field inspections, visible challenges such as leakage, sediment accumulation and general inefficiencies were noted. Critical stages of the water treatment process namely coagulation, flocculation, sedimentation, filtration, and disinfection were monitored to assess operational effectiveness.

3.2.2 Water Sampling

Three sampling points were selected at the Standerton Water Treatment Plant (SWTP) for the purpose of evaluating water quality across different stages of the treatment and distribution process. The first sampling point was located at the raw water intake from the Vaal River. The second point was a stand-alone tap situated within the SWTP premises, representing the final treated water. The third sampling point was located approximately 3 km downstream of the plant at the Sasol garage, representing water at a consumer distribution point. The rationale for selecting these three sampling locations was to assess water quality before treatment, immediately after treatment, and during distribution. This approach allows for a comprehensive evaluation of the effectiveness of the treatment process and the integrity of the distribution system. Water quality data (Appendix A) were obtained from DWS, Mpumalanga office, for the period 2016 to 2020. DWS officials conducted monthly sampling at the three designated points and submitted the samples for laboratory analysis. The results were evaluated against the standards set by the WHO, DWA and SANS-241 for drinking water quality to determine whether the SWTP consistently produces water that is safe and suitable for human consumption.

3.3 Data Analysis

3.3.1 Water Quality

The water quality data provided by the DWS included key physicochemical and microbiological parameters such as pH, free chlorine, turbidity, TDS, EC, Fe, Mn, *E. coli* and total coliforms. These parameters were used to assess the performance of the SWTP with respect to its treatment processes and to determine whether the treated water complies with established drinking water

quality standards. The analysis aimed to evaluate whether the treated water meets the guideline limits recommended for domestic use, as outlined by WHO (2011), SANS-241 (2015) and DWA (2015). Both physicochemical and microbiological indicators were used to determine the degree of compliance and safety of the water distributed to the community. Data analysis is a critical component of the monitoring, examining, organizing and interpreting process of the data collected during scientific research or experiments to draw conclusions, test hypotheses and identify patterns or trends and give actionable insights that inform management and operational decisions. In this study, water quality data from the final treatment point and a downstream distribution point (Sasol Garage) were used to assess the quality of drinking water supplied to residential areas including Goldi Chicken, the Central Business District (CBD) and the surrounding industrial zones in Standerton.

3.3.2 Water Quantity

Water quantity refers to the measurable volume of water available to meet the demands of various sectors, including domestic, industrial and agricultural users. In Standerton, rapid urbanisation and population growth have intensified the pressure on available water resources, necessitating a careful assessment of whether current supply levels are sufficient to meet the increasing demand. The primary water sources, such as the Vaal river, must maintain adequate flow levels and storage capacities to ensure reliable and continuous supply. Insufficient water quantity can place significant stress on municipal infrastructure, including pipes, pumps and reservoirs, potentially resulting in service inefficiencies such as low pressure or intermittent supply. Furthermore, a reduction in water volume can lead to higher concentrations of pollutants negatively affecting water quality due to decreased dilution capacity and impaired natural purification processes.

Water quantity is also a critical indicator of long-term sustainability, guiding decisions around conservation measures and infrastructure upgrades. Water quantity is quantified using metrics such as litres per day per household, cubic metres per second (m^3/s) for river discharge rates and megalitres (ML) to express the storage capacity of reservoirs. Accurate monitoring and analysis of these parameters are essential to ensure that water supply systems in Standerton remain efficient, resilient and capable of supporting both current and future needs. This allowed for the identification of discrepancies that could indicate inefficiencies, such as water losses, over abstraction or underutilization of the plant's capacity. It was observed that the volumes of water abstracted frequently exceeded the allowable limits stipulated in the plant's water use license

issued by the Department of Water and Sanitation (DWS), which permits a maximum abstraction of 27 ML/d. This finding suggests potential non-compliance with regulatory requirements and raises concerns about the sustainability of water resource use. Furthermore, consistent over abstraction may place additional strain on the source water body, in this case the Vaal River and could negatively impact the long-term reliability of the water supply system.

3.4 Water Supply Efficiency and Water Balance for Standerton

According to Vieira et al. (2008), assessing water supply efficiency is critical in identifying the key challenges that hinder water treatment processes from consistently producing water of acceptable quality. Understanding these challenges allows for targeted interventions to improve treatment performance and reduce risks to public health. The evaluation of water supply efficiency not only supports the identification of operational inefficiencies within the system but also plays a vital role in preventing contamination throughout the supply chain. This ensures that both consumers and the environment are protected through the continuous provision of clean, safe drinking water. The water balance approach was employed to calculate the inflow and outflow within the system in order to verify whether the volume of water entering the system equaled the sum of the outflows and the change in storage. To evaluate water supply system efficiency, water balance analysis was conducted by comparing the total volume of raw water abstracted with the plant's treatment capacity and the volume of treated water output. This allowed for the identification of discrepancies that could indicate inefficiencies, such as water losses, over abstraction or underutilization of the plant's capacity.

It was observed that the volumes of water abstracted frequently exceeded the allowable limits stipulated in the plant's water use licence issued by the DWS, which permits a maximum abstraction may place additional strain on the source water, in the case the Vaal River and could negatively impact the long-term reliability of the water supply system. This method serves as a fundamental tool for tracking the movement and distribution of water throughout the entire treatment process. It enables plant operators to monitor the quantity of raw water entering the facility, assess the volumes processed at various treatment stages and determine the final output of treated water. Conducting a comprehensive water balance analysis, potential issues such as leaks, operational inefficiencies or inconsistencies in water accounting were identified. Additionally, this

approach supports the optimisation of treatment processes and storage management over time, thereby enhancing overall plant efficiency and performance. The assessment of water supply efficiency in this study was conducted following the methodology outlined by Vieira et al. (2008). Specifically, Equation 3.1 was used as the foundational formula for calculating water supply system efficiency. This equation typically expresses efficiency as the ratio of the volume of treated water successfully delivered to consumers to the volume of raw water abstracted, thereby providing a quantitative measure of system performance. A higher efficiency value indicates minimal losses and effective operation, while a lower value may highlight areas requiring improvement in either infrastructure, management practices, or treatment processes.

$$WSE = \frac{TWA}{TWS} \times 100\% \quad (3.1)$$

Where WSE is the water supply efficiency, TWA is the total water available and TWS is the total water supply.

The water balance (Equation 3.2) was used for calculating the inflow and out flow from the system to confirm whether water in the system or area is equal to its outflows plus change in s. In a water treatment plant, a water balance is used to track the flow of water throughout the entire treatment process. This enables operators to track on the amount of raw water entering the plant, the amount being treated at each stage and the amount of clean water being produced. This assist to identify potential challenges such as leaks, inefficiencies or disparities in water usage and optimise treatment operation storage over time. An equation for water balance can be used to explain how water enters and exits a system as follows.

$$In = \Delta s - (L + D) \quad (3.2)$$

In is inflow into the area, ΔS is change in storage in the area (the demand per day), L is the water losses in the area and D is water deficiency in terms of demand.

3.5 Limitations and Challenges Encountered During Data Collection

One of the primary challenges encountered during the data collection process was obtaining data from DWS in Mbombela. Access to official records was often delayed due to the unavailability of key personnel. On several occasions the designated official responsible for assisting with data access was not present in the office, which significantly hindered timely data acquisition. Furthermore, historical data covering the period from 2016 to 2020 was particularly difficult to obtain. The data was either not readily available in digital format, poorly archived or subject to

bureaucratic procedures that prolonged the retrieval process. These limitations impacted the comprehensiveness of the dataset and introduced delays in the research timeline. Consequently, efforts had to be made to triangulate information from secondary sources to supplement missing data and ensure the continuity of the research.

Chapter 4

Results and Discussion

4.1 Preamble

This chapter examines the Standerton water supply system, including the Vaal River as a source of raw water, the system layout, water quality results for raw water, treated (final) water, and water from the Sasol garage, as well as the evaluation of supply efficiency, the water balance, and the overall sustainability of the Standerton water supply system.

4.2 Water Supply in Standerton

4.2.1 Raw Water Supply from Vaal River

The Standerton water supply system includes two raw water pump stations, Pump Station 1 and Pump Station 2 (Figure 4.1). At Pump Station 1, five of the original six pumps are currently operational, while one is undergoing repairs. Pump Station 2 is non-operational although one of its two pumping units has been replaced, it has not yet been commissioned. Presently, the system abstracts approximately 43 ML/d of raw water from the source. The Standerton Water Treatment Plant (SWTP) is designed to treat up to 37 ML/d. Recent renovations have focused on upgrading the sand filtration units to improve treatment efficiency and the sand media in all filters is currently being replaced. Treated water is conveyed through four bulk pumping mains which serve both residential and industrial users. These mains supply water to four reservoir sites, each comprising two reservoirs. The current water demand is approximately 45 ML/day, which exceeds the plant's design capacity, highlighting a potential risk to sustainable service delivery.





Figure 4.1: Raw water pumps 1 and 2 closer to Vaal River

Residents of Standerton are experiencing inconsistent and poor-quality water supply services. Laboratory analyses were conducted on municipal water samples to assess compliance with water quality standards. Results indicate that in many suburbs, water is available only once or twice per week. The distribution system suffers from poor maintenance; when pump failures occur, they are repaired, but frequently malfunction again within a few months. The repair process is often delayed, leading to prolonged service interruptions and unreliable water delivery. Furthermore, the municipality has not consistently replaced damaged or stolen water meters, despite this being a statutory responsibility. Ageing infrastructure, including old pipelines, often results in pipe bursts and leaks that are not addressed promptly due to budgetary constraints and competing project priorities. These observations align with previous studies (Drangert & Sharatchandra, 2017; Hess et al., 2017; Vaux et al., 2020). In addition, the lack of systematic monitoring of the water supply infrastructure has contributed to increased incidents of water theft and unauthorised connections within the Standerton.

4.2.2 Layout of the Standerton Water Supply System and Distribution Network Diagram

The layout of the Standerton water supply system (Figure 4.2) illustrates the water reticulation network, depicting the conveyance of water from the treatment plant to various distribution points. This layout comprises the design of the pipeline network, reservoirs, pump stations, hydraulic

zoning, and service area coverage.

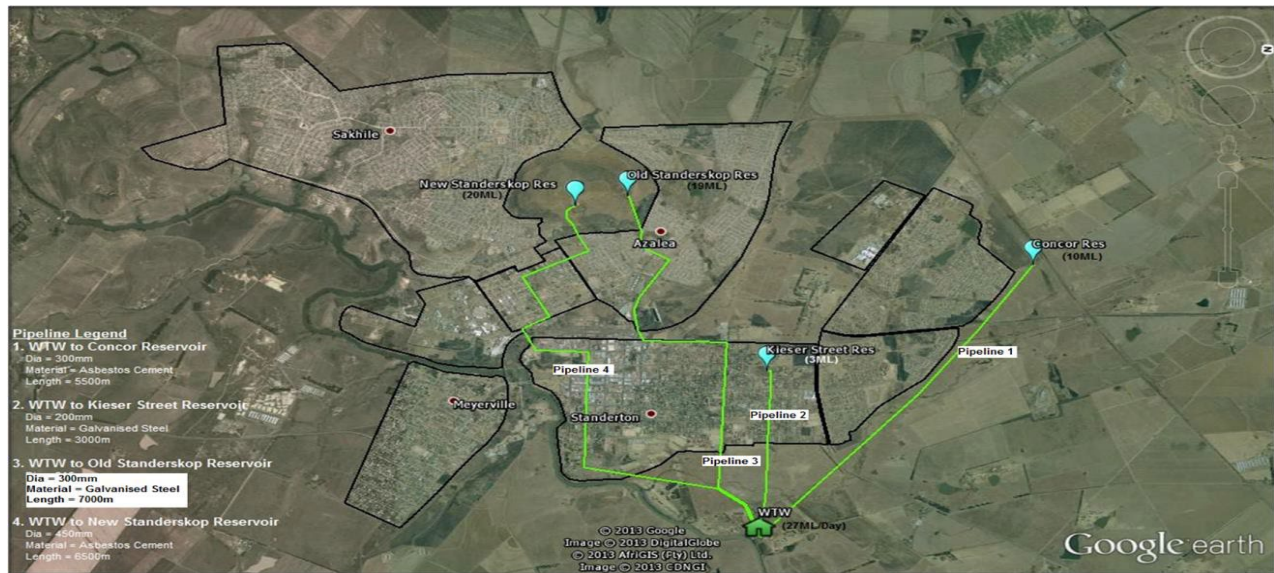


Figure 4.2: Standerton water supply scheme

The layout of the Standerton water supply system (Figure 4.2) illustrates the water reticulation network, depicting the conveyance of water from the treatment plant to various distribution points. This layout comprises the design of the pipeline network, reservoirs, pump stations, hydraulic zoning, and service area coverage.

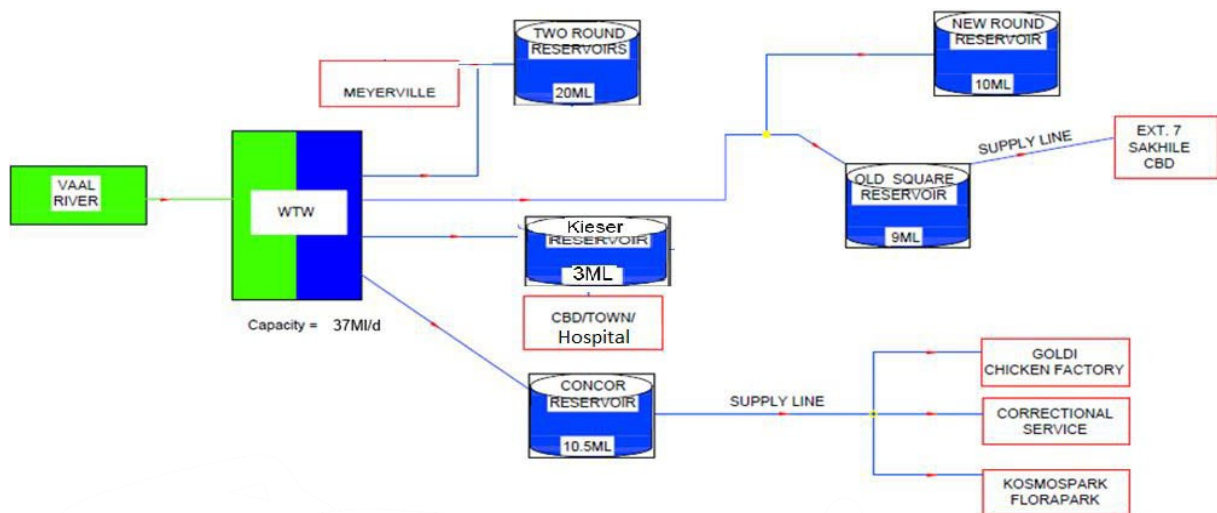


Figure 4.3: Standerton bulk water schematic diagram

The pumping system consists of five units, including three main pumps and two pumps on duty, which supply water through the rising main to the Concor Reservoir bulk line (Figure 4.4). Currently, both backup pumps are under repair and not operational. The rising main to Concor Reservoir is a 5 km long asbestos cement (AC) pipeline with a diameter of 300 mm. The presence of a single air valve along the pipeline limits the system's capacity, reducing the delivery rate to 5.45 ML/d instead of the design capacity of 8.45 ML/d. This pipeline supplies two reservoirs at Concor, which have a combined storage capacity of 10.5 ML/d.

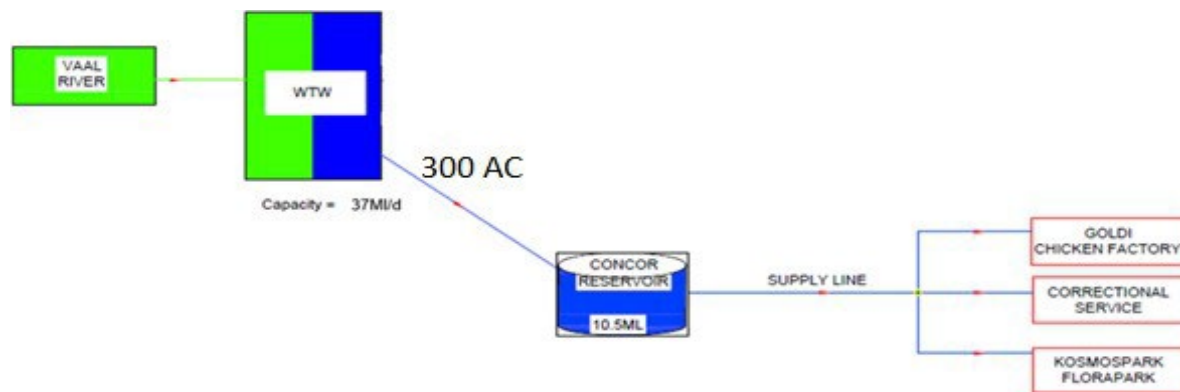




Figure 4.4: Rising Main to Concor Reservoir

The Kieser Reservoir bulk line is supported by two pumping units, one of which is currently non-operational and serves as a standby pump (Figure 4.5). Water is conveyed through a 2.89 km rising main constructed of 200 mm diameter galvanized steel pipe to the Kieser Street reservoirs. These two reservoirs have a combined storage capacity of 3 ML/d and supply water to key demand areas, including the hospital, central business district (CBD), and surrounding residential zones, which collectively require approximately 8 ML/d. However, both reservoirs are experiencing leakage issues, compromising storage efficiency and contributing to water losses within the supply system. The existing leaks exacerbate supply demand imbalances and highlight the need for urgent maintenance and infrastructure rehabilitation to ensure reliable water delivery to these critical service areas.





Figure 4.5: Kieser Reservoir

The Standerskop reservoir bulk lines are supported by four pumping units, including one standby unit connected via cable (Figure 4.6). The system features a 6.4 km rising main constructed from a 450 mm diameter asbestos cement (AC) pipeline, which supplies water to the New Standerskop reservoirs while traversing various suburbs and the town of Standerton. Along this pipeline, there are approximately thirteen off-takes that distribute water into the local network. These include a 200 mm diameter main feeding Meyerville and a 400 mm diameter main serving Sakhile Extension 4. Due to the current system configuration, potable water supply across the area is unevenly distributed, the bulk rising main functions simultaneously as a pumping main and as a bulk distribution pipeline. The two New Standerskop reservoirs each have a storage capacity of 10 ML/d but are currently compromised by leakages, which reduces effective storage capacity and contributes to water losses. Addressing these infrastructure issues is critical to improving system

reliability and ensuring equitable water supply.



Figure 4.6: Two Round Reservoir (New Standerskop) Bulk Supply line

The bulk supply to the New Round and Old Square reservoirs is supported by three pumping units, of which only one is currently operational. Water is conveyed via a 1.5 km rising main composed of 300 mm diameter asbestos cement (AC) pipe to the Showground where the pipeline splits into two branches: a 315 mm diameter uPVC pipeline leading to the Old Square reservoir and a 300

mm diameter galvanized steel pipeline that also serves as a distribution main through several off-takes (Figure 4.7). The total length of the pipelines from Showground to the reservoirs is approximately 5.8 km. The two reservoirs have a combined storage capacity of 19 ML/d. However, the Old Square reservoir is compromised due to leakage, reducing its effective storage capacity and contributing to water losses in the system. Meanwhile, the New Round reservoir remains out of service as it was never commissioned by the Gert Sibanda District Municipality, further limiting the available storage and distribution capacity.

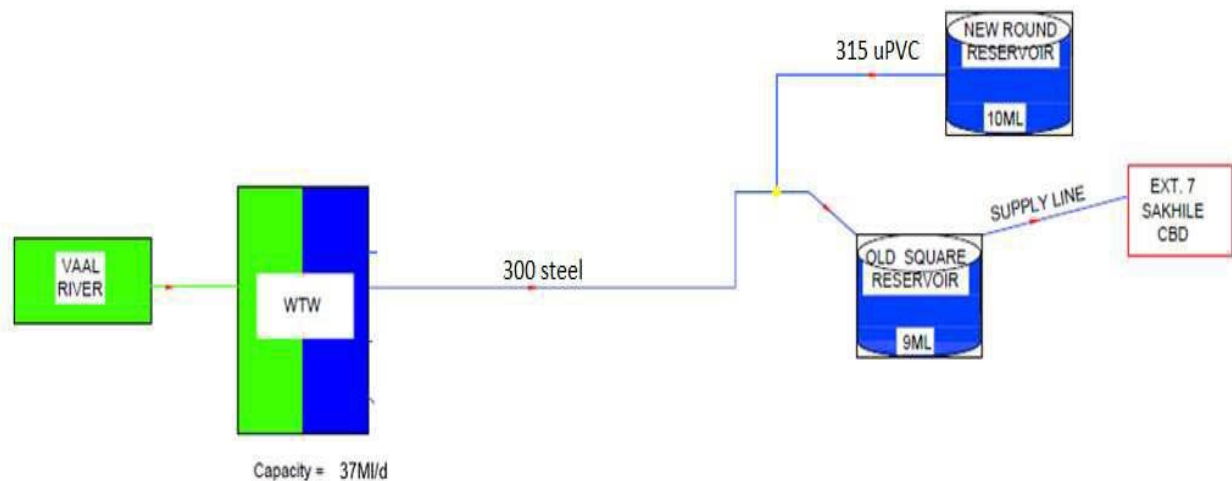




Figure 4.7: New round and old square reservoir

4.3 Water Quality Results for Raw, Final and Sasol Garage

The value of pH in raw water ranged from 6.61 to 8.9 with the average of 7.6 and final water ranged from 6.75 to 8.7 with the average of 7.46 and Sasol garage ranged from 6.8 to 8.69 with the average of 7.54 for the period of 5 years, respectively (Figure 4.8). During August 2019 and December 2020 pH values of raw and final water of Standerton were greater than 8. However, at the water quality range of 6.0 to 9.0, it is anticipated that neither taste nor health will be significantly impacted by the toxicity of dissolved range metal ions and protonated species. Amphoteric oxides may start to dissolve at a pH of higher than 8.5, while aluminium solubility starts to increase at pH 6. There may occasionally be very modest impacts on flavour. Despite a minor pH drop from raw to finished water as a result of solubility, plant performance was adequate. The salts of weak acids are the main source of alkalinity in natural water. The healthiest home water is typically thought to have a pH between 5.5 and 8.5. Excessive of high and low pH values can be detrimental for the quality of water. This indicates that pH level remained stable throughout the distribution system from the point of treatment to the decisive point of consumption. The average pH values recorded at the raw, final, and furthest point water were most within the specified drinking water quality standards throughout the assessment period. This means the pH of water supplied to consumer in Standerton consistently met regulatory requirement for safe

drinking water. In water treatment systems, maintaining proper pH levels can improve chemical reactions, stop microbiological development, stop corrosion, and maximise the efficiency of treatment chemicals. The characteristics of a liquid that contains water are greatly influenced by its pH. For example, the pH of water may affect the body's ability to absorb specific components, like metals and minerals. Because they are more accessible to the body than the pH, heavy metals in lower pH water are typically more harmful. Since pH affects the flavour, corrosiveness, and efficacy of water treatment procedures, it is a crucial factor in drinking water quality. Water quality and public health protection depend on maintaining pH within the advised range.

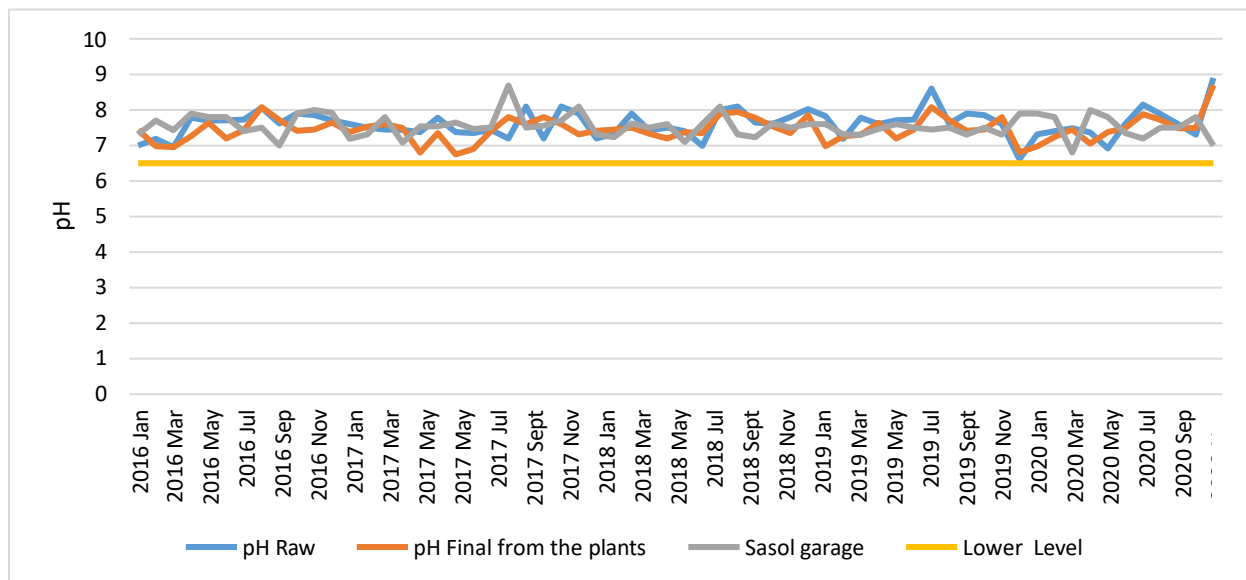


Figure 4.8: pH of raw, final water and Sasol garage (Furthest point)

The value of chlorine concentration of raw water ranges from 0,00 to 1.35 mg/L with the average value of 0.13 mg/L and 0.00 to 2.20 mg/L for final water with the average of 0.56 mg/L and for Sasol garage ranges from 0.02 to 0.048 mg/L with the average of 0.02 mg/L, respectively (Figure 4.9). The recommended value of 5 mg/L prescribed by SANS-241 (2015), WHO (2015) and DWS (2011). Since the furthest point has low chlorine concentration there is likelihood of contamination with bacteria and at this point E-coli was found to be 1 count/100ml, an indication of health risk consuming this water. Apart from domestic use, industries and commercials may not prefer to use such contaminated water. There are several factors that can reduce chlorine content in the distribution system. One of such factors is turbidity. In terms of turbidity below 5 NTU, the whole distribution network indicates significant presence of turbidity. final water has high Fe and Mn, which proves that Fe and Mn removal was not effective which indicates that there was no pre-

chlorination or less dosage of chlorine at this process with very no or very less effect for oxidation of Fe and Mn ions. These ions are removed through filtration. Since Fe and Mn ions were not removed at this stage, they are formed immediately after disinfection of final water where oxidation quickly occur. Ferrous ions are oxidized to ferric ions and manganous ions oxidized to manganous ions. Ferric, which are yellow to brownish and manganic ions which are black in colour, contribute to formation of turbidity. The oxidation then occurred throughout the reticulation system where the ions form turbidity up to consumer point, which is Sasol garage. The solids that form turbidity may reduce disinfection, and that the bacteria can be enveloped by these solids preventing the bacteria from being destroyed, water at the consumer point would be contaminated with bacteria. Illegal connections and pipe burst may allow silt to get into the pipes increasing turbidity with the reduction of disinfection, promoting bacterial contamination. Lack of Fe and Mn removal from water supply, water with high turbidity, and distribution contamination with bacteria is an indication of inferior performance of treatment plant. Total Coliform bacteria are present in high numbers, which confirms poor disinfection process.

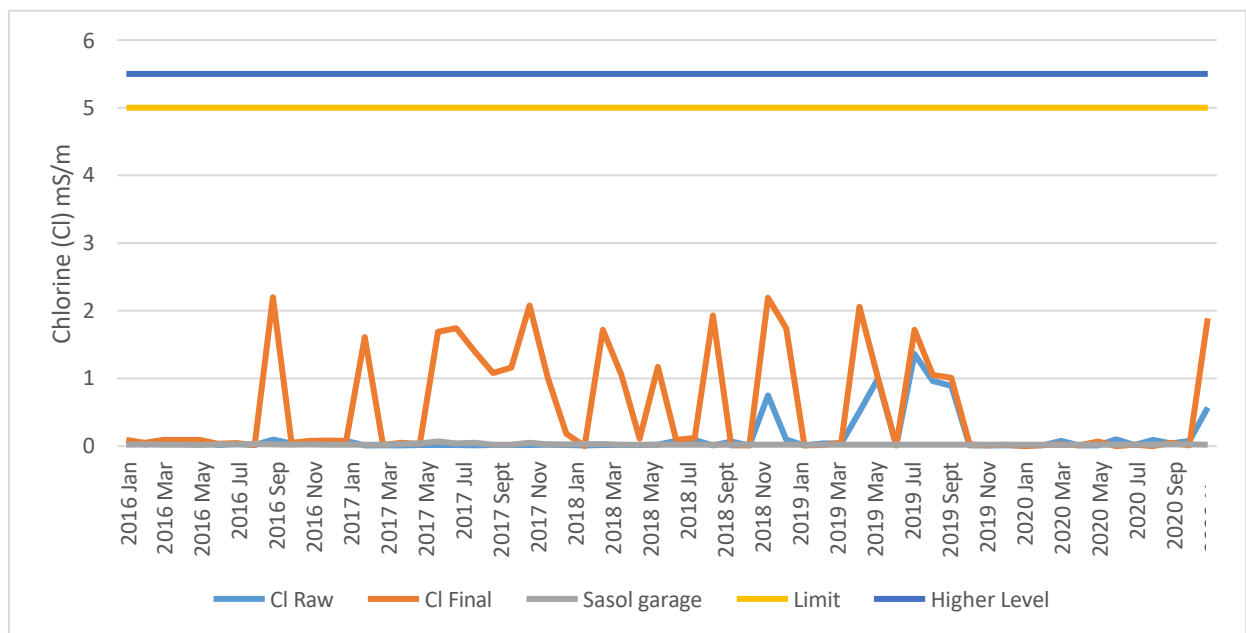


Figure 4.9: Chlorine for raw, final water and Sasol garage

The EC detected in drinking water for raw water ranged from 15.2 to 58.7 mS/m with the average of 32.23 mS/m and final water ranged from 12.7 to 58.4 mS/m with the average of 29.30 mS/m and Sasol garage ranged from 14.8 to 70 mS/m with the average of 27.17 mS/m (Figure 4.10). The

values for EC recorded for the period of 5 years was within drinking water standard limit of SANS-241 (2015) (170 mS/m), WHO (2011) (75 mS/m) and DWA (2015) (150 mS/m). EC is directly proportional to TDS with equation $EC \text{ (mS/m at 25 } ^\circ\text{C)} \times 6.5 = TDS \text{ (mg/L)}$. An increase in EC is an increase to TDS. TDS is inversely proportional to pH. Increase in pH results in decrease of TDS, hence EC. In the production process, the pH is 7.45 final and 7.74 water at the furthest point which is Sasol garage, this implies that both the EC and TDS become low. TDS has direct relationship to water hardness. Because the pH of processed water is above 7 and EC and TDS are bound to be low. Water hardness refers to the amount of dissolved minerals, primarily calcium and magnesium in water which makes it difficult to create a lather with soap, which implies Standerton water is soft and it lather with soap. Hard water does not lather easily, while soft water does.

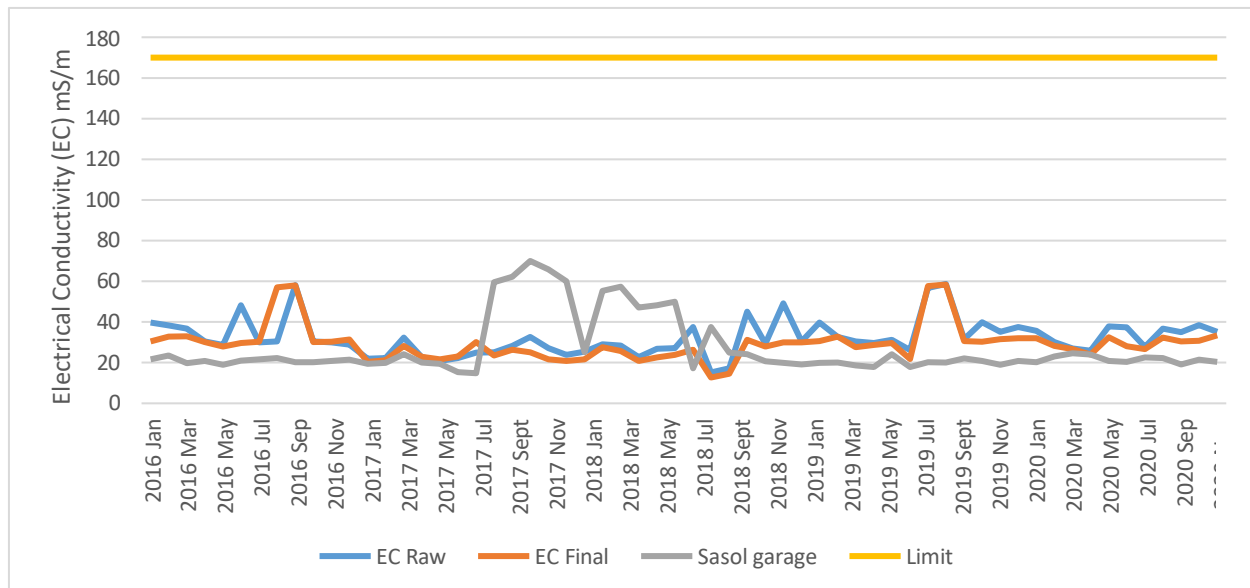


Figure 4.10: Electrical conductivity for raw, final water and Sasol garage

Turbidity which refers to the cloudiness of water caused by particles such as silt, clay, fine organic matter and microscopic organisms that are suspended in the water. The turbidity of SWTP for raw water ranged from 0.54 to 10.98 NTU with the average of 5.32 NTU and final water ranged from 0.35 to 9.74 NTU with the average of 4.27 NTU and Sasol garage ranged from 0.39 to 4.9 NTU with the average of 1.89 NTU for the period of 5 years, respectively (Figure 4.11). The results indicate that turbidity concentration in some months exceeded the recommended of 1, 3 and 5 NTU prescribed by SANS-241 (2015), WHO (2011) and DWA (2015). High turbidity could also have resulted from soil runoffs and untreated waste from sewage which end up in the river through

runoff. High turbidity in drinking water can have several adverse effects, including turbidity can indicate the presence of pathogens like bacteria, viruses, and parasites (e.g., *Cryptosporidium* and *Giardia*) that attach to suspended particles and may evade disinfection (WHO, 2017). It can increase the risk of waterborne diseases. Toxic chemical substances, metals, and pesticides can cling to suspended particles in drinking water. By adhering to suspended particles, microorganisms might lessen their exposure to disinfectants used in water distribution systems, increasing their chances of surviving and spreading disease. High turbidity in water is also bad for the ecosystem and can affect lakes, streams and other bodies of water due to suspended particles that can lower biological productivity, light penetration, habitat quality and recreational value. Water resources may fill more quickly as a result of this effect and streams may become more silted up and sedimentated which could be detrimental to fish and other wildlife habitats. Additionally, particles can act as attachment sites for contaminants like metals and microorganisms.

Reduced disinfection effectiveness on suspended particles shields microorganisms from chlorine or other disinfectants making the water treatment process less effective. High turbidity makes water appear cloudy or muddy which is unappealing to consumers. Taste and odour problems in organic matter can contribute to high turbidity and may lead to unpleasant tastes and odours. If the filtration system is stressed, high turbidity can clog filters and reduce the efficiency of water treatment systems, leading to higher operational costs. To ensure turbidity levels are within safe limits usually less than 1 NTU for treated water by implementing land management practices to reduce runoff and sedimentation into water sources to prevent soil erosion. Control pollution by minimizing agricultural runoff, industrial discharges, and deforestation near water sources. Adding coagulants like aluminium sulfate (alum) to the water to aggregate fine particles into larger clumps (flocs) that can be easily removed. Allow water to sit undisturbed so that heavier particles settle at the bottom. Use sand, gravel, or membrane filters to remove remaining particles and reduce turbidity further. Treat water with disinfectants like chlorine or UV light to kill pathogens that may cling to suspended particles.

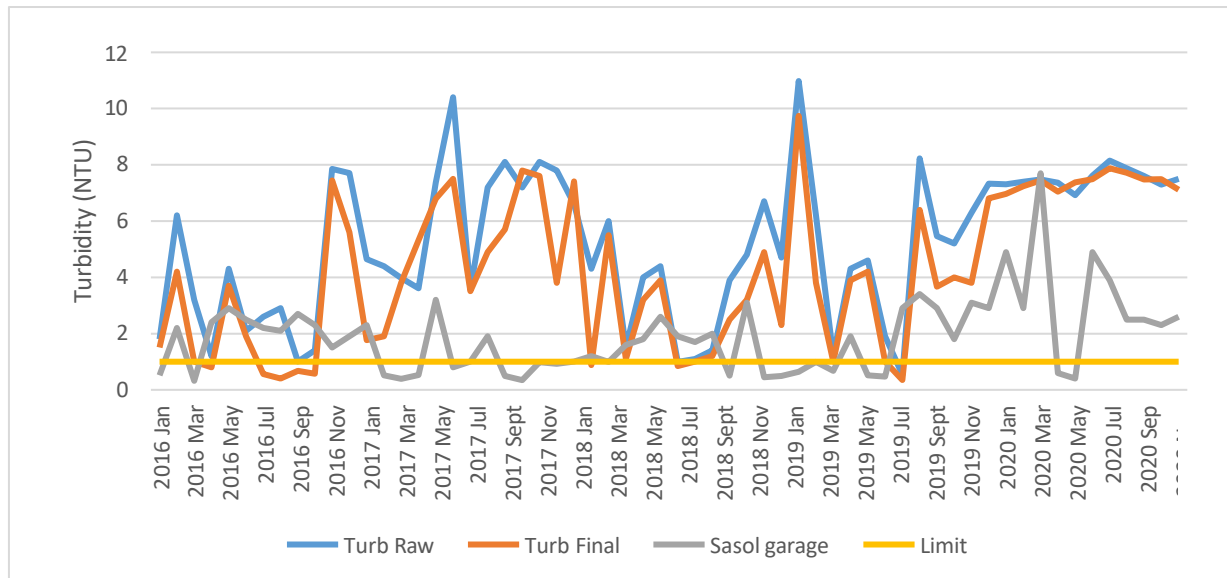


Figure 4.11: Turbidity for raw, final water and Sasol garage

TDS for raw water ranged from 89 to 162 mg/L with the average of 140.52 mg/L and final water ranged from 73 to 167 mg/L with the average of 125.34 mg/L and for Sasol garage the value recorded ranged from 72 to 373 mg/L for the period of 5 years, respectively (Figure 4.12). TDS were within the limit of drinking water guidelines of 450, 500 and 450 SANS -241 (2015), WHO (2011) and DWA (2015) for the 5 years period. High TDS value suggest the presence of bicarbonate, phosphates and chloride. This usually lead to increase in salinity which changed the ionic composition of the water. The amount of chemical components dissolved in water is measured by TDS. Minerals and salts including calcium, potassium, sodium, bicarbonates, chlorides, magnesium, and sulphates give water an undesirable taste and discolour it. Anything dissolved in water that isn't a water molecule is basically measured by TDS. Other components of water quality, like corrosion and water scaling potential, are also closely associated with TDS.

In water treatment, Corrosion is the process by which a metal surface deteriorates owing to a chemical reaction with its surroundings; this reaction is frequently enhanced by the composition of the water, including its TDS level. TDS is the measure of all dissolved minerals and organic materials in water. Since both TDS and EC is low water produced by the treatment system has low corrosion effects. Because the EC is not high, corrosion is low. To mitigate high corrosion in water, water treatment often involves adjusting pH levels adding corrosion inhibitors like orthophosphate and managing the mineral composition of the water. Water that generates a solid deposit that starts

to cover the piping and eventually clogs it is known as scale-forming water, not caustic water. This scale may eventually create a breeding ground for disease-causing bacteria, slime development, and other annoyances by trapping trace metals (USEPA, 2002).

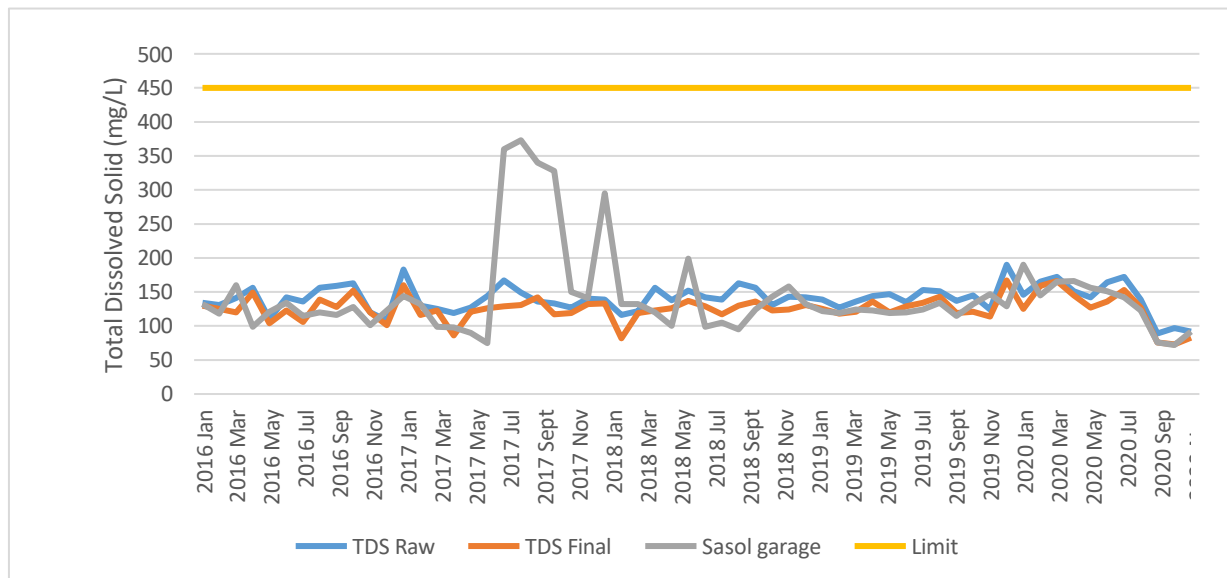


Figure 4.12: Total dissolved solid (TDS) for raw, final water and Sasol garage

The guideline for *Escherichia coli* (*E-coli*) is 0 colony forming units (CFU)/100 ml for WHO (2011), SANS-241 (2015) and DWA (2015). There must be no detectable concentration of *E-coli* in drinking water after water treatment. The *E-coli* counts in raw water ranged from 5 to 5200 with the average value of 232.73 CFU/100 ml and for final water ranged from 0 to 20 CFU/100ml with the average value of 2.29 CFU/100ml and Sasol garage ranged from 1 to 10 CFU/100ml, respectively (Figure 4.13). The *E-coli* above 0 CFU/100 ml shows that *E-coli* was not within the standards limits of drinking water guideline of 0 CFU/100ml for SANS-241 (2015), WHO (2011) and DWA (2015). The presence of *E-coli* in water might be due to lack of chlorine gas in the treatment water works and the source might have been contaminated by *E-coli* from the discharge from the industries and agricultural runoff and the equipment which were not functioning may result in incomplete removal of *E-coli* and other pathogens (WHO, 2017). The presence of *E-coli* in treated water can result from inadequate chlorination and filtration processes. If the raw water source is contaminated with fecal matter from human or animal waste, *E-coli* may persist in the water supply despite treatment efforts. Common contamination sources include agricultural runoff, wastewater discharges, sewage leaks and surface water pollution. Additionally, cross-connections

or breaches in the distribution system caused by physical damage or poor maintenance can introduce *E-coli* from external sources into treated water. Activities occurring upstream, such as sewage runoff into the river, further exacerbate source water contamination. Exposure to *E-coli* is strongly associated with gastrointestinal illnesses, including diarrhea, vomiting and abdominal cramps, which can be fatal if proper precautions and treatment are not administered (WHO, 2017).

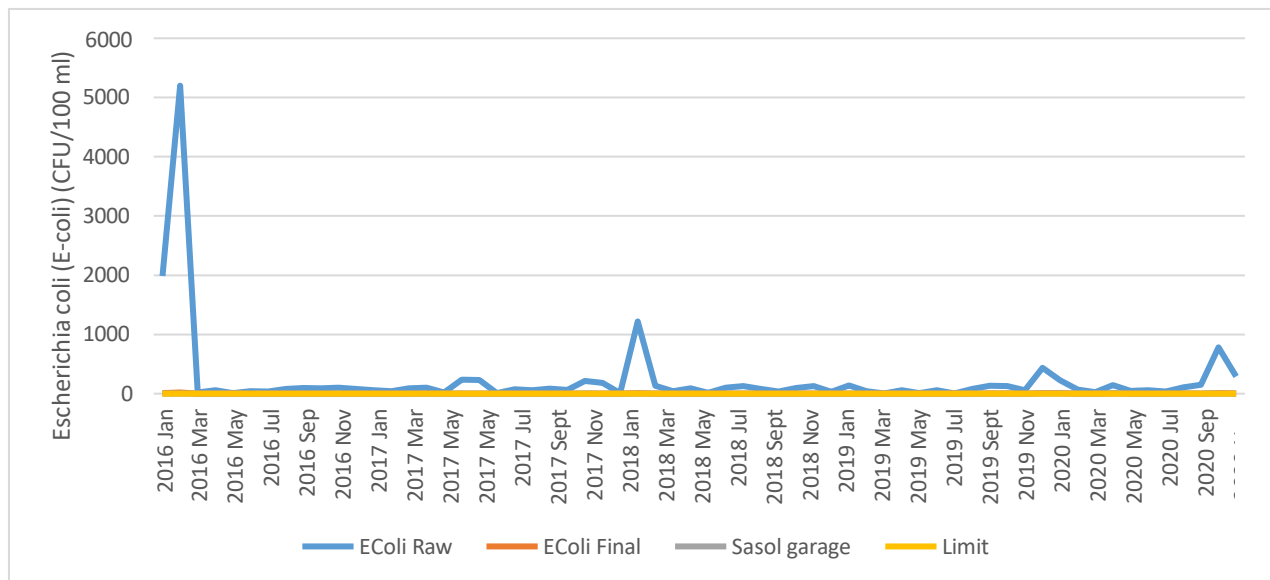


Figure 4.13: *E-Coli* counts for raw, final water and Sasol garage

Over a five year period, total coliform levels at Sasol garage ranged from 1 to 79 CFU/100 mL, with an average of 3.37 CFU/100 mL. In raw water, total coliforms ranged from 5 to 7,710 CFU/100 mL, averaging 1,660.71 CFU/100 mL, while in the final treated water, levels ranged from 1 to 206 CFU/100 mL, with an average of 30.95 CFU/100 ML, respectively (Figure 4.14). Between 2016 and 2020, raw water consistently exhibited high total coliform counts, often exceeding the acceptable limits for water quality. However, total coliform concentrations in the final treated water at the Sasol garage were mostly within guideline limits during several months of this period. Specifically, total coliform levels in March, April and June to December of 2016, as well as June to September of 2017, complied with the drinking water standards of 10 CFU/100 mL set by SANS (2015), WHO (2011) and DWA (2015).

While the majority of coliform bacteria are harmless, some can cause illness. After being exposed to these germs, a person may have fever, diarrhoea, vomiting, or upset stomach. These bacteria provide a greater risk to the elderly and children. There are several ways that coliform bacteria

might get into water sources. Untreated sewage, animal waste, agricultural runoff, and malfunctioning septic systems are a few typical sources. If contaminated water bodies, like lakes or rivers, are not adequately treated, they can also transfer coliform bacteria into drinking water supplies. The effectiveness of drinking water treatment, the integrity of the distribution system, and the overall hygienic quality of water are all commonly evaluated using total coliform bacteria. They ought to be undetectable in sources of treated water. They indicate insufficient treatment, contamination and/or aftergrowth following treatment, or an overabundance of nutrients, if they are discovered. Sometimes, they can be a sign that the pathogens that cause infectious diseases are present. Bacteria from the genera *Escherichia*, *Citrobacter*, *Enterobacter*, *Klebsiella*, *Serratia*, and *Rahnella* are among the diverse group of bacteria known as total coliforms. Not all of the bacteria that are categorised as coliforms are derived from faeces, even though the majority of them are.

The main application of total coliform counts is in the assessment of water treatment procedures. They are a sign of post-treatment drinking water contamination or microbial development in the distribution system. When found in combination with other faecal coliforms, the total coliform group, which includes bacteria of faecal origin, suggests the potential presence of bacterial pathogens like *Salmonella* spp., *Shigella* spp., *Vibrio cholerae*, *Campylobacter jejuni*, *col*, *sinia enterocolitica*, and pathogenic *E-coli*. Typhoid fever, cholera, salmonellosis, dysentery, and gastroenteritis are among the illnesses that these organisms can cause. A person should be treated if they have contracted an infectious disease linked to water.

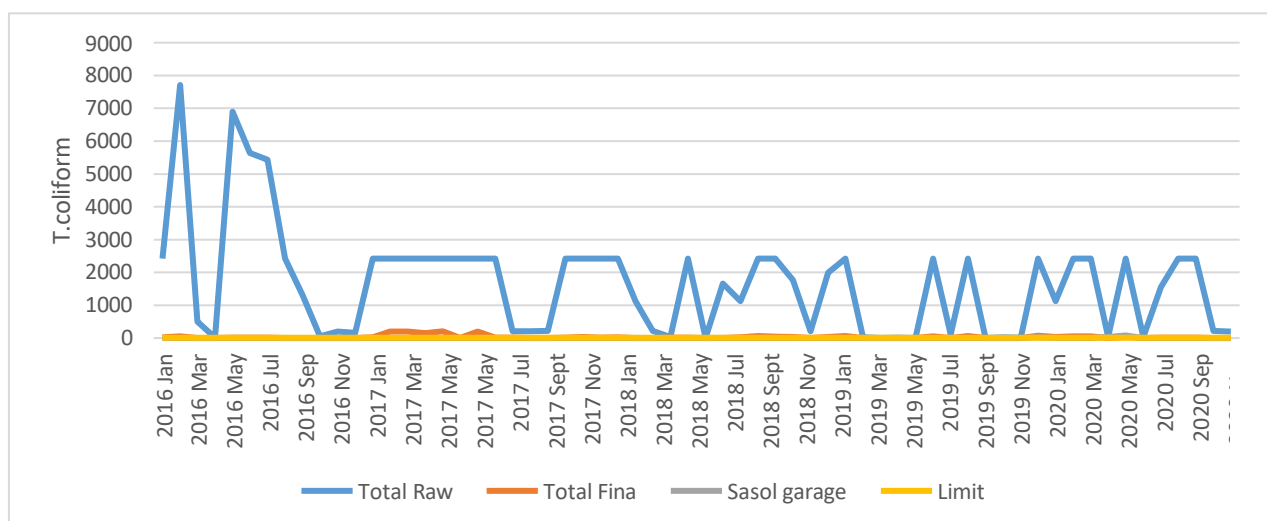


Figure 4.14: Total coliform raw, final water and Sasol garage

Manganese (Mn) unlike Aluminium (Al) is an essential micronutrient for plant and animals but can be toxic when present in high concentration. Insufficient quantity of Mn in plant can impair photosynthetic productivity causing chlorosis a yellowing of leaves or a failure of leaves to develop properly. In vertebrates, deficiency of Mn often manifests in skeletal deformities and reduced reproductive capabilities. Mn in raw water ranged from 0.01 to 19.0 mg/L with the average of 2.47 mg/L and final water ranged from 0.01 to 7.7 mg/L with the average of 1.16 mg/L and Sasol garage ranged from 0.01 to 6.8 mg/L with the average of 1.31 mg/L for the period of 5 years, respectively (Figure 4.15). The concentration of Mn in 2016, 2017, 2018 and 2019 was above the target water quality range of 0.05 mg/L for WHO (2011), SANS-241 (2015) and DWA (2015) and in 2020 from January to December there was a slightly change, the concentration of Mn was within the limit of 0.05 mg/L, this might be due to the decrease from raw water from industrial discharges in the river and runoff from agricultural activities.

High level of Mn in drinking water after may be associated with the treatment processes deployed at the treatment works that is not effectively remove manganese from raw water, the treatment may be operating at or its maximum capacity, limiting its ability to effectively treat the water for manganese removal. Inadequate treatment capacity can result in insufficient contact time or treatment resources, reducing the efficiency of manganese removal processes. Corrosion of iron or manganese containing material within the distribution system can release manganese into the water after treatment. Aging or deteriorating infrastructure such, as pipes, fittings, water storage tanks may contribute to high manganese levels in the treated water if corrosion control measures are inadequate.

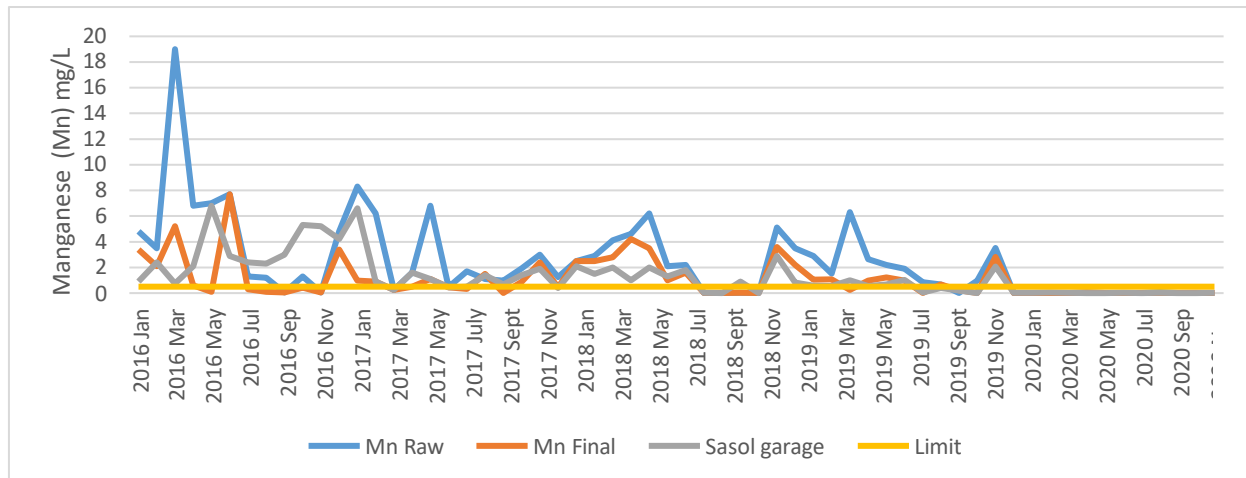


Figure 4.15: Manganese for raw, final water and Sasol garage

Natural water contains different amounts of iron (Fe), the fourth most prevalent element in the earth's crust, depending on the local geology and other chemical characteristics of the body of water. Fe concentrations in raw water ranged from 0.01 to 49.1 mg/L with an average of 10.29 mg/L, final water ranged from 0.01 to 25.1 mg/L with an average of 4.39 mg/L, and Sasol garage ranged from 0.01 to 26.4 mg/L with an average of 4.3 mg/L over a 5 years period, respectively (Figure 4.16). In most months, Fe levels fell short of the 0.1 mg/L drinking water requirement set by WHO (2011), SANS-241 (2015) and DWA (2015). The results indicated that there was a presence of Fe in 2016, 2017, 2018 and 2019 from raw, final and Sasol garage and in 2020 the concentration of Fe was within the limits of WHO (2011), SANS-241 (2015) and DWA (2015) of 0.01 mg/L. If treatment methods such as oxidation, filtration or Fe exchange are not effectively removed, Fe elevated level may persist in the treated water. Several factors contribute to high Fe levels in water even after treatment i.e. Standerton water source may naturally contain elevated levels of Fe due to geological formation or mineral deposits in the area, even after treatment some Fe may remain in the water due to presence in the raw water. Insufficient treatment or inadequate treatment processes or malfunction at water treatment plant can lead to incomplete removal of Fe from the water.

Fluctuation in water chemistry such as changes in pH, temperature or dissolved oxygen levels can affect solubility and stability of iron compounds in water. Microorganisms present in the water distribution system such as iron reducing bacteria can facilitate the conversion of soluble iron into

insoluble forms leading to release of Fe back into the water. Biological processes within the distribution system may contribute to Fe recontamination after treatment. Environmental factors such as rainfall, runoff and seasonal changes in water flow rates can influence the composition of raw water sources and affect treatment plant operations. Seasonal variations may impact the occurrence and concentration of iron in the water supply. Industrial discharge or pollution sources in the vicinity of the water supply system may introduce iron containing contaminants into the raw water sources leading to higher iron levels in the treated water. Effluent from mining operations, or agricultural activities could contribute to iron concentration contaminants.

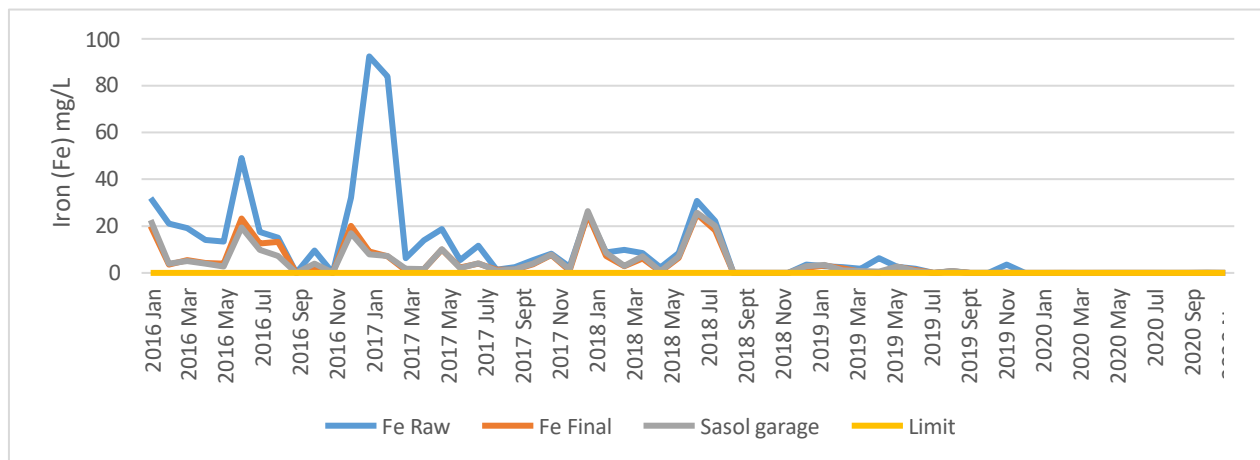


Figure 4.16: Fe raw, final water and Sasol garage

4.4 Summary of the Relationship of Parameters Beyond Water Quality Guidelines

The relationship between variables such as Mn, Fe, turbidity, total coliform, and E-coli beyond guidelines highlight the potential health risks and impacts on water quality. Mn and Fe in drinking water may cause aesthetic issues such as discoloration and metallic taste. Mn beyond its threshold can lead to neurological effects, especially in vulnerable populations like children. Interaction with high turbidity can mask the presence of metals like manganese and iron reducing the effectiveness of water treatment and complicating removal processes. Turbidity is the indicator of contamination and high turbidity indicates the presence of suspended particles that can harbour pathogens such as coliforms and E-coli. These particles protect microorganisms from disinfection, reducing water treatment efficiency. Turbidity increases the likelihood of co-precipitation of Mn and Fe during sedimentation, altering the chemistry of water treatment processes. Total coliform and E-coli, the presence of these bacteria above acceptable levels indicates faecal contamination, posing risks of

waterborne diseases. E-coli specifically signals recent faecal pollution, potentially introducing pathogens such as viruses and parasites. Interplay with higher turbidity often correlates with increased bacterial levels, as organic particles provide surfaces for bacterial growth and protection from UV disinfection. A combined impact on water quality of the presence of elevated Mn, Fe, turbidity, and microbial contaminants overwhelms standard treatment systems, leading to poor water quality. Iron and manganese deposits can promote biofilm formation, fostering microbial growth. Interventions require integrated strategies focusing on both physical (Filtration) and chemical (Chlorination) methods for effective removal. Effective water treatment must address these interlinked variables holistically to ensure safe and potable water by regular monitoring and targeted interventions for these parameters are crucial.

4.5 The Impact of Overflow of Water from the Flocculation Channels on a Daily Basis in SWTP

Figure 4.17 illustrates water losses observed during site visits at the Standerton Water Treatment Works (WWTW), specifically due to overflows from the flocculation channels. Although pre-chlorination processes were in place, a notable loss of chlorine occurred during this stage, resulting in both chemical wastage and financial loss. These inefficiencies are exacerbated by the high operational costs associated with electricity and chlorine gas used in the pre-treatment phase. The primary cause of these water losses is the over-pumping of raw water into the plant, which has led to the facility operating continuously 24 hours a day in an effort to maintain adequate storage levels in the municipal reservoirs. This operational strain system from the fact that the plant was originally designed to supply water at a maximum treatment capacity of 37 ML/d. However, due to rapid population growth, the plant is currently required to process over 43 ML/d exceeding its design capacity and still fails to meet the water demand of the Standerton community.

To address water wastage and improve supply efficiency, Standerton could benefit from adopting innovative communication and monitoring strategies, such as leveraging digital platforms (e.g., WhatsApp, Facebook, Twitter and SMS) to enhance public awareness and encourage community reporting of leaks and illegal connections. Evidence from other developing contexts, such as in India, has shown that such approaches significantly improve service delivery by facilitating accurate meter readings, increasing investments in smart metering technologies, and enhancing

accountability (Gupta et al., 2016). Implementation of similar strategies in Standerton could lead to a substantial reduction in unaccounted-for water. Furthermore, enforcing strict regulations against illegal water connections with penalties such as heavy fines or imprisonment would act as a deterrent and reinforce compliance. These combined efforts would support more sustainable and efficient water resource management in the municipality.



Figure 4.17: Water loss due to overflow from flocculation channels daily

4.6 Results on Water supply efficiency and Water balance

The water balance presented in Table 4.1 outlines the key variables and corresponding values related to the water supply system, while Figure 4.18 illustrates the water balance diagram for the Standerton Water Treatment Plant (SWTP). The water balance is categorised into two main components: (1) the volume of raw water abstracted and entering the treatment plant, and (2) the volume of final treated water distributed to the Standerton community.

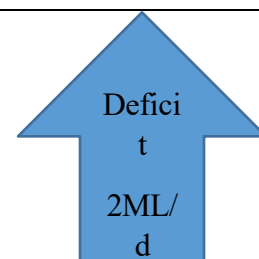
The original design capacity of the SWTP was 37 ML/d, which was appropriate for the projected population at the time of construction. However, under the current socio-political context and post-apartheid development planning, the water supply network has expanded to include additional communities that were not accounted for in the initial infrastructure design. This expansion combined with accelerated population growth and climate change impacts, has significantly increased the water demand. To meet the present day water requirements of Standerton, a water

supply capacity of 45 ML/d is required to meet the demand. Although an attempt was made to increase the plant's output to meet this target, only 28.2 ML/d of treated water is currently being delivered. The shortfall is attributed to substantial water losses, primarily from overflowing flocculation channels and frequent pipe bursts caused by excessive internal pressure. Furthermore, 85 ML/d of raw water is abstracted from the Vaal River, yet only 43 ML/d was initially planned for treatment and supply. However, system inefficiencies including leaks, burst pipes and illegal connections contribute to a daily water loss of approximately 17.2 ML/d from the treated water supply.

In addition, a 2 ML/d shortfall exists between the planned supply 43 ML/d and the actual demand 45 ML/d, resulting in a total water deficit of 19.2 ML/d. This cumulative deficit significantly hinders the ability of the SWTP to meet community demand and has led to persistent water shortages and service disruptions across Standerton. Figure 4.18 visually represents the imbalance between abstraction, treatment, distribution, and losses within the Standerton water supply system, clearly highlighting the unsustainable state of current water service operations.

Table 4.1: Water balance based on the demand supply scenario and the diagram of water balance of water supply in Standerton

Variable	Values
The treatment plant design capacity	37 ML/d
Water demand	45 ML/d
Raw water pumped into the treatment plant	85 ML/d
Water produced in the treatment plant	43 ML/d
Water loss from the treatment plant	42 ML/d
Water distributed in Standerton	25.8 ML/d
Water loss in Standerton	17.2 ML/d
Water deficit	2 ML/d



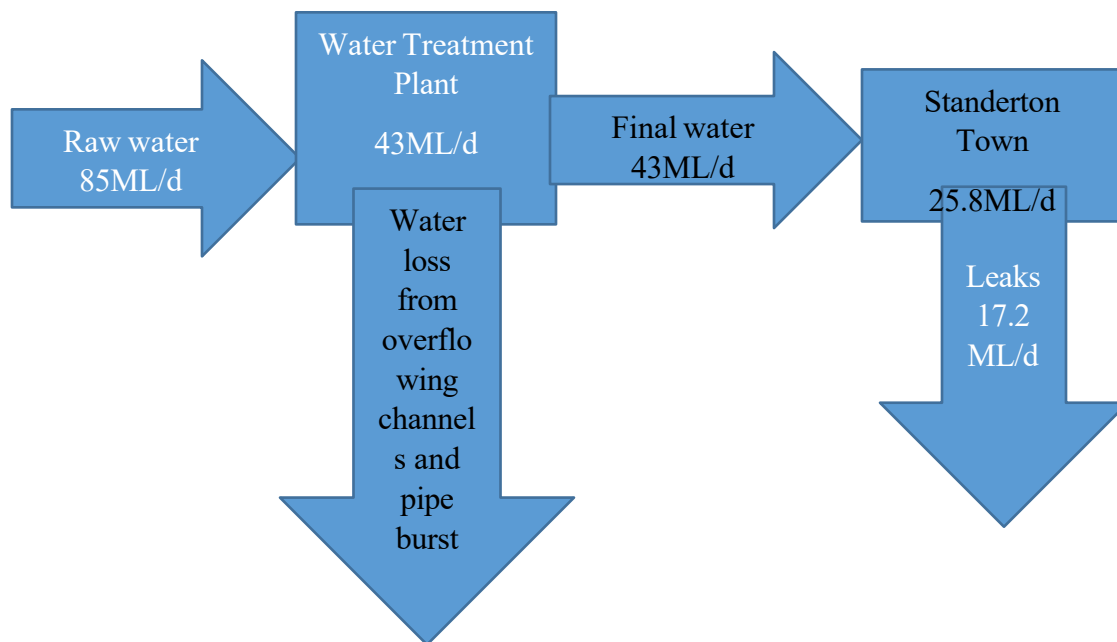


Figure 4.18: Diagram of water balance of water supply in Standerton

The current operational water supply for Standerton consists of 40 ML/d delivered through the Standerton Water Treatment Plant (SWTP) and an additional 3 ML/d of raw water abstracted directly from the Vaal River by Goldi Chicken using water tankers. This brings the total water supply to 43 ML/day. Despite this apparent improvement from a previous supply capacity of 37 ML/d, the current operation still falls short of the estimated demand of 45 ML/d. This discrepancy clearly demonstrates the municipality's inability to meet the growing water supply needs of the Standerton area.

The treatment plant is operating significantly above its design capacity of 37 ML/d, creating substantial hydraulic overload within the system. This excessive load exerts undue pressure on the pipe network within the treatment works, resulting in frequent leakages and infrastructure failures, which are classified as water losses. These losses further reduce the volume of treated water available for distribution to critical users such as Goldi Chicken, the central business district (CBD), and surrounding residential areas. Consequently, the community experiences intermittent water shortages and supply crises. Key contributing factors to these inefficiencies include inadequate maintenance, undersized and deteriorating pipeline infrastructure, and elevated internal pressure levels within the distribution network. The absence of trained operators and continuous

system monitoring also exacerbates the treatment plant's poor performance. Additionally, the aging infrastructure is no longer capable of accommodating the town's current water demands, contributing to further losses and operational instability. Water Supply Efficiency (WSE) is calculated using the standard efficiency equation, expressed as a percentage. Based on the available data, the water loss is calculated as follows:

- Planned water supply (TWA): 43 ML/d
- Water loss (40% of TWA): $43 \text{ ML/d} \times (40 \div 100) = 17.2 \text{ ML/d}$
- Effective available water for distribution: $43 \text{ ML/d} - 17.2 \text{ ML/d} = 25.8 \text{ ML/d}$

Thus, the SWTP is effectively supplying only 25.8 ML/d of water quality, significantly below the planned target. This substantial shortfall reflects the unsustainability of current water supply operations. The inefficiency of the system not only affects domestic consumption but also has broader socio-economic implications for local businesses and public health. Therefore, strategic infrastructure upgrades, operational monitoring and efficiency optimization are urgently required to restore and sustain reliable water service delivery in Standerton.

$$WSE = \frac{TWA}{TWS} \times 100\%$$

$$WSE = \frac{25.8 \text{ ML/d}}{43 \text{ ML/d}} \times 100\%$$

$$= 60\%$$

The estimated Water Supply Efficiency (WSE) for the Standerton Water Treatment Plant (SWTP) is approximately 60%. This figure reflects significant inefficiencies in the water supply system, as 40% of the intended water supply is lost before reaching end users. Such losses have a cascading effect on local socio-economic conditions, negatively impacting businesses such as Goldi Chicken through reduced production capacity, which in turn contributes to job losses, increased poverty, compromised public health and strain on household economies. Although the municipality has a planned daily water supply of 43 ML/d intended to meet the town's potable water demand, it has only been able to effectively supply around 60% of this volume. This discrepancy highlights systemic losses between the treatment plant and the point of consumption, confirming that the

current water supply plan is unsustainable and does not meet the efficiency requirements necessary to support all intended domestic and industrial water uses.

To enhance operational efficiency and sustainability, the municipality must prioritise scheduled maintenance and the replacement of aging infrastructure components, particularly backwash pumps and other critical mechanical systems. Infrastructure refurbishments and pump upgrades should be supported by continuous performance monitoring and operational adjustments. Improving the quality of treated water to meet regulatory standards can also reduce water wastage associated with reprocessing due to non-compliance. Furthermore, it is essential to mitigate the impact of pollution particularly sewage and industrial effluents entering the Vaal River, which serves as the raw water source. The implementation of a robust leak detection and repair system across both treatment and distribution infrastructure is critical to minimising water losses and ensuring supply reliability. The adoption of smart metering technologies, real-time monitoring systems and process automation will support more effective resource management and reduce inefficiencies within the treatment process. Lastly, community engagement through public education campaigns promoting responsible water use among residents and businesses can reinforce technical interventions and contribute to overall system resilience.

4.7 Water Supply Sustainability in Standerton

Sustainability is a key component of water use efficiency, requiring that water supply systems provide consistent and uninterrupted access to water for their intended purposes. However, the Standerton Water Treatment Plant (SWTP) faces significant challenges that compromise the sustainability of its operations. Leaks, illegal connections and ageing infrastructure are major contributing factors preventing the municipality from achieving its strategic objectives. Furthermore, the municipality is unable to generate sufficient revenue due to inefficiencies in billing systems and widespread non-payment. The absence of metering within the distribution network hinders the early detection of water losses and illegal bypassing of water meters by residents remains a persistent issue.

As a result of these challenges the sustainability of the water supply system is severely undermined. Although approximately 90% of households in Standerton have access to piped water, an estimated 40% of the water is lost through leaks and poor maintenance, primarily due to deteriorating

infrastructure. The study identified numerous infrastructure-related issues affecting Standerton's water supply system. While a small portion of the bulk pumping mains consist of steel pipes, the majority are made of asbestos cement, which is prone to frequent failures. These pipe bursts regularly disrupt water supply to communities and result in substantial water losses.

Additionally, the presence of multiple offtakes along the main supply line from the Standerton Water Treatment Works (WTW) to the various reservoirs has negatively impacted pipeline capacity. Ageing pipelines have led to reduced hydraulic pressure and increased leakage rates, further exacerbating the inefficiency of the water distribution system. These infrastructural and operational deficiencies present major obstacles to achieving long-term sustainability and reliability in the provision of potable water in Standerton.



Figure 4.19: Standerton Water Treatment Works

Chapter 5

Conclusion and Recommendations

5.1 Conclusion

The primary aim of this study was to assess the water supply system efficiency and water quality at the Standerton Water Treatment Plant (SWTP) within Lekwa Local Municipality. SWTP served as the case study to evaluate key aspects of water treatment and distribution processes and the extent of compliance with regulatory water quality standards.

Objective 1: Assessment of Raw Water Quality

The first objective was to assess the quality of raw water supplied from the Vaal River to the SWTP. The results indicated that raw water quality parameters, including turbidity, iron (Fe), manganese (Mn), *Escherichia coli* (*E- coli*) and total coliforms were frequently below acceptable standards. This was expected, as site inspections revealed that water was sometimes either untreated or only partially treated due to chemical shortages. Following the treatment levels of free chlorine, *E-coli*, Fe, Mn, and total coliforms were higher, suggesting ineffective disinfection and chemical dosing. The inadequate addition of chlorine gas during treatment likely contributed to these exceedances. An analysis of variance showed no statistically significant differences in water quality parameters between raw water, treated water at the plant and the furthest distribution point (Sasol Garage), although some trends in raw water quality were observed.

Objective 2: Evaluation of the Water Distribution Network

The second objective was to evaluate the water reticulation system. The findings showed that much of the water distribution infrastructure was inefficient. Field observations revealed frequent leaks and overflows which could be attributed to poor pipe installation, vandalism or excessive pressure from over pumping, resulting in pipe bursts. The type and condition of the pipelines were identified as contributing factors to the recurring bursts, compromising the stability and reliability of the distribution system.

Objective 3: Assessment of Water Quality from Treatment to End-Use

The third objective focused on comparing the quality of treated water at the plant and at various distribution points. The analysis revealed significant deterioration in water quality during transmission. Water quality at consumer points, including Standerton residents and Goldi Chicken (a major water user), was inferior to that at the plant. Literature suggests that treatment plant performance and conditions within the distribution system such as contamination, pipe corrosion, chemical reactions and intermittent water supply can contribute to this degradation. Agricultural runoff and industrial discharges into the Vaal River, were also noted as external contributors to raw water quality decline.

Objective 4: Operational Assessment of the Treatment Plant

The fourth objective was to investigate the operational procedures of the SWTP. The plant was found to be functioning above its design capacity, primarily due to poor chemical management, lack of routine monitoring and frequent equipment failures. Many plant operators and supervisors lacked specialized training and qualifications in water treatment processes which compromised the plant's ability to meet treatment standards and effectively remove contaminants.

Objective 5: Water Balance and Supply Efficiency

The fifth objective involved determining the water supply system efficiency using a water balance approach. Flow measurements from the Vaal River source through the treatment process to the furthest distribution point were recorded. It was found that 85 ML/d was abstracted from the source but only 43 ML/d reached the treatment plant indicating a loss of 42 ML/d. These losses were largely attributed to overflow from the flocculation channels and inefficiencies in raw water transfer. From the treatment plant, only 28.2 ML/d of treated water reached consumers, highlighting substantial distribution losses due to illegal connections, burst pipes, reservoir leakage and prolonged repair times.

Objective 6: Sustainability of the Water Supply

The sixth objective assessed the sustainability of the water supply system. The study concluded that the SWTP currently lacks sustainability as water supply is irregular and there won't be supply for up to two or three days at a time. Factors contributing to this unreliability include raw water pump breakdowns, delayed maintenance and poorly managed chlorine gas dosing. The use of a jar

test a standard procedure to guide chemical dosing and coagulant application was found to be either inconsistently applied or absent at the plant.

Objective 7: Compliance of Treated Water with Quality Standards

The final objective was to evaluate the compliance of treated water with national and international drinking water quality guidelines. This was done by comparing measured water quality parameters with limits set by the World Health Organization (WHO, 2011), the Department of Water Affairs (DWA, 2015), and South African National Standard (SANS 241, 2015). Over a five-year period, parameters such as pH, electrical conductivity (EC), and total dissolved solids (TDS) complied with recommended standards at both the treatment plant and the furthest distribution point. However, turbidity, free chlorine, total coliforms, Fe, and Mn consistently exceeded allowable limits in both locations. These exceedances indicate systemic treatment inefficiencies and possible contamination during distribution. Despite temporal variations in water quality, the overall trend showed that compliance was not consistently achieved, especially for parameters critical to public health.

The main contribution of this research lies in providing a comprehensive evaluation of both the operational efficiency and water quality performance of the Standerton Water Treatment Plant. By integrating field measurements, water quality analysis and infrastructure assessment, the study identifies key inefficiencies in the treatment and distribution processes, such as operation beyond design capacity, inadequate process monitoring and frequent equipment failures. It highlights the extent of non-compliance with national and international water quality standards, particularly concerning parameters such as free chlorine, turbidity, Fe, Mn, and *E-coli*. Furthermore, the research underscores the impact of insufficient technical training among plant personnel and delayed maintenance on overall system performance. These findings offer valuable insights for municipal authorities and water services providers, guiding targeted interventions to improve operational practices, enhance compliance and ensure reliable delivery of safe drinking water to the community. The study also serves as a model for assessing water treatment systems in similarly constrained municipalities across South Africa.

The operational effectiveness of the Standerton Water Treatment Plant (SWTP) was critically evaluated, revealing several significant shortcomings that negatively affect the quality and

reliability of water supplied to the community. Key issues identified include improper chemical dosing, inadequate process monitoring, insufficient maintenance practices, and a lack of proper training and technical skills among process controllers. These factors collectively compromised the plant's ability to perform essential treatment functions effectively and to consistently meet household water use standards. The study found that the SWTP was unable to fully remove pollutants from the raw water, resulting in treated water that frequently failed to comply with national and international water quality guidelines. Elevated concentrations of iron (Fe), manganese (Mn), free chlorine, and total coliforms were consistently observed, indicating substandard water quality. Contributing factors to these non-compliances include the type and condition of the distribution infrastructure such as aging pipes, siltation and corrosion buildup within the pipelines, frequent pipe bursts, and leaks that expose water to environmental contaminants.

This research underscores the critical importance of operational efficiency in each stage of the water treatment process to ensure the effective removal of contaminants. The findings offer practical insights for municipal authorities, equipping them with the necessary evidence to improve plant operations, address infrastructure challenges and implement capacity-building programs for plant personnel. Acting on these recommendations, the municipality can enhance the reliability, safety and sustainability of the water supply system in Standerton.

5.2 Recommendations

The study established that SWTP is faced with aging infrastructures, pump station, the water treatment plant and reticulation system which are major challenges causing water crises. It is essential therefore that the infrastructures (water treatment works and reticulation system) must be upgraded in line with population projection.

Illegal connections of water should be prevented by installing yard pipes in communities which were not properly installed. Multidisciplinary planning to handle immigration appropriately and proactive planning for housing provision to avoid shacks.

Surveillance, operation and maintenance should be a cornerstone of existence and life of the water supply systems ensuring sufficient water supply and sustainability. These require adequate technical skills, equipment's and instruments, adequate funding and management, planning, research, monitoring, and evaluation.

The value of water is as essential as gold and a good economic resource that deserves to be used sparingly, responsibly, effectively, efficiently and in a sustainable manner. It therefore requires government, stakeholders, municipalities and Standerton Town to promote education and awareness campaigns in Lekwa municipalities to preserve and conserve water in many ways. These will assist instilling ownership of water, the will and love to protect it anywhere. Where there are leaks, people or community members should report to relevant offices. Lekwa Municipality must place communication channels at the disposal of its community members for effective reporting of any malfunctioning of network water system.

Recording of all water abstraction, processed water and the water supplied in Standerton, informs the adequacy and deficit or inefficient water supply. It is therefore municipality should carry out water balance as an ongoing basis to assess ability and capability of the water supply processes to be effective and efficient. On these grounds, metering is essential both for assessment and revenue collection. Maintenance and calibration of these meters is essential. Vandalism is an essential criminality that ravages the equipment and materials that sustain water supply network. Electrical equipment's cables and pipe fissures are stolen away all the time. The municipality must set up security and surveillance strategies and systems to protect water supply systems.

As it essential to supply safe and clean potable water to industries, commercial businesses and domestic use, the study established that water from Vaal River, has low hardness, corrosion, salinity with no scale forming. However, change was with turbidity, Fe, Mn, *E-coli*, and Total Coliforms. In all these parameters, the water treatment plant is not doing well, such that treatment processes are not efficient that bacteria found in the reticulation system is an indication that water is not safe for consumption or use for food and beverages production. The data (turbidity, Fe and Mn) show that water is not in good condition, indicating inefficiency of treatment processes (pre-chlorination, flocculation, filtration), such that unclean water to consumers. In terms of destroying bacteria in the reticulation system, shock chlorination can be carried out; however, this may

increase oxidation of Fe and Mn in the distribution system, thereby increasing turbidity and staining. To offset this, municipality should increase chlorine gas at prechlorination process and refurbish filtration tank. As the flocculation channels are overflowing because of their design capacity, which is small against water loaded resulting in lots of water lost, about 42 ML/d. In this regard the water treatment works require total upgrade to satisfy the need of all stakeholders in both quantity and water quality.

References

- Auditor-General South Africa, (2022). Consolidated General Report on the Local Government Audit Outcomes 2020–21. Pretoria: AGSA.
- Auditor-General South Africa, (2022). Local Government Audit Outcomes 2020/21. Pretoria: AGSA.
- Adams, T. and Machete, L. (2020). Community engagement and water conservation: Lessons from South Africa', *Journal of Environmental Management*, 45(2), pp. 678–689.
- Algotsson, E., Murombo, T., Davis, M. and Poole, M. (2009) Water supply and sanitation in South Africa: Environmental rights and municipal accountability.
- APHA, (2012). *Standard Methods for the Examination of Water and Wastewater (22nd ed.)*. American Public Health Association, American Water Works Association, and Water Environment Federation.
- Argent, R.M. (2004). An overview of model integration for environmental applications: Components, frameworks, and semantics', *Environmental Modelling & Software*, 19, pp. 219–234.
- Ashbolt, N. J. (2004). Microbial contamination of drinking water and disease outcomes in developing regions. *Toxicology*, 198(1–3), 229–238.
- Ayers, R. S., & Westcot, D. W. (1995). *Water Quality for Agriculture (FAO Irrigation and Drainage Paper 29 Rev. 1)*. Food and Agriculture Organization of the United Nations.
- AWWA (2012). *Water Treatment Plant Design* (4th ed.). American Water Works Association.
- Backeberg, G.R. & Sanewe, A.J. (2010). Towards productive water use and household food security in South Africa. *Water SA*, 36(4), pp. 1-7.
- Basson, M.S., Van Niekerk, P.H. and Van Rooyen, J.A. (1997). Overview of water resources availability and utilisation in South Africa. May. Report No. P RSA/00/0197. Pretoria: Department of Water Affairs and Forestry.
- Bennich, A., Engwall, M. and Nilsson, D. (2023). Operating in the shadowland: Why water utilities fail to manage decaying infrastructure.' *Water Research*, [online]. Available at: [insert URL if available] (Accessed: [insert date]).
- Bhandari, P., Sharma, S. and Singh, R. (2023). Impact of maintenance practices on water supply system efficiency: A case study. *Journal of Water Resources Management*, 37(2), pp.123–136. <https://doi.org/10.1007/s11269-023-03567-4>.

- Bitton, G. (2005). *Introduction to Wastewater Microbiology* (4th ed.). Wiley-Liss.
- Chaleunvong, K. (2009). *Data collection techniques*. Vientiane: GFMER – WHO – UNFPA – LAO PDR. Training Course in Reproductive Health Research. 25 pp.
- Council for Scientific and Industrial Research (CSIR). (1993). *Guidelines for the provision of engineering services and amenities in residential township development (“Red Book”)*. Compiled for the South African Housing Advisory Council. Pretoria: CSIR.
- Creswell, J.W. (2007). *Qualitative inquiry and research design: Choosing among five approaches*. 2nd ed. Thousand Oaks, CA: Sage Publications.
- Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J., & Tchobanoglous, G. (2012). *Water Treatment: Principles and Design* (3rd ed.). Wiley.
- Davies, K., Doolan, C., Van der Honert, R. and Shi, R. (2014). Water-saving impacts of smart meter technology: An empirical 5-year, whole-of-community study in Sydney, Australia. *Journal of Environmental Management*, 138, pp. 42–51.
- Department of Water Affairs and Forestry (DWAF). (2004). *National Water Resource Strategy*. Pretoria: Government Printer.
- Department of Water Affairs and Forestry (DWAF). (2004). *National Water Resource Strategy: First Edition*. Pretoria: Department of Water Affairs and Forestry.
- Department of Water and Sanitation (DWS). (2004). *National Water Conservation and Demand Management Strategy*. Pretoria: Government Printer.
- Department of Water Affairs and Forestry (DWAF). (2006). *Potential savings through WC/WDM in the Upper and Middle Vaal Water Management Areas*. Report No. P RSA C000/00/4405/02. Compiled by WRP Consulting Engineers (Pty) Ltd, DMM Development Consultants, and P.D. Naidoo on behalf of the Directorates: Water Use Efficiency and National Water Resource Planning. Pretoria: Department of Water Affairs and Forestry.
- Department of Water Affairs and Forestry (DWAF). (2007). *Vaal River System: Large Bulk Water Supply Reconciliation Strategies*. Report No. P RSA C000/00/4405/07. Compiled by WRP Consulting Engineers (Pty) Ltd, DMM Development Consultants, and P.D. Naidoo on behalf of the Directorates: Water Use Efficiency and National Water Resource Planning. Pretoria: Department of Water Affairs and Forestry.

- Department of Water Affairs and Forestry (DWAF). (2008). Integrated mine water management: Best practice guideline for water resource protection in the South African mining industry. Pretoria: Department of Water Affairs and Forestry.
- Department of Water and Sanitation (DWS). (2013). Strategic Framework for Water Services. Pretoria: DWS.
- Department of Water and Sanitation (DWS). (2013). National Water Resource Strategy II. Pretoria: Government Printer.
- Department of Water and Sanitation (DWS). (2015). Water Tariff Setting Guidelines for Water Services Authorities. Pretoria: DWS.
- Department of Water and Sanitation (DWS). (2017). Guidelines for the Development of Water Services Development Plans (WSDPs). Pretoria: DWS.
- Department of Water and Sanitation (DWS). (2018). National Water and Sanitation Master Plan: Volume 1 – Call to Action. Pretoria: Department of Water and Sanitation.
- Department of Water and Sanitation (DWS). (2018). National Water and Sanitation Master Plan: Volume 1 – Call to Action. Pretoria: Department of Water and Sanitation.
- Department of Water and Sanitation (DWS). (2018). National Water and Sanitation Master Plan: Volume 1 – Call to Action. Pretoria: Department of Water and Sanitation.
- Department of Water and Sanitation (DWS). (2020) National Water Resources Strategy. [online] Available at: <https://www.dws.gov.za/documents/strategies/NWRS2.pdf> [Accessed 12 Jul. 2025].
- Department of Water and Sanitation (DWA). (2020). National Water and Sanitation Master Plan: Volume 1. Pretoria: Department of Water and Sanitation.
- Department of Water and Sanitation (DWS). (2020) National Water and Sanitation Master Plan. [online] Available at: <https://www.dws.gov.za> [Accessed 12 Jul. 2025].
- Department of Water Affairs (DWA). (2022.) Annual Performance Plan 2022/23. Pretoria: Department of Water and Sanitation.
- Department of Water and Sanitation (DWS). (2023). No Drop Report: WP11432 – Professional service provider under the Water Services Term Contract No. WP11359 to provide specialist and technical support for the Programme for a period of six months. Final Draft – November 2023. Pretoria:

- Dlamini, N. (2023). Challenges of water distribution infrastructure and their impacts on service delivery in South African municipalities. Unpublished MSc thesis. University of Cape Town.
- Department of Provincial and Local Government (DPLG). (2004). Free Basic Services: A Policy Framework. Pretoria: Government Printer.
- Edberg, S. C., Rice, E. W., Karlin, R. J., & Allen, M. J. (2000). Escherichia coli: the best biological drinking water indicator for public health protection. *Journal of Applied Microbiology*, 88 (S1), 106S–116S.
- Engelbrecht, F.A., Adegoke, J., Bopape, M.J.M., Naidoo, M., Garland, R. and Thatcher, M., 2015. Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environmental Research Letters*, 10(8), p.085004.
- Environmental Protection Agency (EPA). (2002). Jar Testing Procedures for Water Treatment Plants. Washington, DC: EPA.
- Ekdopayi, R., Moyo, T. and Khosa, S., 2018. Challenges in municipal water service delivery: A case study of selected South African municipalities. *Journal of Water Resource Management*, 10(1), pp.55–63.
- Erasmus, B. P. J. (2014). on route in South Africa: Explore South Africa region by region. Jonathan Ball Publishers. p. 401. ISBN 9781920289805.
- Food and Agriculture Organization (FAO). (2016). The Water-Energy-Food Nexus: A new approach in support of food security and sustainable agriculture. Rome: FAO.
- Ferdowsi, A., Farzad, P., Behzadian, K., Mousavi, S.F. and Mohammad, E. (2024) 'Urban water infrastructure: A critical review on climate change impacts and adaptation strategies.
- Ferdowsi, S., Johnson, M. and Patel, R. (2024). Assessment of water supply efficiency: integrating infrastructure, consumption, and behavioural factors. *Journal of Water Management Studies*, 15(1), pp.23–38.
- Filho, W.L., Totin, E., James, F., Samora, A., Macrice, A.M., Abubakar, M., Azadi, I.R., Patrick, H., Nunn, D., Ouweneel, B., Williams, P.A. and Simpson, N.P. (2022). Understanding responses to climate-related water scarcity in Africa', Global Adaptation Mapping Initiative Team,
- Friedman, M. (1962) Price theory: A provisional text. Chicago: Aldine Publication Co.

- Funke, N. et al., 2005. Scoping study on the development and sustainable use of surface and groundwater resources for small-scale agriculture in South Africa. WRC Report No. TT 243/04.
- Garlipp, K.D.C.O. (2022) Water consumption patterns in urban areas. M.Sc. Dissertation. Pretoria: University of Pretoria. Great Escarpment". <https://en.wikipedia.org> (2010), Encyclopædia Britannica.
- Global Water Partnership, 2000. Integrated Water Resources Management. TAC Background Papers, No. 4. Stockholm: GWP.
- Haigh, M., Fox, H., Rawlins, M. and Maro, P., 2010. Headwater control and community participation: experiences from Lake Victoria, Tanzania. *Water International*, 35(3), pp.278–289. <https://doi.org/10.1080/02508060.2010.487308>.
- Haigh, M., Haigh, C. and Tewari, B.P., 2010. Integrated Water Resources Management: South Asia. Dordrecht: Springer.
- Haigh, E.H., Fox, H.E. and Davies-Coleman, H.D. (2010). Framework for local government to implement integrated water resource management linked to water service delivery. Grahamstown: Institute for Water Research, Rhodes University.
- Harken, B., Chang, C.F., Dietrich, P., Kalbacher, T. and Rubin, Y. (2019). Hydrogeological modelling and water resources management: Improving the link between data, prediction, and decision making', *Water Resources Research*, 55, pp. 10340–10357.
- Hem, J. D. (1998). Study and Interpretation of the Chemical Characteristics of Natural Water (Vol. 2254). U.S. Geological Survey.
- Howe, C.W and Linaweaver, F. P. (1967). The impact of Price on Residential Water Demand and its Relation to Hope, R.A., Dixon, P.J. & Von Maltitz, G.P., 2008. The role of improved domestic water supply in livelihoods and poverty reduction in Limpopo Province, South Africa. *Water SA*, 34(3), pp. 393-400. System Design and Price Structure. *Water Resources Research*, 3 (1): 13-32.
- Hobbs, P.J. & Cobbing, J.E. (2007). A hydrogeological assessment of acid mine drainage impacts in the Witwatersrand Basin, South Africa. *Environmental Geology*, 53(4), 715–726.
- Hosking, S.G., Du Preez, M., Campbell, E.E., Wooldridge, T.H.E. and Du Plessis, L.L. (2002). Evaluating the environmental use of water: Selected case studies in the Eastern and Southern Cape. WRC Report No. 1045/1/02. Pretoria: Water Research Commission.

- Hutton, G. and Varughese, M. (2016). The costs of meeting the 2030 Sustainable Development Goal targets on drinking water, sanitation, and hygiene. Washington, DC: World Bank, Water and Sanitation Program.
- Hyandye, C. B., Worqul, A., Martz, L. W. (2018). The impact of future climate and land use/cover change on water resources in the Ndembera watershed and their mitigation and adaptation strategies. volume 7, Article number.
- Hyandye, C.B., Martz, L.W. and Mziray, P.G. 2018. Assessing the impacts of land use and climate change on water resource availability. *Physics and Chemistry of the Earth*, 105, pp.10–20.
- International Conference on Water and the Environment (ICWE). (1992). The Dublin Statement on Water and Sustainable Development. Dublin: ICWE.
- Intergovernmental Panel on Climate Change (IPCC). (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report. Cambridge: Cambridge University Press. Available at: <https://www.ipcc.ch/report/ar6/wg2/> [Accessed 12 Jul. 2025].
- Iglesias, E. and Blanco, M. (2008). New directions in water resources management: The role of water pricing policies', *Water Resources Management*.
- Jacobs, H.E. and Haarhoff, J. (2007). Prioritisation of parameters influencing residential water use and wastewater flow', *Journal of Water Supply: Research and Technology – AQUA*, 56(8), pp. 495–514. Available at: <http://www.iwaponline.com/jws/toc.htm> [Accessed 12 Jul. 2025].
- Jacobs, H.E., Geustyn, L.C., Loubser, B.F. and Van der Merwe, B. (2004). Estimating residential water demand in Southern Africa', *Journal of the South African Institution of Civil Engineering*, 46(4), pp. 2–13. Paper 568.
- Kumpel, E., & Nelson, K. L. (2013). Comparing microbial water quality in an intermittent and continuous piped water supply. *Water Research*, 47(14), 5176–5188. <https://doi.org/10.1016/j.watres.2013.05.058>.
- LeChevallier, M. W., Cawthon, C. D., & Lee, R. G. (1981). Factors promoting survival of bacteria in chlorinated water supplies. *Applied and Environmental Microbiology*, 42(1), 159–167.
- Leclerc, H., Mossel, D. A. A., Edberg, S. C., & Struijk, C. B. (2001). Advances in the bacteriology of the coliform group: their suitability as markers of microbial water safety. *Annual Review of Microbiology*, 55, 201–234.

- Le Maitre, D.C., Versfeld, D.B. and Chapman, R.A. (1999). Alien invading plants and water resources in South Africa: A preliminary assessment. Water Research Commission Report No. TT 99/98. Pretoria: WRC.
- Leyds, G.A. (1964). A history of Johannesburg: The early years. Johannesburg: Nasional Boekhandel, p. 318.
- Lockwood, H. and Smits, S. (2011). Supporting rural water supply: Moving towards a service delivery approach. Rugby, UK: Practical Action Publishing.
- Louw, D.B. (2001). The development of a methodology to determine the true value of water and the impact of a potential water market on the efficient utilisation of water in the Berg River Basin. WRC Report No. 943/1/02. Pretoria: Water Research Commission.
- Makanda, K., Nzama, S. and Kanyerere, T. (2022). Assessing the role of water resources protection practice for sustainable water resources management water resource classification.
- Malobela, I.P. and Pramod, S. (2011). Management of water resources in South Africa: A review', Civil and Chemical Engineering Department, University of South Africa – UNISA, Florida Campus, Johannesburg. Accepted 24 October 2011.
- McCarthy, T.S. (2011). The impact of acid mine drainage in South Africa. South African Journal of Science, 107(5-6), pp.1–7.
- McLoughlin, C., Hohlfield, T., Schachtschneider, K. and Ashton, P. (2021). Water quality management and governance in South Africa: A critical review. South African Water Research Commission.
- Momba, M.N.B., Tyafa, Z., Makala, N., Brouckaert, B.M. and Obi, C.L. (2016). Safe drinking water still a dream in rural areas of South Africa: The example of a small community in the North West Province. Water SA, 32(5), pp.715–720. <https://doi.org/10.4314/wsa.v32i5.52690>
- Molobela, M.N. (2011). Water use and management in South Africa: A case study of the Olifants sub-basin. MSc thesis, University of the Western Cape.
- Mekonnen, M.M. and Hoekstra, A.Y. (2016). Four billion people facing severe water scarcity. Science Advances, 2(2), pp.e1500323. <https://doi.org/10.1126/sciadv.1500323>
- McKenzie, R. (2007). Aqualite: Water Balance Software – User Guide. WRC Report No. TT 315/07. Pretoria: South African Water Research Commission.

- McKenzie, R.S. (2008a). ILI and performance indicators', Proceedings of Water Loss Asia 2008 Conference, 15–16 July 2008, Sunway Pyramid Convention Centre, Kuala Lumpur, Malaysia.
- McKenzie, R.S. (2008b). Assessment and characterisation criteria for quantifying total system losses', Global Water Leakage Summit, Thistle Marble Arch, London, 17 June 2008.
- Momba, M.N.B. and Makala, N. (2017). Comparative assessment of the performance of selected small water treatment plants in the Mpumalanga and North West provinces, South Africa. *Water SA*, 43(4), pp.566–576.
- Moller, J. (2003). Personal communication. Prominent farmer near Kakamas/Keimoes. Contact details withheld for privacy.
- Mokgobu, M.L. (2023). The application of space technology and the challenges of managing water infrastructure in a selected South African municipality.
- Mokoena, L. (2022). Assessment of infrastructure challenges impacting water treatment plants in South Africa. Unpublished MSc thesis. University of Johannesburg.
- Movik, S. (2009). Allocation discourses: South African water rights reform. PhD thesis. Wageningen University.
- Muller, M. (2022). Water conservation and demand management in South Africa: An overview', *Journal of Water Resource Management*, 35(7), pp. 1023–1045.
- Mthembu, T. (2022). Impacts of Urbanisation on Water Resources in South African Cities: A Case Study of eThekweni Municipality. Unpublished MSc thesis. University of KwaZulu-Natal.
- National Treasury. (2019). Budget Review. Pretoria: National Treasury.
- Nataro, J. P., & Kaper, J. B. (1998). *Diarrheagenic Escherichia coli*. *Clinical Microbiology Reviews*, 11(1), 142–201.
- Nkosi, M.I., Mathivha, F. and Odiyo, O.J. (2021). Impact of land management on water resources: A South African context', *Sustainability*, 13(2), p. 701. doi: 10.3390/su13020701.
- Nkonsi, Z., Mabuda, M. and Nel, S. (2018). Water scarcity and its impact on socio-economic development in South Africa. *Journal of Water Resources and Management*, 9(2), pp.45–53.

- Ntuli, F. & Mafereka, M. (2020). Performance challenges in municipal wastewater treatment plants: A case of Mpumalanga Province. *Water SA*, 46(3), 379–386. <https://doi.org/10.17159/wsa/2020.v46.i3.8652>.
- OECD (2015). *Water and Wastewater Governance: Fit for the Future?* OECD Publishing.
- Omarova, A., Tussupova, K., Hjorth, P., Kalishev, M. and Dosmagambetova, R. (2019). Water supply challenges in rural areas: A case study from Central Kazakhstan', *International Journal of Environmental Research and Public Health*, 16(5), p. 688. PMID: PMC6427320. PMID: 30813591.
- Republic of South Africa (RSA). (2002). *Free Basic Water Policy*. Pretoria: Government Printer.
- Republic of South Africa (RSA). (1996). *The Constitution of the Republic of South Africa, 1996. Act 108 of 1996*. Government Gazette No. 17678. Pretoria: Government Printer.
- Republic of South Africa (RSA). (1997). *Water Services Act (No. 108 of 1997)*. Pretoria: Government Gazette.
- Republic of South Africa (RSA). (1998). *National Water Act (No. 36 of 1998)*. Pretoria: Government Gazette.
- Republic of South Africa (RSA). (1998a). *Local Government: Municipal Structures Act, No. 117 of 1998*. Pretoria: Government Printer.
- Republic of South Africa (RSA). (2000). *Local Government: Municipal Systems Act, No. 32 of 2000*. Pretoria: Government Printer.
- SALGA, (2015). *Challenges of Local Government in Water Service Delivery*. Pretoria: South African Local Government Association.
- Schreiner, B. & van Koppen, B. (2002). Catchment management agencies for poverty eradication in South Africa. *Physics and Chemistry of the Earth*, 27(11–22), pp. 969–976.
- Schreiner, B. and Van Koppen, B. (2021). *Integrated water resource management: Strategies*.
- South African National Biodiversity Institute (SANBI). (2019). *Wetland Ecosystem Guidelines*. Pretoria: SANBI.
- South African Institution of Civil Engineering (SAICE). (2017). *Infrastructure report card for South Africa*. [online] Available at: <http://saice.org.za/wp-content/uploads/2017/09/SAICE-IRC-2017.pdf> [Accessed 12 Jul. 2025].

- South African Local Government Association (SALGA). (2021). State of Local Government Report. [online] Available at: <https://www.salga.org.za> [Accessed 12 Jul. 2025].
- South African Bureau of Standards (SABS). (2015). South African National Standard (SANS) 241: Drinking Water Part 1: Microbiological, Physical, Chemical, and Radiological Determinants. Pretoria: SABS.
- Smith, J. and Brown, A. (2021). Challenges in water infrastructure: The need for modernization', *Journal of Water Resource Management*, 20(3), pp. 150–165.
- Smith, J. (2022). Sustainable water management in South African towns: Case studies and approaches', *Water Resources Journal*, 45(3), pp. 123–145.
- Smith, J. and Brown, A. (2021). Challenges in domestic water supply systems: A case study of Standerton', *Journal of Water Resource Management*, 15(2), pp. 200–215.
- Smith, J. (2023). Research on domestic water supply efficiency in Standerton: Justification and impact', *Journal of Water Resource Management*, 18(2), pp. 78–92.
- Spellman, F. R. (2018). *Water and Wastewater Treatment: A Guide for the Nonengineering Professional*. CRC Press.
- Stephenson, D. and Turner, K. (1996). Water demand patterns in Gauteng', *IMIESA*, 21(1), pp. 11–16.
- Steyn, M. (2022). Policy coherence and integrated water resource management in South Africa: An intersectoral perspective. *Water Policy*, 24(6), pp.1032–1047.
- Sutton, M.A., Howard, C.M., Erisman, J.W., Billen, G., Bleeker, A., Grennfelt, P., Grizzetti, B. and van Grinsven, H. (2013). *Our Nutrient World: The Challenge to Produce More Food and Energy with Less Pollution*. Centre for Ecology and Hydrology, Edinburgh.
- Tang, Q. (2020). Global change hydrology: Terrestrial water cycle and global change', *Science China Earth Sciences*, 63, pp. 459–462.
- Tchobanoglous, G., Stensel, H.D. and Tsuchihashi, R. (2014). *Wastewater Engineering: Treatment and Resource Recovery*. 5th ed. New York: McGraw-Hill Education.
- United Nations, (2015). *Water Supply and Sanitation Collaborative Council: Monitoring water supply and sanitation services*. Geneva: United Nations.

- United Nations Educational, Scientific and Cultural Organization. (UNESCO). (2003). Water for People, Water for Life: UN World Water Development Report. Paris: UNESCO Publishing.
- United Nations Educational, Scientific and Cultural Organization (UNESCO). The United Nations World Water Development Report. (2019). Leaving No One Behind. Paris: UNESCO Publishing.
- UN-Habitat, 2020. World Cities Report (2020). The Value of Sustainable Urbanization. Nairobi: United Nations Human Settlements Programme.
- United States Environmental Protection Agency (USEPA). (2002). Technical Factsheet on: Turbidity. EPA 816-F-02-006. Available at: <https://www.epa.gov/sites/default/files/2015-09/documents/turbidity.pdf> [Accessed 12 July 2025].
- Van Dijk, M.P. and Zhang, M. (2019). Urban water management paradigms in Chinese cities', Sustainability, 11, p. 3001.
- Van der Merwe, B., Makgae, M. and Mema, V. (2018). Water losses and the performance of municipal water supply systems in South Africa. Water Research Commission Report No. TT 750/18. Pretoria: Water Research Commission.
- Van Koppen, B. & Schreiner, B., 2014. Moving beyond integrated water resource management: developmental water management in South Africa. International Journal of Water Resources Development, 30(3), pp. 543–558.
- Van Vuuren, S.J. and Van Beek, J.C. (1997). Her-evaluering van die bestaande riglyne vir stedelike en industriële watervoorsiening gebaseer op gemete waterverbruik: Fase 1 Pretoria voorsieningsgebied. Report for the Water Research Commission by the Department of Civil Engineering, University of Pretoria. WRC Report No. 705/1/97. Pretoria: Water Research Commission.
- Vawda, S., King, N. and Muller, M., (2010). Water Pricing and Policy in South Africa. Water Resources Development, 26(3), pp.321–337.
- Vieira, P., Alegre, H., Rosa, M.J. and Lucas, H. (2008). Drinking water treatment plant assessment through performance indicators', Water Science and Technology: Water Supply, 8(3), pp. 245–253.

- Walwyn, D.R. and Brent, A.C. (2015). Renewable energy gathers steam in South Africa', *Renewable and Sustainable Energy Reviews*, 41, pp. 390–401. <https://doi.org/10.1016/j.rser.2014.08.049>.
- Weston, D. and Goga, S. (2016). Natural resource governance systems in South Africa. Report to the Water Research Commission. Pegasys Strategy and Development (Pty) Ltd.
- World Health Organization (WHO). (2017). Guidelines for Drinking-water Quality: Fourth Edition Incorporating the First Addendum. Geneva: WHO. Available at: <https://www.who.int/publications/i/item/9789241549950> [Accessed 12 July 2025].
- Wright, E.P. and Burgess, W.G. (1992). The hydrogeology of crystalline basement aquifers in Africa'. Geological Society Special Publication No. 66. London: Geological Society, pp. 1–27.
- Webb, M. (2015). Coal 2015: A review of South Africa's coal sector. Johannesburg: Creamer Media.
- Wicke, B. (2011). Bioenergy production on degraded and marginal land. Utrecht: Utrecht University.
- Xu, Y., Seetal, A. and Gounden, T. (2021). Assessing wastewater treatment infrastructure challenges in rural South Africa: A case study of KwaZulu-Natal. *Water SA*, 47(2), pp.195-204.
- Zinn, C., Bailey, R., Barkley, N., Walsh, M.R., Hynes, A., Coleman, T., Savic, G., Soltis, K., Primm, S. and Haque, U. (n.d.) How are water treatment technologies used in developing countries and which are the most effective? An implication to improve global health.

APPENDICES

APPENDIX A: STANDERTON WATER TREATMENT WORKS DATA RESULTS FROM 2016 TO 2020

Table 5.1: Results of the Monitoring Sites

2016		SP Name	Physical Parameters		Chemical Parameters					Biological Parameters	
			pH	EC	Turbidity	TDS	Free Chlorine	Fe	Mn	E. Coli	Total coliform
				mS/m	mg/l					MPN	
			Target Water Quality Range (TWQR)								
			6.5-8.5		0-1	0-450	0-5	0-0.1	0-0.5	0	10
			0-170								
January 2016	Raw water		7.00	39.7	1.8	134	0.080	32	4.8	1986	2420
	Standerton WTW (Tap inside treatment plant)		7.44	30.5	1.5	130	0.090	20	3.4	11	20
	Sasol garage (Furthest point)		7.31	21.6	0.52	132	0.023	22.5	0.89	1	1
February 2016	Raw water		7.19	38.3	6.2	131	0.020	21	3.5	5206	7710
	Standerton WTW (Tap inside treatment plant)		6.98	32.8	4.2	125	0.050	3.51	2.1	20	56
			7.7	23.5	2.5	118	0.026	3.92	2.4	1	1
March 2016	Raw water		6.95	36.9	3.2	141	0.070	19.2	19	56	50
	Standerton WTW (Tap inside treatment plant)		6.99	33.0	1.0	120	0.090	5.52	5.2	1	1
	Sasol garage		7.43	19.8	0.32	160	0.019	5.09	0.75	1	1
April 2016	Raw water		7.78	28.7	1.2	156	0.059	14.1	6.8	10	14
	Standerton WTW (Tap inside treatment plant)		7.26	28.0	0.8	149	0.090	4.2	0.6	1	1
	Sasol garage (Furthest point)		7.90	19.0	2.4	99	0.020	3.9	2.1	1	1
May 2016	Raw water		7.00	48.2	4.3	110	0.060	13.4	7.0	42	6900
	Standerton WTW (Tap inside treatment plant)		7.64	29.6	3.7	104	0.091	3.9	0.1	1	16
	Sasol garage (Furthest point)		7.80	21.0	2.9	121	0.017	2.7	6.8	1	1
June 2016	Raw water		7.71	29.9	2.1	142	0.018	49.1	7.7	37	5643
	Standerton WTW (Tap inside treatment plant)		7.00	30.3	1.9	123	0.036	23.3	7.7	1	9
	Sasol garage		7.80	21.6	2.5	134	0.024	19.4	2.9	1	1
July 2016	Raw water		7.73	30.5	2.6	136	0.029	17.5	1.3	78	5432
	Standerton WTW (Tap inside treatment plant)		7.43	57.1	0.56	106	0.040	12.6	0.3	1	9
	Sasol garage		7.40	22.3	2.2	115	0.025	9.9	2.4	1	1
August 2016	Raw water		8.06	58.2	2.9	156	0.015	15.1	1.2	97	5432
	Standerton WTW (Tap inside treatment plant)		8.08	58.0	0.40	139	0.015	13.2	0.09	1	12

	Sasol garage	7.5	20.2	2.1	120	0.029	7.2	2.3	1	1
September 2016	Raw water	7.62	29.9	1.0	159	0.098	0.02	0.05	88	2420
	Standerton WTW (Tap inside treatment plant)	7.72	30.3	0.67	128	2.2	0.02	0.05	1	1
	Sasol garage	7.00	20.9	2.7	116	1.5	0.05	3.0	1	1
October 2016	Raw water	7.90	28.9	1.4	163	0.041	9.61	1.3	101	1299
	Standerton WTW (Tap inside treatment plant)	7.41	31.4	0.57	152	0.050	2.42	0.42	1	1
	Sasol garage	7.90	21.5	2.3	128	0.019	3.9	5.3	1	1
November 2016	Raw water	7.85	30.4	7.85	120	0.052	0.09	5.2	78	57
	Standerton WTW (Tap inside treatment plant)	7.45	30.1	7.45	120	0.080	0.06	0.05	1	1
	Sasol garage	8.00	20.9	7.5	101	0.025	0.06	0.03	1	1
December 2016	Raw water	7.71	30.4	4.65	108	0.070	32.1	4.8	57	201
	Standerton WTW (Tap inside treatment plant)	7.65	30.1	1.77	101	0.082	20.1	3.4	1	1
	Sasol garage	7.92	20.2	2.3	123	0.022	17.0	4.28	1	1

2017	SP Name	Physical Parameters		Chemical Parameters						Biological Parameters	
		pH	EC	Turbidity	TDS	Free Chlorine	Fe	Mn	E. Coli	Total coliform	
			mS/m	mg/l						MPN	
		TWQR									
		6.5-8.5		0-1	0-450	0-5	0-0.1	0-0.5	0	10	
	Raw water	7.73	22.0	4.4	183	0.080	92.5	8.3	43	157	
	Standerton WTW (Tap inside treatment plant)	7.60	20.3	1.9	160	0.080	9.1	0.97	1	1	
	Sasol garage (Furthest point)	7.38	19.5	0.52	144	0.09	8.0	6.6	1	1	
	February 2017	Raw water	7.19	22.3	3.98	130	0.010	84	6.2	89	2420
Standerton WTW (Tap inside treatment plant)		7.50	21.2	3.81	116	1.61	7.1	0.89	1	24	
		7.53	19.9	0.39	132	0.90	7.3	0.89	1	1	
March 2017		Raw water	7.31	32.3	3.61	125	0.010	6.3	1.6	100	2420
	Standerton WTW (Tap inside treatment plant)	7.45	28.2	5.32	123	0.050	1.1	0.51	6	201	
	Sasol garage	7.60	24.1	0.53	99	0.030	1.8	1.61	1	1	
April 2017	Raw water	7.44	22.7	7.38	119	0.015	14	6.8	21	2420	
	Standerton WTW (Tap inside treatment plant)	7.49	22.9	6.8	86	0.030	1.63	1.1	1	199	
	Sasol garage (Furthest point)	7.08	20.1	3.2	98	0.040	1.60	1.1	1	1	
May 2017	Raw water	7.38	20.8	10.4	127	0.017	18.8	1.04	236	2420	
	Standerton WTW (Tap inside treatment plant)	6.80	21.7	7.5	121	1.69	10.0	0.45	1	150	
	Sasol garage (Furthest point)	7.54	19.4	0.8	90	0.70	10.1	0.45	1	1	
June 2017	Raw water	7.78	22.2	3.56	144	0.015	5.49	1.7	230	2420	
	Standerton WTW (Tap inside treatment plant)	6.75	23.1	3.51	126	1.74	2.32	0.33	1	5	
	Sasol garage	7.65	15.5	1.0	75	0.40	2.09	0.5	1	1	
July 2017	Raw water	7.44	24.9	7.2	167	0.017	11.6	1.5	12	2420	
	Standerton WTW (Tap inside treatment plant)	7.40	30.1	4.9	129	1.08	3.90	1.1	1	201	
	Sasol garage	7.57	14.8	1.9	360	0.21	4.12	1.4	1	1	
August 2017	Raw water	7.20	25.1	8.1	149	0.014	1.4	0.97	72	2420	
	Standerton WTW (Tap inside treatment plant)	7.80	23.6	5.7	131	1.16	1.32	0.01	1	9	
	Sasol garage	8.69	59.6	0.49	373	0.20	0.96	0.67	1	1	
September 2017	Raw water	8.10	28.1	7.2	136	0.018	2.43	1.92	56	210	
	Standerton WTW (Tap inside treatment plant)	7.60	26.3	7.8	142	2.08	1.41	0.87	1	1	
	Sasol garage	7.50	62.3	0.35	340	0.40	1.53	1.4	1	1	
October 2017	Raw water	7.20	32.7	8.1	133	0.020	5.46	3.0	83	218	
	Standerton WTW (Tap inside treatment plant)	7.80	25.1	7.6	117	1.01	3.64	2.4	1	1	
	Sasol garage	7.56	70.0	0.98	328	0.24	3.98	1.9	1	1	

November 2017	Raw water	8.10	27.1	7.8	127	0.014	8.16	1.25	62	2420
	Standerton WTW (Tap inside treatment plant)	7.60	21.6	3.8	119	0.18	7.65	0.45	1	32
	Sasol garage	7.70	65.8	0.92	150	0.24	7.83	0.39	1	1
December 2017	Raw water	7.90	23.9	6.6	140	0.010	2.58	2.5	215	2420
	Standerton WTW (Tap inside treatment plant)	7.31	20.9	7.41	132	0.98	0.95	2.5	1	15
	Sasol garage	8.10	60.1	1.0	141	0.32	1.45	2.1	1	1

2018		SP Name	Physical Parameters		Chemical Parameters					Biological Parameters	
			pH	EC	Turbidity	TDS	Free Chlorine	Fe	Mn	E. Coli	Total coliform
				mS/m	mg/l					MPN	
			TWQR								
			6.5-8.5		0-1	0-450	0 -5	0-0.1	0-0.5	0	10
			0-170								
January 2018	Raw water	7.20	25.4	4.3	139	0.015	7.99	4.1	212	2420	
	Standerton WTW (Tap inside treatment plant)	7.41	21.6	0.88	133	1.05	6.8	2.8	1	30	
	Sasol garage (Furthest point)	7.31	25.1	1.2	295	0.82	7.1	2.0	1	1	
February 2018	Raw water	7.33	29.0	6.0	116	0.28	2.87	4.1	181	2420	
	Standerton WTW (Tap inside treatment plant)	7.45	27.6	1.5	82	0.016	0.76	2.8	1	15	
	Sasol garage	7.23	55.3	1.1	132	0.11	0.45	2.0	1	1	
March 2018	Raw water	7.90	28.4	1.6	122	0.22	25.1	6.2	11	2420	
	Standerton WTW (Tap inside treatment plant)	7.50	25.8	4.0	119	0.020	25.1	3.5	1	32	
	Sasol garage	7.62	57.3	3.2	132	1.17	26.4	2.0	1	1	
April 2018	Raw water	7.42	22.7	1.8	156	0.080	8.71	2.1	1221	2420	
	Standerton WTW (Tap inside treatment plant)	7.33	20.9	4.4	123	0.99	7.23	1.0	10	18	
	Sasol garage (Furthest point)	7.50	47.2	3.9	120	0.90	8.56	1.3	1	1	
May 2018	Raw water	7.50	26.9	2.6	138	0.080	8.51	2.2	135	2420	
	Standerton WTW (Tap inside treatment plant)	7.21	22.5	0.99	126	0.12	6.11	1.6	1	25	
	Sasol garage (Furthest point)	7.62	48.2	0.84	100	0.10	7.13	1.8	1	1	
June 2018	Raw water	7.40	27.1	1.9	152	0.01	2.29	3.1	42	219	
	Standerton WTW (Tap inside treatment plant)	7.38	23.8	1.1	137	1.93	0.61	2.6	1	1	
	Sasol garage	7.10	50.0	1.0	199	0.97	0.68	1.9	1	1	
July 2018	Raw water	6.99	37.5	1.7	142	0.070	8.5	2.7	89	34	
	Standerton WTW (Tap inside treatment plant)	7.35	26.4	1.4	129	1.3	6.46	2.4	1	10	
	Sasol garage	7.61	17.3	1.2	99	0.98	6.92	1.6	1	1	
August 2018	Raw water	8.0	15.2	2.0	139	0.01	30.8	1.8	17	2420	
	Standerton WTW (Tap inside treatment plant)	7.89	12.7	3.9	117	0.12	25.1	1.2	1	14	
	Sasol garage	8.10	37.6	2.5	107	0.10	25.75	0.99	1	1	
September 2018	Raw water	8.10	17.3	4.8	163	0.75	22.1	4.7	99	5	
	Standerton WTW (Tap inside treatment plant)	7.94	14.5	3.2	130	2.19	18.2	3.8	1	1	
	Sasol garage	7.31	25.0	0.45	95	1.18	20.1	3.1	1	1	
October 2018	Raw water	7.65	45.1	6.7	156	0.021	0.01	5.1	128	1660	
	Standerton WTW (Tap inside treatment plant)	7.78	31.1	4.9	136	1.74	0.01	3.6	1	8	
	Sasol garage	7.23	24.1	0.49	124	0.95	0.02	2.9	1	1	

November 2018	Raw water	7.61	29.3	3.9	131	0.010	0.01	3.5	78	1120
	Standerton WTW (Tap inside treatment plant)	7.54	28.0	2.6	123	1.2	0.01	2.2	1	23
	Sasol garage	7.62	20.7	0.58	143	0.86	0.02	0.83	1	1
December 2018	Raw water	7.80	49.1	4.2	142	0.040	3.5	2.9	38	2420
	Standerton WTW (Tap inside treatment plant)	7.35	30.0	2.7	131	1.7	2.2	1.04	1	62
	Sasol garage	7.50	19.9	1.2	132	0.89	2.84	0.58	1	1

2019	SP Name	Physical Parameters		Chemical Parameters					Biological Parameters	
		pH	EC	Turbidity	TDS	Free Chlorine	Fe	Mn	E. Coli	Total coliform
			mS/m			mg/l			MPN	
		Target Water Quality Range (TWQR)								
		6.5-8.5	0-170	0-1	0-450	0-5	0-0.1	0-0.5	0	10
January 2019	Raw water	8.02	30.5	10.98	139	0.019	2.9	1.53	94	2420
	Standerton WTW (Tap inside treatment plant)	7.85	30.0	9.74	125	0.051	3.1	1.08	1	41
	Sasol garage (Furthest point)	7.60	19.1	0.64	122	0.040	3.45	0.56	1	1
February 2019	Raw water	7.83	39.7	6.2	127	0.051	2.4	6.31	126	1764
	Standerton WTW (Tap inside treatment plant)	6.98	30.6	3.8	118	2.06	1.9	0.24	1	32
		7.60	19.9	0.99	119	1.09	1.09	0.99	1	1
March 2019	Raw water	7.19	32.7	4.3	135	0.02	1.8	2.19	31	210
	Standerton WTW (Tap inside treatment plant)	7.26	32.8	3.9	121	1.02	0.6	1.23	1	5
	Sasol garage	7.31	20.0	1.9	121	0.99	0.8	0.68	1	2
April 2019	Raw water	7.78	30.4	4.6	144	0.010	6.3	1.9	140	1990
	Standerton WTW (Tap inside treatment plant)	7.31	27.6	4.2	136	0.010	0.2	0.96	1	32
	Sasol garage (Furthest point)	7.19	18.6	0.52	123	0.020	0.5	1.02	1	1
May 2019	Raw water	7.61	29.7	1.9	147	0.021	2.6	0.85	40	2420
	Standerton WTW (Tap inside treatment plant)	7.64	28.7	1.01	120	1.72	2.6	0.53	1	58
	Sasol garage (Furthest point)	7.47	17.9	0.47	119	1.36	2.79	0.49	1	1
June 2019	Raw water	7.71	31.2	2.9	143	0.02	1.8	0.23	5	19
	Standerton WTW (Tap inside treatment plant)	7.20	29.7	0.54	134	1.01	1.2	0.01	1	1
	Sasol garage	7.60	24.1	0.35	158	0.89	0.83	0.19	1	1
July 2019	Raw water	7.73	26.2	8.23	135	0.01	0.01	0.98	56	5

August 2019	Standerton WTW (Tap inside treatment plant)	7.45	21.8	6.4	129	0.025	0.01	0.01	1	1
	Sasol garage	7.50	17.9	3.4	120	0.019	0.04	0.01	1	1
	Raw water	8.60	56.7	5.47	153	0.010	0.67	2.7	9	12
	Standerton WTW (Tap inside treatment plant)	8.08	57.7	3.67	134	0.010	0.67	2.4	1	1
	Sasol garage	7.45	20.2	2.9	124	0.00	0.89	1.6	1	1
September 2019	Raw water	7.62	58.7	5.2	151	0.020	0.01	1.8	58	7
	Standerton WTW (Tap inside treatment plant)	7.72	58.4	4.0	143	0.019	0.02	1.2	1	1
	Sasol garage	7.50	20.0	1.8	137	0.013	0.03	0.99	1	1
October 2019	Raw water	7.90	31.5	6.3	119	0.012	0.01	4.7	4	2420
	Standerton WTW (Tap inside treatment plant)	7.41	30.6	3.8	115	0.017	0.02	3.8	1	52
	Sasol garage	7.30	22.1	3.1	145	0.021	0.01	3.1	1	1
November 2019	Raw water	7.85	39.9	7.3	121	0.016	3.5	5.1	78	112
	Standerton WTW (Tap inside treatment plant)	7.45	30.3	6.8	132	0.080	0.97	3.6	1	1
	Sasol garage	7.50	20.9	2.9	124	0.026	0.99	2.9	1	1
December 2019	Raw water	7.60	35.1	7.3	114	0.01	0.07	3.5	134	8
	Standerton WTW (Tap inside treatment plant)	7.80	31.5	6.9	147	0.01	0.03	2.2	1	1
	Sasol garage	7.30	19	4.9	190	0.02	0.05	0.83	1	1

2020	SP Name	Physical Parameters		Chemical Parameters					Biological Parameters	
		pH	EC	Turbidity	TDS	Free Chlorine	Fe	Mn	E. Coli	Total coliform
			mS/m	mg/l					MPN	
		TWQR								
		6.5-8.5		0-1	0-450	0-5	0-0.1	0-0.5	0	10
January 2020	Raw water	6.61	37.6	7.0	190	0.01	0.05	3.52	127	20
	Standerton WTW (Tap inside treatment plant)	6.81	32.0	6.4	167	0.070	0.02	2.81	1	1
	Sasol garage (Furthest point)	7.90	20.9	2.5	129	0.023	0.02	2.08	1	1
February 2020	Raw water	7.31	35.6	6.8	165	0.00	0.03	0.01	56	10
	Standerton WTW (Tap inside treatment plant)	6.97	32.0	6.3	159	0.10	0.01	0.01	1	1
	Sasol garage	7.90	20.2	4.1	145	0.02	0.01	0.02	1	1
March 2020	Raw water	7.31	30.2	7.4	172	0.015	0.02	0.01	435	2420
	Standerton WTW (Tap inside treatment plant)	6.97	28.2	7.2	166	0.021	0.01	0.01	1	76
	Sasol garage	7.90	23.1	2.9	165	0.019	0.01	0.03	1	24
April 2020	Raw water	7.40	27.0	7.8	151	0.080	0.01	0.02	223	1120
	Standerton WTW (Tap inside treatment plant)	7.24	26.7	7.4	145	0.11	0.01	0.01	8	28
	Sasol garage (Furthest point)	7.80	24.7	7.7	166	0.25	0.01	0.01	1	5

May 2020	Raw water	7.48	25.9	7.3	142	0.021	0.01	0.06	67	2420
	Standerton WTW (Tap inside treatment plant)	7.45	24.9	7.0	127	1.89	0.01	0.04	1	56
	Sasol garage (Furthest point)	6.8	24.0	6.0	156	0.57	0.04	0.01	1	4
June 2020	Raw water	6.92	37.9	6.9	164	0.015	0.01	0.01	25	2426
	Standerton WTW (Tap inside treatment plant)	7.38	32.5	7.3	136	2.06	0.01	0.01	1	51
	Sasol garage	7.81	20.8	0.4	151	0.67	0.01	0.02	1	1
July 2020	Raw water	7.30	37.3	7.6	145	0.03	0.03	0.08	147	40
	Standerton WTW (Tap inside treatment plant)	7.49	28.1	7.4	166	1.23	0.01	0.01	3	1
	Sasol garage	7.80	20.4	4.9	156	0.98	0.01	0.02	10	34
August 2020	Raw water	7.61	27.8	8.1	164	0.019	0.01	0.01	45	2420
	Standerton WTW (Tap inside treatment plant)	7.49	26.7	7.8	136	1.96	0.01	0.00	1	36
	Sasol garage	7.35	22.5	3.9	151	1.52	0.01	0.01	1	79
September 2020	Raw water	8.15	36.8	7.8	172	0.01	0.01	0.02	56	34
	Standerton WTW (Tap inside treatment plant)	7.88	32.4	7.7	153	1.14	0.01	0.01	1	1
	Sasol garage	7.20	22.3	2.5	142	0.87	0.01	0.02	1	1
October 2020	Raw water	7.88	35.1	7.6	139	0.010	0.01	0.06	34	1553
	Standerton WTW (Tap inside treatment plant)	7.72	30.5	7.4	127	0.025	0.01	0.02	1	12
	Sasol garage	7.50	19.1	2.5	123	0.018	0.05	0.04	1	1
November 2020	Raw water	7.60	38.4	7.3	92	0.015	0.05	0.08	104	2420
	Standerton WTW (Tap inside treatment plant)	7.48	30.8	7.4	83	2.11	0.01	0.02	2	17
	Sasol garage	7.50	21.5	2.7	92	0.99	0.01	0.05	1	1
December 2020	Raw water	7.90	35.1	7.5	165	0.018	0.01	0.03	152	2420
	Standerton WTW (Tap inside treatment plant)	8.70	33.4	7.1	159	1.52	0.01	0.00	1	10
	Sasol garage	7.84	20.4	2.6	145	1.10	0.01	0.00	1	1

Appendix B: Monthly Meter Reading

Table 5.2: Shows the Results of the Monthly Meter Reading

Month	2016	2017	2018	2019	2020
January	2173884	3366390	4656886	5947382	7233545
February	2285204	3473377	4763873	6054369	7340532
March	2390191	3577694	4868190	6158686	7444849
April	2497178	3789014	4979510	6270006	7551836
May	2608498	3796001	5086497	6374323	7663156
June	2713485	3900318	5190814	6481310	7767473
July	2820472	4011638	5302134	6588297	7874460
August	2931792	4118625	5409121	6692614	7985780
September	3036779	4222942	5513488	6803934	8090097
October	3143766	4334262	5624758	6910921	8197084
November	3155086	4441249	5731745	7015238	8208404
December	3259403	4545566	5836062	7122225	8312712
AVERAGE	2735043.48	3964756.33	4843468.92	6534942.08	7805827.33

Appendix C: Observation and Tools used for Field Research

Table 5.3: Shows Detailed observation and tools used for field research at Standerton Water Treatment Works

Stage	Focus Area
Raw Water Source	Water quantity and quality at intake point
Treatment Processes	Operational efficiency, chemical dosing, filtration
Storage and Pumping	Clear water reservoirs, pump reliability
Distribution System	Network condition, losses, delivery quality
Raw Water Abstraction (Grootdraai Dam)	
Observation Focus	Tools/Methods
Source water quality	Portable multiparameter water quality meter for pH, turbidity, temperature
Water level/flow	Visual inspection and flow meter readings
Catchment contamination	Visual signs of pollution (algae blooms, waste, runoff)
Sediment load	Turbidity tubes, suspended solids sampling
Water Treatment Process observation	
Chemical dosing (e.g., chlorine, lime)	Jar test kits, chlorine comparators, review dosing logs
Coagulation and flocculation	Visual observation of sedimentation tanks and floc formation
Filtration efficiency	Turbidity meter before and after filtration
Disinfection effectiveness	Free & total chlorine test kits, pH meter

Treatment efficiency records	Review plant logs, downtime logs, SCADA data (if available)
Clear Water Storage and Pumping observation	
Pump station operation	Pump logs, observation of on/off cycles, noise and leaks
Power backup availability	Visual check of generator or solar system status
Reservoir hygiene	Check for algae, open vents and unsealed lids
Retention time	Estimate based on inflow/outflow data, flow meters and tank capacity
Distribution System	
Leakage and burst rate	Pipe inspection, municipal repair logs, visual and acoustic survey
Pressure fluctuations	Digital pressure gauges and pressure loggers at strategic points
Digital pressure gauges, pressure loggers at strategic points	
Non-revenue water	Compare input vs. billed volume (NRW calculation)
Household water quality	Grab samples tested for <i>E. coli</i> , chlorine residual, turbidity
Pipe material and condition	Visual inspection (open manholes), GIS mapping (if available)
Tool/Instrument	Purpose
SCADA System	Real-time data on flow, pump status, chlorine, turbidity
Survey Questionnaires	For consumers and plant operators (perception of quality and service)
Checklists	For systematic observation at each component
GPS & GIS Mapping Tools	Mapping water infrastructure, leak locations, and sampling sites
Digital Camera/Phone	Photo documentation of equipment, leaks, turbidity, etc.
Documentation Tools	

• Field notebook or mobile data collection app	• Note pad and Cellphone
Observation checklist	Customized to Standerton WTW layout
Flow and Pressure Monitoring	Flow meters, pressure gauges/loggers
Documentation	Checklists, field notebooks, cameras, mobile data collection apps
Operational Analysis	Pump logs, chemical dosing records
Water Clarity and Quality	Raw water showed moderate turbidity, especially after rainfall events.
Signs of Pollution	Runoff from nearby settlements and agricultural areas was noted.
Intake Infrastructure	Screens partially clogged; possible inefficiency in preventing debris.
Treatment Process Efficiency	
Chemical Dosing (Chlorine, Coagulants)	Inconsistent dosing due to manual operation; sometimes overdosing or underdosing.
Filtration System	Sand filters appeared aged and poorly maintained; high turbidity post-filtration.
Sedimentation Tanks	Sludge accumulation noted; maintenance not performed frequently.
Clear Water Storage and Pumping	
Pump Station Operations	Intermittent pump failure; pump downtime not always recorded accurately
Disinfection Process	Chlorine levels at times fell below minimum SANS 241 standard due to irregular dosing.

Equipment Functionality	Frequent breakdowns of pumps and mixers; lack of backup power during load-shedding.
Reservoir Conditions	Signs of algae in some reservoirs due to stagnant water and poor sealing and cracks where water leaking was noticed.
Water Retention Time	Excessive retention time in some tanks leading to possible water quality decline.
Distribution System Efficiency	
Leaks and Pipe Bursts	High frequency of visible leaks and old asbestos pipes in many areas
Non-Revenue Water (NRW)	High levels of NRW (suspected above 40%) due to leaks and illegal connections.
Pressure Fluctuations	Low pressure areas identified, especially at network periphery.
Consumer Water Quality (At Tap)	Intermittent chlorine residual; some samples showed turbidity and taste complaints.
Response Time to Breakdowns	Delays in repair due to shortage of materials and skilled staff.
Operational and Management Aspects	
Staff Training and Capacity	Many operators lacked up-to-date technical training.
Monitoring and Records	Poor data logging; absence of real-time monitoring (no automated SCADA).
Compliance with SANS 241	Non-compliance noted in microbial and chlorine residual parameters.
Maintenance Practices	Mostly reactive; minimal preventative maintenance observed.
Community Feedback	
Supply Reliability	Unpredictable interruptions during load shedding and pump failures.

Communication with Municipality	Limited updates or transparency during water outages or quality concerns
Summary of Observation	
Efficiency	Significant inefficiencies in pumping, leak control, dosing systems, and infrastructure.
Water Quality	Treated water often fell below national standards due to poor disinfection and maintenance.
Operational Capacity	Limited skilled staff, poor monitoring tools, and lack of backup systems hinder effectiveness.
Sampling Points	
○ At raw water intake ○ After filtration and disinfection at tap inside the plant ○ At Sasol garage 3 km from the tap	
Sampling Frequency	
○ Daily for chlorine and turbidity (during visit) ○ Once per location for microbiological and chemical tests (grab samples)	Twice per day
Interview guides	For operators and managers
Report template	To record findings and link observations to SANS 241 standards and supply efficiency metrics