ANALYSIS OF FACTORS, INFRASTRUCTURE, METERING, AND ADMINISTRATION INFLUENCING THE LEVEL OF NON-REVENUE WATER IN HAZYVIEW TOWN, SOUTH AFRICA

Dissertation submitted in fulfillment of the requirements
for the degree
Master of Philosophy in Integrated Water Management at
The Independent Institute of Education, IIE MSA.

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9 March 2026

DECLARATION

I, Koena Given Moabelo, hereby declare that this dissertation, "*Analysis of factors, infrastructure, metering, and administration influencing the level of Non-Revenue Water in Hazyview Town, South Africa*", is submitted as my own work and has not been submitted previously for a degree at this or any institution of higher learning. All sources referred to in this study have been acknowledged satisfactorily in the text and the list.

SIGNATURES

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Dr Tendai Sawunyama

ACKNOWLEDGEMENTS

First and foremost, I am grateful to Almighty God for granting me the health and strength necessary to complete my master's degree. I extend my sincere gratitude to the numerous people who have devoted their time, effort, thoughts, and knowledge to my research. I want to thank you sincerely.

- My supervisor, Dr. Schoeman, for helping to shape this thesis. My perspective has changed as a result of the knowledge you have shared with me.
- Dr. Sawunyama, the subject matter expert, for your supervision, constructive criticism, and guidance. I learned a great deal, especially about real-world scenarios.
- I want to thank my work colleagues for their support and for covering my duties during my absence.
- My family and my wife for love and support. Studying kept me away from home at times, and I appreciate their understanding in that regard.

DEDICATION

This master's thesis is dedicated to my mother, Noko Moabelo.

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ACRONYMS AND ABBREVIATIONS

AL	Apparent Losses
CBD	Central Business District
CoCT	City of Cape Town
CoM	City of Mbombela
DMA	District Metered Area
DSS	Decision Support System
DWS	Department of Water and Sanitation
CER	Cost Efficiency Ratio
IWA	International Water Association
LGBTQ+	Lesbian, Gay, Bisexual, Transgender, Queer, and Others
LM	Local Municipalities
MGCA	Mpumalanga Green Cluster Agency
MTTR	Mean Time to Repair
NRW	Non-Revenue Water
PMZ	Pressure Management Zones
PRV	Pressure Reducing Valve
PWA	Provincial Water Authority
RL	Real Losses
RW	Revenue Water
SCADA	Supervisory Control and Data Acquisition
SIV	System Input Volume
TOC	Theory of Constraints
US	United States
WCWDM	Water Conservation and Water Demand Management
WDN	Water Distribution Network
WDS	Water Distribution System
WMDs	Water Management Devices
WL	Water Loss
WSP	Water Service Provider

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BY

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Degree: Master of Philosophy in Integrated Water Management

ABSTRACT

Non-revenue water (NRW) undermines service reliability and municipal finances, yet the local drivers in small South African towns remain under-explained. This study qualitatively investigated factors influencing NRW in Hazyview (City of Mbombela), using the Theory of Constraints and Managerial Efficiency to guide interpretation. Data were generated through semi-structured interviews with municipal staff, a focus group with external stakeholders, and an analysis of policy and operational documents, using criterion-based purposive and maximum variation sampling. Transcripts and documents were inductively coded and thematically analysed, with cross-source triangulation.

Findings indicate three reinforcing pathways: (i) physical losses from ageing, pressure-stressed assets and extended leak run-times; (ii) apparent losses driven by illegal connections, meter tampering, and under-registering or inaccessible meters; and (iii) administrative constraints data quality gaps, slow leak response, limited enforcement, and skills and budget shortfalls that delay detection and correction and hinder technology uptake. These results suggest prioritizing pressure management and district metered areas (DMAs), targeted meter audits and replacements, stronger credit control and bylaw enforcement, and a phased adoption of Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR) to shorten detection-to-repair cycles. The study is limited by its single-site, cross-sectional design and small purposive sample; however, it offers actionable insights for similar municipal contexts.

Keywords: **Administrative practices; District Metered Areas; Hazyview; Non-revenue water; Pressure management; Qualitative study; Theory of Constraints; Water demand management.**

CHAPTER 1

GENERAL INTRODUCTION AND BACKGROUND

1.1 Introduction

This chapter discusses the context, purpose, objectives, and rationale of this study. It also defines and clarifies important concepts about the study. The operational definitions used and the dissertation's structure are also presented.

1.2 The context of the study and Background

Non-Revenue Water (NRW) poses a serious obstacle to sustainable water management worldwide, affecting financial stability and resource efficiency in urban water systems. A significant obstacle to effective water management worldwide is NRW. More than 40% of the global population may be affected by severe water stress by 2050 (AbuEltayef, AbuAlhin, & Alastal, 2023). AbuEltayef *et al*. (2023) revealed that the 2030 Agenda places a strong emphasis on sustainability for both the current and future generations by explicitly integrating water resources, supply, and sanitation. Despite this, NRW hinders sustainability by wasting energy, water, and money that is not collected from water bills (AbuEltayef *et al.,* 2023; Farouk, Rahman & Romali, 2023).

A study conducted by Chea (2022) revealed that NRW is staggering, with more than 32 billion cubic metres of treated water being lost each year through leakages from distribution networks, and an additional 16 billion cubic metres per year is delivered to customers but not invoiced because of theft, poor metering, and corruption. It is estimated that the yearly cost to water utilities worldwide, as reported in the agency report, is 14 billion United States (US) dollars. In certain low-income nations, this loss amounts to roughly 50-60% of the total water delivered, with an average of 35% worldwide (Chea, 2022). It is also estimated that 126 billion cubic meters of water are lost worldwide each year, which amounts to a cost of almost $39 billion (Liemberger & Wyatt, 2018; Viljoen & van der Walt, 2018; Oberascher, Möderl, & Sitzenfrei, 2020).

A study by Viljoen and van der Walt (2018) found that although 41% of the municipal water provided in South Africa is not revenue-generating, 35% is lost due to leakage, and 64% of households have access to reliable water service delivery. In developing countries like South Africa, water is a scarce resource. Water availability is essential for life, prosperity, and all human endeavours (Taha *et al*., 2020; Bayu, Kim & Oki, 2020). Therefore, the management of NRW is significant, as it may be profitable for a municipality or other water utility to supply water services. Along with improving cash flow, it may also result in postponed investment in water production, which is becoming increasingly expensive. Measuring the cost-effectiveness of NRW reduction methods in the City of Mbombela is therefore crucial.

In Mpumalanga, the water balance indicates NRW of 153.3 million m3/annum (54.0%) and water losses of 131.2 million m^3/annum (46.3%) (DWS, 2023). Mpumalanga Green Cluster Agency (MGCA) (2021) supported this, stating that 46.2% of the province's NRW represents R3.6 billion in lost revenue annually. Some Local municipalities (LMs) have access to NRW data. Govan Mbeki LM (21%), Mbombela LM (42%), Steve Tshwete LM (31%), and Emalahleni LM 47%. The trends in the province show a steady increase in System Input Volume (SIV) and NRW over the previous eight years, and are currently at their highest level in

10 years (DWS, 2023). Maloba and Matlala (2023) assert that Emalahleni LM, Emakhazeni LM, and Steve Tshwete LM together account for over 65% of Mpumalanga's NRW, reported across Mpumalanga’s 17 municipalities.

Maloba and Matlala’s (2023) study has highlighted the NRW problem in the municipalities of Steve Tshwete, Emakhazeni, and Emalahleni. The study’s conclusion indicates that NRW is a significant problem in these regions, with a sizable amount going unaccounted for. The factors identified as contributing to NRW include inadequate infrastructure, community noncompliance, management issues, and political interference. Remarkably, the primary causes of NRW in the three municipalities were real losses, including burst pipes, water leaks, storage overflow, and broken pipes. According to the City of Mbombela’s water balance over the past five years, Hazyview has experienced the highest NRW levels among the systems, ranging from 55% to 61%. The Hazyview area incurs annual losses of 954,000 KL (Figure 1.1) of its System Inputs Volume, which equates to 21 million rand at R22.75/kl (City of Mbombela, 2023). This means that Hazyview has NRW levels higher than those in other systems in the municipality. The problem is NRW, which is a significant contributor to municipalities' struggles to generate revenue. Therefore, the overall aim is to investigate factors influencing NRW levels in Hazyview within the City of Mbombela.

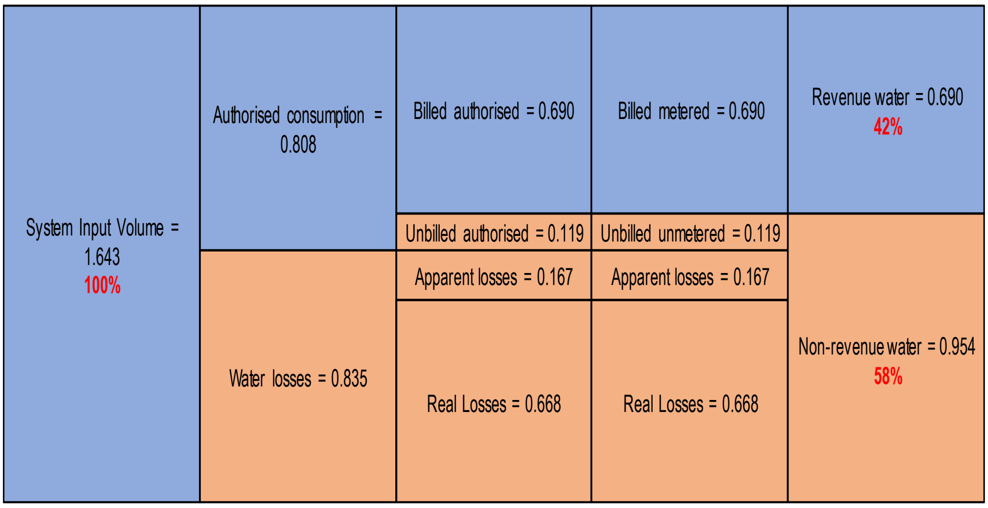

Figure 1-1: Hazyview Water Balance

Source: (CoM, 2023)

The City of Mbombela is the capital city of Mpumalanga Province, situated in the eastern part of South Africa (Figure 1.2) within which Hazyview town islocated. There are three sections of Hazyview town namely: Vakansiedorp, Numbipark, and the Central Business District (CBD). There are approximately 1363 houses and 4537 people living in the town, respectively. A significant percentage of Non-Revenue Water (NRW), 53%, is experienced in the Hazyview area, as per the Water Conservation and Water Demand Management (WC/WDM) Strategy for the City of Mbombela (City of Mbombela, 2020). Due to the high NRW levels, Hazyview was selected (City of Mbombela, 2020). Water meters are installed to verify measurements, and the area was chosen for its simple, isolated water supply system. The amount of money that can be made from water bills, the quality of services, and customer satisfaction all depend heavily on high NRW to meet the demand (Taha, Sharma, Lupoja, Fadhl, Haidera & Kennedy, 2020).

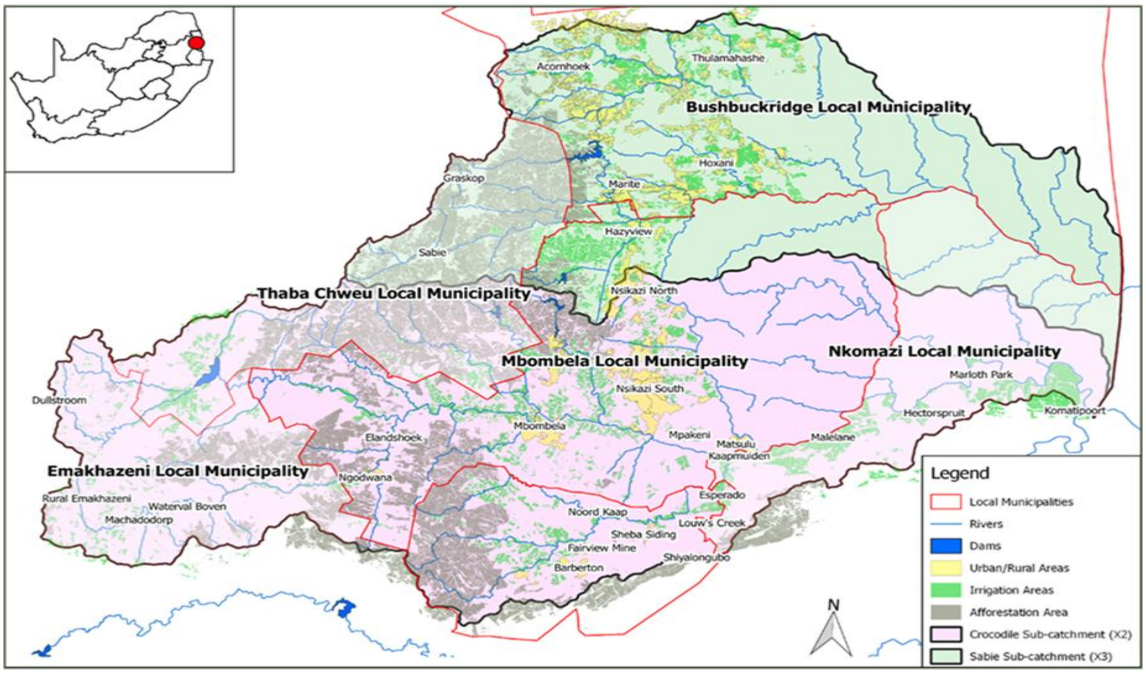

Figure 1-2: Ehlanzeni District Municipality Map

Source: Department of Water and Sanitation (DWS)(2023)

The primary objective of this study is to qualitatively investigate the infrastructure, metering, and administrative factors that contribute to Non-Revenue Water (NRW) in Hazyview, within the City of Mbombela. This research employed interviews, focus groups, and document analysis to comprehend the complexities of physical and commercial losses affecting NRW. By gaining insights into the experiences and perceptions of municipal workers, residents, and other stakeholders, the study aimed to identify underlying causes and propose contextually appropriate strategies to reduce NRW. Results from this qualitative inquiry are likely to offer practical insights that can be adapted to similar urban contexts, enhancing NRW management practices across South Africa.

To ground the Theory of Constraints and Managerial Efficiency, which were used in this study. The Managerial Efficiency Theory of Profit was proposed by Timothy Scott Archer in 2010. The Archer Managerial Efficiency theory stipulates that "*if* *an average firm tends to earn only a normal return on its investment in the long run, then firms that are more efficient than the average would earn above-normal returns and (economic) profits.*" The theory further holds that high profits will provide organisations with an incentive to expand output (Archer, 2010). This theory will provide the researcher with insight into why most municipalities are inefficient and incur losses or very little profit, thereby hampering their ability to grow and expand water service delivery to the people of this country. According to this theory, the researcher believes that most municipalities currently incurring high NRW losses are unable to grow because they earn a very low return on investment, making their situation unsustainable.

The Theory of Constraints was developed by Eliyahu M. Goldratt in 1984. The theory postulates that "every system, no matter how well it performs, has at least one constraint that limits its performance, which is the system's weakest link (Mabin, 2015). According to Şimşit, Günay and Vayvay (2014) and Kihumba (2013), the theory states that "a constraint is any factor that limits the organisation from getting more of whatever it strives for, which is usually profit and the theory further says that a system can have only one constraint at a time, and that other areas of weakness are non-constraints until they become the weakest link". Based on the works of Goldratt (1999), this theory applies to the Hazyview in the City of Mbombela, where NRW is the most significant constraint for the success of the municipality because it eats into the profits of the municipality and reduces its capacity to have a reliable surplus, which can be reinvested in furtherance of water supply. Figure 1.3 below shows the conceptual framework of the study.

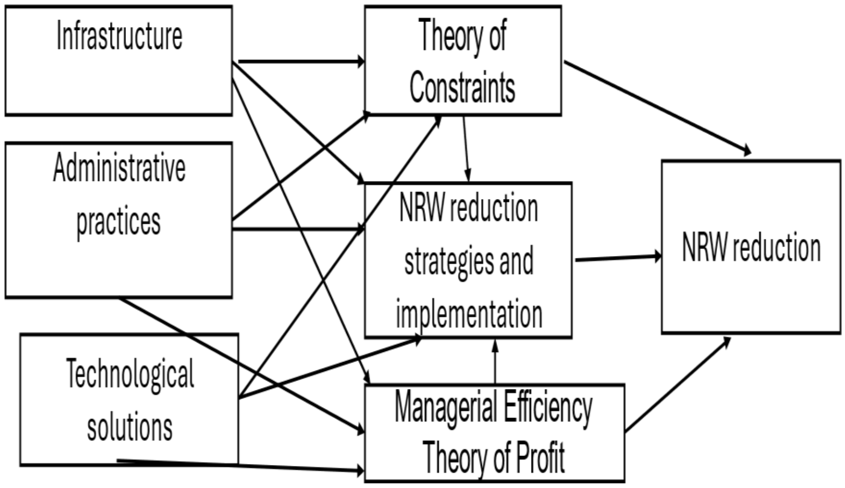

Figure 1-3: Conceptual Framework

Source: Own compilation (2025)

A study by Shushu, Komakech, Dodoo-Arhin, Ferras, and Kansal (2021) found that aging infrastructure networks and inadequate system pressure control are significant contributors to water loss in sub-Saharan Africa. Chea (2022) revealed that the successful implementation of NRW reduction strategies is squarely the responsibility of management. If management lacks the goodwill and support to implement the NRW-reduction interventions, the strategies are likely to fail. Management can support strategy implementation by allocating resources, training staff, providing reporting, benchmarking, and supervising the strategy implementation process to ensure the desired results are achieved (Chea, 2022). Management also plays a crucial role in staff motivation by recognizing work efforts aimed at achieving a desirable NRW level for their respective water companies (Chea, 2022). Water utility firms can leverage their financial resources, human resources, strong organisational policies, dynamic organisational structures, and workers' commitment to implement effective NRW reduction strategies and achieve superior strategic performance (Chea, 2022). Equipment for leak detection has undergone significant changes in recent years. Modern electrical technology has been integrated into acoustic equipment to help the operator identify and pinpoint leaks (El-Zahab & Zayed, 2019).

1.3 Problem Statement

Non-Revenue Water (NRW) in South Africa is a significant issue that has increased over the past decade (Gupta & Kulat, 2018; AbuEltayef *et al.,* 2023). NRW is a significant contributor to municipalities' struggles to generate revenue. Studies indicate and reflect that it is a water loss WL that is either leakage or real loss RL (Gupta & Kulat, 2018; Oberascher et al., 2020; Taha *et al.,* 2020; DWS, 2023a). Although NRW is well known, the factors influencing NRW levels in Hazyview Town within the City of Mbombela Municipality remain poorly understood. Despite numerous studies on NRW, few have applied a qualitative methodology to gain a deeper understanding of the underlying infrastructural, administrative, and social dynamics in Hazyview, which could inform more targeted and effective interventions. This study is the first in the City of Mbombela to employ a qualitative approach in uncovering the administrative, infrastructural, and technological factors driving NRW. Therefore, it is important to investigate the factors influencing NRW levels in the City of Mbombela, specifically in Hazyview. The 41% national water loss rate and the deteriorating condition of the country's water infrastructure pose a significant threat to future water security (Viljoen & van der Walt, 2018). Netshitanini, Adeeyo, and Edokpayi (2023) stated that the 2010 NRW of 36.8% equated to approximately R7 billion per year, taking inflation and rising water costs into account. Currently, this expense is estimated to be between R 15 billion and R 20 billion per year (Netshitanini *et al.,* 2023).

1.4 Aims and objectives of the study

The primary objective of the study was to determine the factors influencing NRW levels in Hazyview within the City of Mbombela.

- To understand the main infrastructural contributors to NRW in Hazyview
- To understand the administrative practices influencing NRW levels
- To explore technological innovations that could mitigate infrastructure-related NRW, such as advanced leak detection systems in Hazyview, City of Mbombela, Mpumalanga province.

The main research question was: What factors influence the level of NRW in Hazyview within the City of MbombelaThe specific questions of the study were as follows:

- What are the main infrastructural contributors to NRW in Hazyview?
- How do administrative practices influence NRW levels?
- Which technological innovations could mitigate infrastructure-related NRW, such as advanced leak detection systems in Hazyview, City of Mbombela, Mpumalanga province?

1.5 Significance of the study

This research aims to close the gap by providing comprehensive insights into the factors influencing NRW in Hazyview and offering actionable recommendations to enhance water management practices and reduce financial losses. The study will make suggestions to assist municipalities in understanding the specific constraints in reducing NRW and recommend actions to improve management of NRW to make economic sense for a water utility like municipality as a water service provider. Moreover, the study will assist municipalities in achieving cost savings and environmental benefits, such as reduced NRW. Other stakeholders and policymakers in the water sector will benefit from reading this study before engaging with strategies to reduce NRW. The study may inform guidelines, policy recommendations, or modifications to existing regulations to better support sustainable water-use practices and advance the academic body of knowledge. Therefore, by systematically investigating the infrastructural, administrative, and technological dimensions of NRW through a qualitative lens, this study aims to provide actionable insights for water utilities and municipalities, thereby contributing to both scholarly understanding and practical interventions. Lastly, this study will be utilized by consultants for strategic planning, infrastructure development, or community engagement strategies in the water sector to inform the government before implementing NRW reduction practices. The study could contribute to educational programs and workshops aimed at improving understanding and implementing technological solutions or innovations to mitigate infrastructure-related NRW, such as advanced leak detection systems.

The goal of this study was to find out which factors influence Hazyview's NRW level. To determine the quantity of water provided in comparison to the quantity billed, the study encompassed the water supply system in Hazyview, from System Input Volume (SIV) to Revenue Water (RW). Data from the Hazyview area was gathered from meter readings, billing information, water infrastructure, and customer support services to support the study's goals. When it comes to NRW studies in the water sector, the majority of authors have focused on a broader scale, often at the municipal or multiple-municipality level. Following the completion of this study, the Hazyview water supply system case was utilised as an example for other municipal systems to identify the components that affect NRW. Municipalities within the province may implement NRW reduction strategies as a model. Recognizing that NRW is a global issue, local management strategies require diverse approaches.

1.6 Research Methodology

This study employed a qualitative approach to collect primary data from municipal staff and stakeholders, using interviews and focus groups with a semi-structured questionnaire to gather loosely structured, verbal data, which proved fruitful for identifying problem areas in the social environment.

1.6.1 Research Design

Consistent with the research approach and the primary research question of this study, which is to explore the nature of infrastructure, metering, and administrative factors contributing to NRW in Hazyview within the City of Mbombela, an exploratory research design is best suited for this research.

1.6.2 Population and Sampling

A purposive sampling strategy (criterion-based purposive sampling and maximum variation) was adopted to achieve the objectives of this study. Twelve municipal workers, from supervisory to management levels in water infrastructure, were interviewed. A focus group was conducted to collect data from 12 stakeholders: water consultants, water committee members, and municipal staff. Moreover, documents, namely, policy documents, previous NRW reports, or operational data from the water systems, were analysed.

1.6.3 Data Collection

A semi-structured interview was employed to collect data from 12 individual municipal staff members, 1 focus group of 12 stakeholders, and documents.

1.6.4 Data Analysis

The thematic analysis approach has been used to derive the categories and codes for the qualitative analysis. Thematic analysis is a method of analyzing qualitative data that involves searching a dataset to identify, analyze, and report themes. It is a method for describing data, but it also involves interpretation in selecting codes and constructing themes in the study. The qualitative data in the study were produced manually by the researcher using a word-processing software.

1.6.5 Ethical Consideration

The following ethical considerations were complied with during data collection:

- Every participant was offered anonymity and assured that their personal contact details would not be linked to the data provided.
- Every participant was assured that the information provided would be handled confidentially and analyzed by combining multiple separate items for research purposes.
- Every participant was fully informed of the procedures and risks included in the research. The consent given included the individual's right to withdraw from the study at any time, details about the study's central purpose, and the procedures to be employed in data collection.

The IIEMSA provided ethical clearance number: M.810325.

1.7 Operational definitions

1.7.1 Water Infrastructure

Water infrastructure is the system of physical structures and equipment used to manage water resources, encompassing the collection, treatment, storage, and distribution of water, as well as the collection, removal, and disposal of wastewater and sewage (Grigg, 2016).

1.7.2 Administrative Practices

Administrative practices in water refer to the systems, policies, and decision-making processes that guide water resource management and service delivery, encompassing areas like regulation, planning, allocation, and stakeholder engagement (Katusiime & Schütt, 2020).

1.7.3 Technological Solutions

Technological solutions for NRW include AI-powered leak detection and predictive maintenance, advanced sensors and smart meters for real-time monitoring, digital tools for modeling and optimizing networks, and advanced analytics to understand network performance (Mlewa, Tole, & Mvuya, 2025).

1.8 Limitations and delimitations

The study was limited to Hazyview, in the City of Mbombela, Mpumalanga.

- Limitations: insider bias, limited generalisability, cross-sectional design, participant availability.
- Delimitations: geographic scope (Hazyview only), thematic scope (NRW not full water management).

1.9 Chapters outline

The remainder of this dissertation is structured as follows:

- **Chapter 1** present the study's background, problem statement, purpose, and objectives, as well as the significance of the research, limitations, and delimitations, is provided.
- **Chapter 2** presents a detailed literature review on global, national, and local perspectives of NRW, including definitions, classifications, and reduction strategies.
- **Chapter 3** outlines the qualitative methodology adopted, including sampling, data collection, and analysis procedures.
- **Chapter 4** presents and analyzes the findings from interviews, focus groups, and document reviews.
- **Chapter 5** concludes the study, summarizes the main findings, discusses implications for policy and practice, and offers recommendations for reducing NRW in Hazyview and similar contexts.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

In this chapter, a comprehensive literature review is presented that relates to the theoretical framework employed in this study. This is followed by a comprehensive review of the literature for the study, examining infrastructural contributors to NRW, administrative practices that influence NRW levels, and technological innovations that could mitigate infrastructure-related NRW, such as advanced leak detection systems in Hazyview, City of Mbombela, Mpumalanga.

2.2 Theoretical framework

In South Africa, particularly in Hazyview, NRW levels significantly exceed the global average, resulting in substantial economic losses and inefficiencies in water distribution. Similarly, in Nigeria, Nasara *et al.* (2021) discovered that the NRW level is greater than the global average of 35%, ranging from 36% to 50%. Moreover, Nasara *et al.* (2021) found that the water utility's NRW reduction management process fell short of the IWA-suggested standard. To ground this study, the NRW reduction framework is informed by the Theory of Constraints and the Managerial Efficiency theory of profits.

The Managerial Efficiency Theory of Profit was proposed by Timothy Scott Archer in 2010. The Archer Managerial Efficiency theory stipulates that "*if an average firm tends to earn only a normal return on its investment in the long run, then firms that are more efficient than the average would earn above-normal returns and (economic) profits*." The theory further holds that high profits will provide organisations with an incentive to expand output (Archer, 2010). This theory provided insight into why most municipalities are inefficient and incur losses or very little profit, which hampers their ability to grow and increase water service delivery to the people of this country. According to this theory, the researcher felt that most municipalities currently incurring high NRW losses are unable to grow because they earn very little return on investment; hence, they are unsustainable.

The Theory of Constraints was developed by Eliyahu M. Goldratt in 1984. The theory postulates that "*every system, no matter how well it performs, has at least one constraint that limits its performance, which is the system's weakest link (*Mabin, 2015)." According to Şimşit, Günay and Vayvay (2014) and Kihumba (2013), the theory states that "a constraint is any factor that limits the organisation from getting more of whatever it strives for, which is usually profit and the theory further says that a system can have only one constraint at a time, and that other areas of weakness are non-constraints until they become the weakest link". Based on the works of Goldratt (1999), this theory applies to the Hazyview in the City of Mbombela, where NRW is the most significant constraint for the success of the municipality because it eats into the profits of the municipality and reduces its capacity to have a reliable surplus, which can be reinvested in furtherance of water supply. Figure 2.1 shows the conceptual framework of the study.

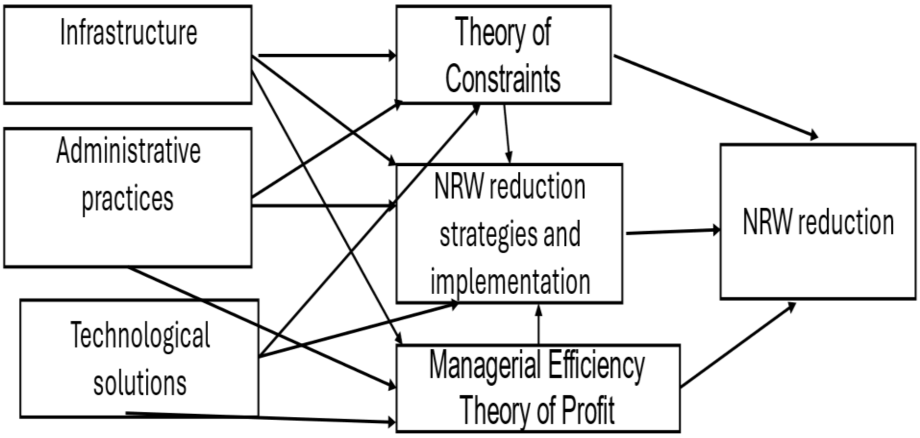

Figure 2-1: Conceptual Framework

Source: Own compilation (2025)

2.3 Factors influencing the level of non-revenue water

This section discusses factors influencing NRW.

2.3.1 Infrastructure and NRW

Water infrastructure is the system of physical structures and equipment used to manage water resources, encompassing the collection, treatment, storage, and distribution of water, as well as the collection, removal, and disposal of wastewater and sewage (Grigg, 2016). NRW is water that has been produced, treated, and pumped into the distribution system, but is "lost" before reaching the customer, generating no income for the utility (Ng'wigulu, 2025). In this section, the age and condition of infrastructure, maintenance practices, pressure management, unauthorised connections, and policy and regulatory aspects influencing infrastructure renewal in South Africa are discussed.

- **Age and condition of infrastructure**

Many water supply infrastructure systems have been in place for long periods and are frequently in need of upgrades (Mwangi, 2017). In addition, ongoing technological development renders the current infrastructure redundant and no longer meets consumers' needs and expectations. This is a significant challenge for water utilities, as a substantial amount of funds needs to be channelled towards renovations and construction. The US alone estimates that this procedure will require trillions of dollars in upgrades to drinking water infrastructure over the coming decades (Ma, Xue, González-Mejía, Garland & Cashdollar, 2015; Greer, 2020).

- **Maintenance practices**

According to Ngabirano (2017; Caplovitz, 2025), in low-income areas, average consumption is often substantially higher due to inadequate maintenance. Insufficient maintenance, especially of meters, results in high costs. Meter maintenance costs refer to the expenses incurred for operating and maintaining water meters after installation. A study conducted by SGS Economics and Planning (2011) found that the annual maintenance cost of a water meter is expected to be 15% of the purchase cost. This cost is particularly concerning, especially in Africa, where most municipalities operate on tight budgets. In South Africa, especially in Mpumalanga province, municipalities do not have enough budget to perform meter maintenance. Kihumba (2013; DRS, 2023) reported that a high level of Non-Revenue Water (NRW) threatens the sustainability of the majority of WSPs in the country, as they generate revenue from far less water than they produce, while operation and maintenance expenditure continues to rise. This has translated to declining revenues and, gradually, to poor service levels in both urban and rural areas. Municipalities face a significant challenge in maintaining a reliable water supply while also managing the interdependent electronic, mechanical, and software components of prepaid metering systems at each connection site and vending point (Heymans, Eales, & Franceys, 2014; Aribisala, 2021). Water infrastructure maintenance involves strategies like asset management systems and condition assessments to track and maintain equipment. Key practices include proactive measures such as preventative maintenance agreements, leak detection, pressure management, and regular component checks.

- **Pressure management**

Water pressure management involves controlling water pressure in distribution networks to reduce water losses, prevent pipe bursts, and save costs by adjusting pressure levels according to real-time demand (Adedeji, Hamam, Abe, & Abu-Mahfouz, 2018; Tian, Gao, Chen, Xie, Que, Munthali, & Zhang, 2023). Key techniques include using pressure-reducing valves (PRVs), dividing the network into District Metered Areas (DMAs), and employing hydraulic modelling to optimize pressure settings, which helps maintain adequate pressure for consumers while minimizing excess pressure during low-demand periods (Li, Shi, Chang, Zhang, Cui, Lu & Mao, 2025). Despite the importance of pressure management, many municipalities struggle with it. A study conducted by Walsh, Shai, and Mbangata (2019) reported that poor pressure management contributes to NRW when systems are used beyond their lifespan and when inappropriate types of systems are used for different purposes, for example, plastic pipes instead of steel pipes. Farley and Liemberger (2005; DRS, 2023) reported that the rate of leakage in water distribution networks is a function of the pressure applied by pumps or by gravity head. A physical relationship exists between leakage flow rate and pressure, as demonstrated by laboratory tests and field tests on underground systems. The frequency of new bursts also depends on pressure. Pressure management is therefore a fundamental element of a well-developed NRW strategy. If pressure is reduced, the rate of increase in leakage will reduce. This has implications for the level of leak detection resources required and for the flow rate from all leakage paths (bursts and background leaks).

- **Unauthorized connections**

A study conducted by Ngabirano (2017) and Ngcobo and Sibisi (2021) found that illegal connections and water theft affect the success of advanced metering. This is because a high rate of disconnection due to households exhausting their free basic water allocation makes illegal reconnection a popular strategy adopted by activists in South Africa (Bond & Dugard, 2008; Gonzalez, 2021). Illegal connections are a better option for consumers, as they are aware of the health risks associated with resorting to other water sources (Ayamba, 2019). Moreover, Ayamba (2019) found that due to the common delay by water service providers in addressing problems, people tamper with prepaid water meters and, in some cases, remove or break them. Therefore, it is crucial to comprehend unauthorized connections in relation to the municipality of Mbombela.

- **Policy and regulatory aspects influencing infrastructure renewal in South Africa**

The No Drop programme is one of the key regulatory tools the Department of Water and Sanitation (DWS) uses to regulate the WSA's performance in water loss and NRW management (DRS, 2023). At the same time, the National Water Resource Strategy Third Edition (NWRS-3) was published on September 1, 2023, by the Department of Water and Sanitation (DWS). It provides a framework for sustainable water resource management, focusing on security, equitable access, and economic growth. Key areas include managing infrastructure, climate change, and institutional capacity DWS, 2023a). Masia & Erasmus (2013) proposed a strategy observing water policy and water planning as the first two stages of the NRW strategy. According to Masia and Erasmus (2013), water planning provides a framework for establishing requirements that enable the water utility or authority to develop a water policy. Water policy examined the scope and boundaries of water demand management to achieve more efficient water use. Moreover, this required fixing targets and objectives to meet the policy and water resource utilization targets with results that could be measured.

The driving factors of NRW water (unbilled, metered, and unmetered consumption) were clearly identified in this strategy's water planning and subsequent water policy design. This also agreed with the incorporation of handling customer errors in data handling and meter accuracy, depicted in Farley and Liemberger’s NRW reduction strategy (Mbadamana, 2022). Abueitayef (2020) proposed the NRW strategy in 2017. This strategy focuses on two key parts, namely, investigating and assessing water losses, and planning and implementing the strategy. The strategy involves a dedicated provincial water authority (PWA) team to manage the national strategy. This includes approvals and funding allocations, monitoring, regulation, and liaison with service providers. Farouk *et al*. (2023) conducted a study on NRW reduction strategies. According to the study, there are three categories of NRW reduction strategies: (1)

decreasing apparent losses (AL), (2) lowering real losses (RL), and (3) reducing water losses, which involves combining RL and AL. Controlling water pressure and preventing water leaks are the most commonly used tactics. Alternative advantages of Water Distribution Network (WDN) rehabilitation over alternative RL-reduction techniques include improved reliability, enhanced hydraulic pressure performance, and water and energy savings. Lastly, the only method that can lower several NRW categories is the use of a Decision Support System (DSS). Policies and strategies to reduce NRW are available. However, Hazyview has excessive NRW, which is why this research is being carried out to qualitatively explore the infrastructure, metering, and administrative factors that contribute to NRW levels in Hazyview within the City of Mbombela.

2.3.2 Management and administrative practices

Administrative practices in water refer to the systems, policies, and decision-making processes that guide water resource management and service delivery, encompassing areas like regulation, planning, allocation, and stakeholder engagement (Katusiime & Schütt, 2020). In this section, administrative causes and management culture issues are discussed.

1) Administrative causes

- **Poor billing**

Ngabirano (2017) reported that several billing policy discrepancies require attention for the successful implementation of Water Management Devices (WMDs). Disparities in billing frequency, for example, are evident in Witsand Atlantis, where a family residing there for 2.5 years had received only 2 bills during this period, none of which they could afford to pay (Ngabirano, 2017). Exorbitant bills for some and none for others are additional disparities that occur in the Cape Town community. For example, interviews with City staff revealed that payment for water services for some residents in Site C of Khayelitsha, where WMDs are installed in newly built RDP houses, would only be required after the formalisation process and associated upgrades are completed (Ngabirano, 2017). In other areas, such as Mitchell's Plain, however, residents believe that WMDs charge higher bills, with some indigents claiming bills of up to R1,400 (approximately US$100) per month for homes with only one tap (Ngabirano, 2017). Various reasons, such as leaks, inherited debts from previous owners, or multiple people using the water, could explain these exorbitant bills (Ngabirano, 2017). However, the above varied experiences with billing not only amplify the worry of residents but also create more mistrust and reluctance to accept WMD installations in homes. It is also important to note that due to low literacy levels in some implementation areas, consumers are unable to comprehend the bills they receive and therefore cannot act on them. The City’s revenue streams from the WMD implementations could prove inconsistent and difficult to track as a result.

A study conducted by Kihumba (2013), Patrick, Nancy, and Adam (2025) reported that effective billing and collection systems, along with high billing and collection rates, are key tools for enhancing the revenue base of the utility, achieving financial viability and sustainability, and thereby registering improvements in the services delivered. This means that effective, efficient systems improve the municipality's financial position and could reduce NRW. While poor revenue collection efficiency is often blamed on customers, the utility may also be at fault for delayed and incorrect billing, inadequate responses to customer queries about billing, poor customer service, and a lackluster effort to collect overdue accounts (Kihumba, 2013).

- **Lack of metering policy**

According to Kihumba (2013) and Rehima (2022), it is common for poorly performing utilities to have low bill-collection rates due to weak enforcement and people's resentment of poor service. The Water Bylaws required the CoCT to issue two compliance notices before disconnection of one's water supply, with each notice specifying a time period for settlement of arrears (Ngabirano, 2017). Many municipalities issue notices to customers who fail to pay their water bills; however, the effectiveness of these notices often depends on whether consistent enforcement measures are implemented.

2) Management culture issues

- **Leadership**

According to Chea (2022), the successful implementation of NRW reduction strategies is squarely the responsibility of management. If management lacks the goodwill and support to implement the NRW-reduction interventions, the strategies are likely to fail. Management can support strategy implementation by allocating resources, training staff, providing reporting, benchmarking, and supervising the strategy implementation process to ensure the desired results are achieved (Chea, 2022). Management also plays a crucial role in staff motivation by recognizing work efforts aimed at achieving a desirable NRW level for their respective water companies (Chea, 2022). Water utilities can leverage their financial resources, human resources, strong organisational policies, dynamic organisational structures, and workers' commitment to implement effective NRW reduction strategies and achieve superior strategic performance (Chea, 2022).

- **Training**

Due to the more advanced skill sets required to ensure the smooth operation and maintenance of the additional hardware and software components of an AMR system, the need for maintenance contracts was realised as municipal staff were trained and equipped to handle these systems (Chanter & Swallow, 2008). In line with the above, municipal personnel responsible for managing metering schemes should be well-trained beforehand to ensure that these metering technologies, most of which are still in the early stages of development, can function efficiently (Ngabirano, 2017). To expand capacity, the National Water & Sewerage Company (NWSC) must computerize invoicing and develop a detailed customer database (Kihumba, 2013). Kihumba (2013) argued that introducing new tools and processes, backed by training courses and advice from both long- and short-term experts, is important.

- **Corruption**

The researchers investigated the causes of the high NRW in numerous locations worldwide through interviews (González-Gómez, García-Rubio, & Guardiola, 2011). They conclude that the primary causes are the absence of incentives for the management unit, the protection of commercial interests due to corruption, the ignorance of citizens who use the water, and a lack of political will (González-Gómez *et al.,* 2011). Mbadamana (2022) revealed that in countries such as Colombia, corruption and fraud are significant causes of NRW. Similarly, corruption among some meter readers is the leading cause of NRW in service areas (Kihumba, 2013).

- **Stakeholder engagement**

Most case studies have revealed that community involvement is crucial in changing attitudes towards advanced meters; therefore, extensive stakeholder engagement must be carried out before any new scheme roll-out (Ngabirano, 2017). Acting under the framework established by the National Water Act (NWA) are several stakeholders, and the Water Services Act (WSA) promulgated in 1994 defined the role of the then DWS as regulator, the role of water boards as bulk providers, and the role of municipalities as service providers (Weston & Goga, 2016). The varied political interests and landscape indicate that stakeholder engagement at all levels is necessary to ensure the political buy-in of both local and other community leaders (Hickey, McGilloway, O'Brien, Leckey, Devlin, & Donnelly, 2018). This will avoid the need for outsourcing of personnel, as was the case when the South African Municipal Workers Union (SAMWU) issued a press statement in November 2007 that condemned the forthcoming roll-out of these WMDs in Cape Town (Ngabirano, 2017), and also minimize issues of vandalism and mass protests against the WMDs.

2.3.3 Technological Innovations

Technological solutions for NRW include AI-powered leak detection and predictive maintenance, advanced sensors and smart meters for real-time monitoring, digital tools for modeling and optimizing networks, and advanced analytics to understand network performance (Mlewa *et al.,* 2025). In this section, the critical evaluation of global and South African examples, the cost-benefit for small towns, suitability for the South African context, integration with NRW management frameworks, and Limitations/barriers to adoption in low-resource municipalities are discussed.

- **Critical evaluation of global and South African examples**

Ngabirano (2017) evaluated four case studies: water management devices in Cape Town; prepaid meters in the iLembe District Municipality and Olievenhoutbosch; and automatic meter reading in the Epping Industrial Area in Cape Town. *Water Management Devices in Cape Town*. The City of Cape Town has been using water management devices to assist low-income consumers in managing their consumption since 2006, with over 160,000 devices installed. These water management devices have resulted in substantial savings in water consumption, but these meters were not found to be economically feasible. Thus, the additional cost of implementing advanced meters is a price the City of Cape Town is willing to pay to reduce consumption—*prepaid Meters in iLembe Municipality*. Prepaid meters were installed in iLembe in 2013 to improve revenue collection and reduce debt, but none of the anticipated benefits were realised. In particular, the scheme was found not to be economically feasible. The municipality faced numerous challenges in implementing the new advanced schemes, raising questions about the durability of the various advanced metering products and their underlying technology. These issues further emphasized the need for feasibility studies before advanced meters are installed.

Prepaid Meters in Olievenhoutbosch. In 2003, prepaid meters were rolled out in Olievenhoutbosch and some benefits obtained from the advanced meters, in large part due to the lower rates for users on the prepaid scheme compared to conventional schemes. Proprietary vending issues were one of the distinct challenges in utilising the scheme. The need to train sufficient municipal personnel to address any issues with the scheme was also recognised. The prepaid meters were not found to be economically feasible. Additionally, it was found that using conventional meters instead of advanced meters would have made the scheme economically feasible even at significantly lower payment rates*, such as automatic Meter Reading in the Epping industrial area*. Advanced Meter Reading technology was piloted in a metering scheme in Epping, Cape Town, in 2008. This case study focuses on industrial, not domestic, consumption, unlike the other case studies. The significant distinction this caused was that social feasibility did not play a role, and individual consumption for this scheme was much higher than in the other domestic cases. However, despite higher consumption rates, the advanced metering system remained prohibitively expensive and caused operational deficits for Cape Town. It was thus discontinued, and the area was returned to conventional metering.

- **Cost-benefit for small towns**

Reduced meter reading costs are achieved by requiring fewer meter readers, resulting in significant reductions in salaries, benefits, vehicle expenses, and other general expenses (House, 2010; Torriti, 2020). The study further reported that upon installation, a high failure rate of approximately 40% was observed, prompting the municipality to try about 4 different metering technologies to address and alleviate these failures. Despite this, the community was accepting of the system, and a significant reduction in consumption was observed, from approximately 40 kl per household to 7 kl per household. In addition, Ngabirano's (2017) study reported that financial benefits were achieved by reversing an annual loss of approximately R 540,000 to an average income gain of approximately R 320,000.

1) **Suitability for the South African context**

- **Vandalism**

A study conducted by Mwangi (2017) reported that the vandalism failure rate is the fraction of existing meters that fail due to vandalism. This examines the intentional acts taken to damage existing water meters. In South Africa, hostility to water metering arose when the community felt a sense of inequality after meters were installed in their region. In high-income areas, vandalism incidents are not as common (Mwangi, 2017). A study by Mwangi (2017) found that the typical vandalism failure rate was 1% per year, ranging from 0% to 3%. Unreliable meters are prone to vandalism, bypassing, and tampering (Heymans et al., 2014). Mpumalanga Province is a rural province with low-income areas; therefore, vandalism may be a significant issue. In addition, due to higher bills, particularly from higher sanitation charges, high instances of vandalism and tampering were reported, especially in cases where lump-sum bills or high debts were difficult for consumers to pay off (Ngabirano, 2017).

- **Maintenance capacity**

There is a shortage of staff to handle the increased meter failure rates and the consequent maintenance requirements, resulting in delayed responses to customer complaints (Yan, Qian, Sharif & Tipper, 2012). In most municipalities, there may be only one team trained to carry out prepaid meter repairs, so no backup capacity is available. Efforts to establish additional teams capable of handling these repairs seem necessary. (Ngobeni, 2016).

2) Integration with NRW management frameworks

The Logical Framework provides a linear, "logical" interpretation of the relationship between inputs, activities, outputs, outcomes, and impacts with respect to objectives and goals. It outlines the specific inputs required to carry out the activities or processes that produce specific outputs, resulting in specific outcomes and impacts. Logical Frameworks serve as the basis for monitoring and evaluation across all stages of a system (Ndege, 2016). Logical Frameworks are valuable tools for:

- Programme Planning and Development: The Logical Framework structure supports programme strategy, clarifying the programme's current stage and intended direction.
- Programme Management: through "connecting the dots" between resources, activities, and outcomes, a logical model can be used as the basis for developing a more detailed management plan. Using data collection and an evaluation plan, the Logical Framework helps track and monitor operations to manage results better. It can serve as the foundation for creating budgets and work plans.
- Communication: A well-built Logical Framework is a powerful communications tool. It can show stakeholders at a glance what a programme is doing (activities) and what it is achieving (outcomes), emphasizing the link between the two.

3) Limitations/barriers to adoption in low-resource municipalities

Barriers to meter adoption in low-resource municipalities include financial constraints (high upfront costs, lack of capital), institutional limitations (poor governance, insufficient infrastructure), technical challenges (integration issues, technological complexities), and socio-behavioural factors (lack of awareness, resistance to change, privacy concerns) (Hansen & Mullin, 2022). A general lack of supportive regulatory frameworks and policies often compounds these issues.

2.4 Knowledge, methodology, and context gaps

Farouk *et al*. (2021). Nasara, Zubairu, Jagaba, Azare, Yerima, and Yerima (2021). Shushu *et al*. (2021). Chea (2022) and Maloba and Matlala (2024) studied NRW. Farouk *et al*. (2021) investigated NRW reduction techniques. This investigation employed a systematic review methodology. Real losses (RL), apparent losses (AL), and water losses (RL + AL) were the three categories into which the discovered NRW-reduction solutions were divided. The two most commonly used tactics are water pressure control and leak prevention. Furthermore, compared to other RL-reduction techniques, WDN rehabilitation offers improved reliability, enhanced hydraulic performance, and water and energy savings. Finally, the only way to reduce several NRW categories is to use DSS. While in Nigeria, Nasara *et al*. (2021) evaluated the NRW management procedures. Nasara *et al*. (2021) discovered that real losses, apparent losses, network operation procedures, and performance improvement tactics are the main determinants of NRW management methods in the research area.

In this study, a quantitative research approach was used. Shushu *et al*. (2021) investigate NRW water management in Mwanza, Tanzania, a rapidly expanding city in sub-Saharan Africa. They discovered that a selected DMA had a higher NRW rate (50%) than the city's total network (37%). Approximately 52% of the entire network experienced pressure above the suggested threshold, whereas true losses in the DMA accounted for approximately 87% of the NRW. The observed leaks and pipe bursts in the DMA were caused by excessive pressure. Potential leaks were reduced to 46% by optimizing pressure with pressure-reducing valves and altering the network topology. Additionally, 83% of the pipes had insufficient flow velocity, resulting in stagnant water and poor water quality. Unplanned spatial and temporal development of the distribution network led to low velocities, which were exacerbated by enormous.

Chea (2022) examined the evaluation of the Kenyan water service provider's NRW reduction tactics. A mixed-methods approach was used in the investigation. The study's conclusions confirmed that Kenyan water firms are implementing all NRW reduction strategies. However, some tactics are more commonly employed than others. The survey results showed that the majority of Water Service Providers (WSPs) fully adopt seven NRW reduction initiatives. The results also showed that several reasons prevent NRW reduction initiatives from being fully implemented. Due to insufficient information to calculate the Incremental Cost Efficiency Ratio (ICER), the cost efficiency of the NRW reduction measures was not assessed. Maloba and Matlala (2024) compared the factors affecting NRW in Mpumalanga, South Africa. A survey approach was used in the study. The results show actual losses in all three towns. Damaged, burst, or leaking pipes, as well as storage overflows, are considered the leading causes of NRW. It follows that these studies primarily employed quantitative and mixed-methods research approaches. This research qualitatively explored the various contributors to NRW in Hazyview, focusing on infrastructure age, technological adoption, and management practices.

The framework by Farouk *et al*. (2023) aims to enhance the understanding of NRW and develop case-specific NRW programs. According to this framework, the key problems of the NRW components include apparent losses, real losses, and mix (water losses).

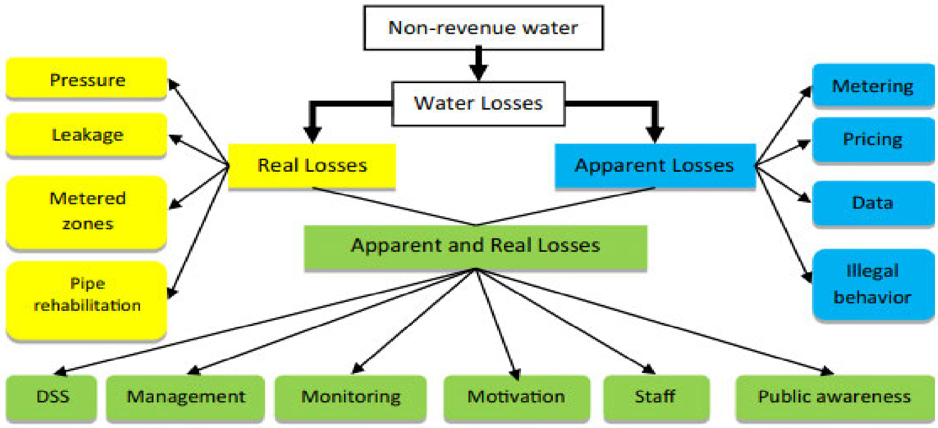

Figure 2-2: Strategies to reduce NRW

Source: Farouk et al. *(2023)*

- **Non-Revenue Water (NRW)**

Taha, Sharma, Lupoja, Fadhl, Haidera, and Kennedy (2020) indicated that either leakage or real loss (RL) in pipes, storage reservoirs, and customer connections accounts for water loss (WL), or apparent loss (AL) is caused by customer meter under-registration, billing, and data handling issues, or unauthorized use. Defects in the distribution system, such as network or connection leaks and water overflow in tanks or reservoirs, are the cause of WL, a particular physical loss. (Gupta & Kulat, 2018; Oberascher, Möderl & Sitzenfrei, 2020). NRW is the total of the volume of WL and unbilled authorized consumption (UAC), which is the authorized use that generated no income, including water used for network cleansing or firefighting (Taha *et al*., 2020). This indicates that NRW accounts for the water generated and subsequently lost before it is used by customers (Farouk *et al*., 2023). This refers to water that is not used or paid for, which impacts the institution's resources and financial health (Netshitanini, Adeeyo, & Edokpayi, 2023).

2.5 Conceptualisation of central research themes

The relationship among the identified factors considered crucial to the topic under investigation is illustrated by the conceptualization of the primary research questions. To determine whether they are related to NRW, this study assessed the infrastructure, water meter, billing information, administrative aspects, and consumer behaviour. As a result, the dependent variable is NRW, while the independent variables are customer, water meters, billing systems, and old infrastructure.

NRW includes water losses and unbilled authorized use, which are further separated into real (physical) and apparent (commercial) losses. Water distribution systems are more susceptible to leaks due to high pressure and old pipes in the distribution network. Variations in water use, customer connection growth and decline, water meter malfunction and reading errors, and other factors can affect NRW fluctuations. There are initiatives and policies in place to reduce NRW. However, Hazyview has excessive NRW, prompting the study to qualitatively explore the infrastructure, metering, and administrative factors contributing to NRW in Hazyview within the City of Mbombela. There were different views about technological solutions or innovations that could mitigate infrastructure-related NRW.

2.6 Conclusion

The comprehensive literature for the study, understanding infrastructural contributors to NRW, administrative practices that influence NRW levels, and technological innovations that could mitigate infrastructure-related NRW, such as advanced leak detection systems, is discussed. The next chapter outlines the qualitative methodology adopted to investigate the infrastructural, administrative, and technological factors influencing NRW in Hazyview.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In Chapter 2, the literature review on the theoretical framework and Non-Revenue Water (NRW) was presented. In this chapter, the research methodology focuses on the research process and the tools and procedures to be employed (Mouton, 2001, p. 56). The study aims to determine the factors influencing NRW levels in Hazyview within the City of Mbombela. The following specific objectives of the research are: to understand the main infrastructural contributors to NRW in Hazyview; to understand administrative practices influencing NRW levels; and to explore technological innovations that could mitigate infrastructure-related NRW, such as advanced leak detection systems in Hazyview, City of Mbombela, Mpumalanga.

Figure 3.1 outlines the research model used in this study. In the next section, the research process will be discussed in more detail, beginning with the research paradigm and methodology, which include the research purpose, philosophy, methods, and strategies. This is followed by the research design, which focuses on the population, sampling, and data collection instruments for collecting and analyzing data on municipal workers and water stakeholders in Hazyview, within the City of Mbombela. The chapter concludes with a discussion of the study's trustworthiness, ethical compliance, limitations, and delimitations.

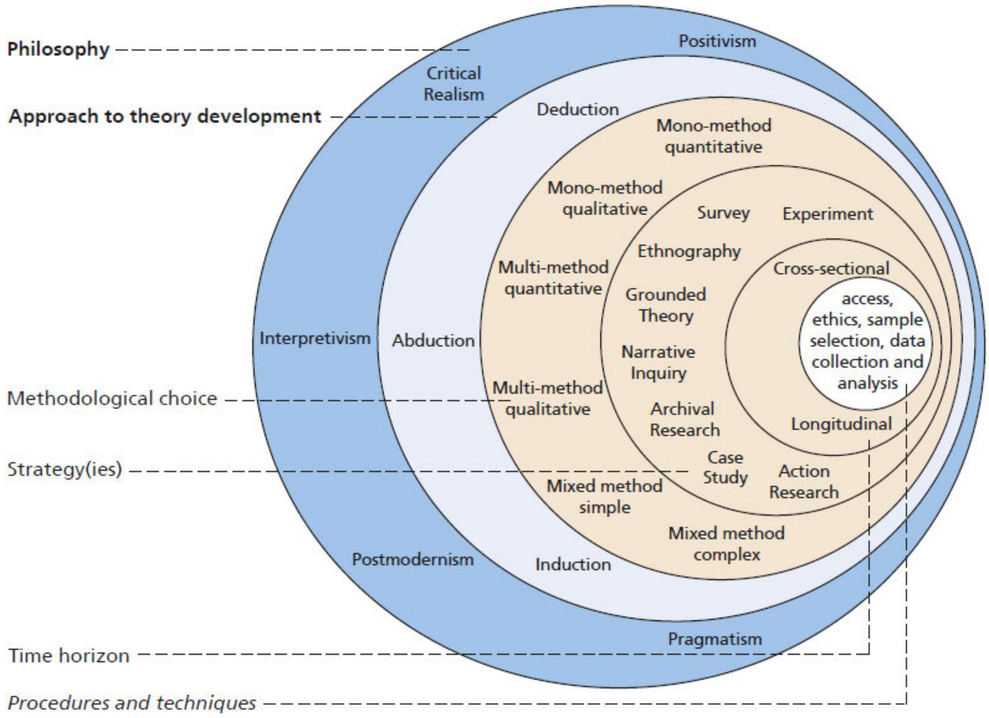

Figure 3-1: Research Model

Source: Saunders, Lewis, and Thornhill (2023:131)

3.2 Research paradigm

According to Rehman and Alharthi (2016), a research paradigm is a fundamental philosophical framework that encompasses a set of presumptions about technique, process, ontology, and epistemology. It determines how people perceive, understand, and interpret the world and its associated components to acquire knowledge and investigate qualitatively the administrative, water metering, and infrastructure elements that contribute to NRW in Hazyview, within the City of Mbombela. An interpretivist paradigm was used for this study. According to an interpretivist paradigm, humans must experience reality firsthand because it cannot be objectively observed from the outside (Ganiyu, Ebohon, & Ajayi, 2021). Instead of testing pre-existing hypotheses, an inductive approach is more appropriate, as it permits theories and explanations to emerge from the data. The interpretivist paradigm prioritizes an in-depth, subjective understanding of multiple realities within a specific context, unlike the objective and generalizable approach of positivism or the pragmatic focus on what works best to solve a problem (Omodan, 2024). It acknowledges the complexity of human behaviour and the researcher's role in interpreting meanings, making it more suitable for social sciences and areas where deep contextual insight is crucial (Omodan, 2024).

This study employs an interpretivist approach to investigate and understand how municipal staff reduce NRW. Interpretivists believe that reality is subjective and shaped by individual experiences, and that multiple realities are socially constructed (Creswell & Poth, 2016). The primary goal of interpretivism is to comprehend the subjective meanings and interpretations that individuals assign to their experiences and the social world around them (Alharahsheh & Pius, 2020). Within the interpretivist paradigm, ontology refers to the nature of reality (Sprake & Palmer, 2022), and what of the participant's subjective reality can be known when they manage water in their municipality. Epistemology refers to the nature of knowledge (Guba & Lincoln, 1994), in which participants construct their own understanding, while administrative practices influence NRW levels. The focus lies in interpreting data within its specific context, as the epistemological position reflects a view about how knowledge can be attained and/or claimed (Creswell & Poth, 2016).

From an interpretive paradigm, the study collected qualitative data from participants and is concerned with the potential to contribute to educational programs and workshops aimed at improving understanding and implementing technological solutions or innovations that could mitigate infrastructure-related NRW, such as advanced leak detection systems.

3.3 Qualitative approach

To qualitatively explore the infrastructure, metering, and administrative factors perceived by staff that contribute to NRW in Hazyview, within the City of Mbombela, a qualitative research approach was adopted. This is because the study explores perceptions and experiences of municipal staff; qualitative inquiry is most suitable. Consistent with the interpretivist paradigm, qualitative studies focus on how people construct their worlds, interpret their experiences, and attribute meanings to those experiences (Creswell & Creswell, 2018). The adoption of a qualitative research approach is best suited to this study because it is primarily concerned with discovering and understanding the research problem from the participants' perspectives (Aspers & Corte, 2019). Since the qualitative research approach yields detailed descriptions of participants' feelings and experiences, it enabled the researcher to address the research questions comprehensively. Moreover, the qualitative method proved useful for describing problem areas in water resources or the environment. Thus, this study followed a qualitative approach to collect primary data from traders, using in-depth interviews and semi-structured questionnaires to generate loosely structured, verbal data useful for identifying problem areas in water resources management.

3.4 Research strategy

This study employed interpretivism, using semi-structured questionnaires with municipal workers and focus groups with water consultants, members of the water committee, and business and community forum members in Hazyview, within the

City of Mbombela in Mpumalanga Province. The study began with interviews, followed by focus groups, and then document review.

3.5 Time horizon

In this research, the time horizon was cross-sectional. A cross-sectional time horizon is defined as the study of a specific phenomenon at a particular point in time and the collection of qualitative data during the same period (Saunders et al., 2023, p. 201). Salkind (2018: 200) stated that the cross-sectional approach enables the investigation of a problem from the perspective of different individuals at a single time point. A cross-sectional approach facilitated the discovery of qualitative infrastructure, metering, and administrative factors that contribute to NRW in Hazyview, within the City of Mbombela. Data collection was done between May and June 2025. Although NRW can fluctuate over time, this study employed a cross-sectional design due to resource and time constraints, and therefore provides a snapshot rather than trends.

3.6 Research design

Figure 3.2 depicts a research design flow diagram**.** The unit of analysis for this study was municipal staff and stakeholder groups**.**

Figure 3-2: Research Design Flow Diagram

Source: Own compilation (2025)

A research design is a strategy for carrying out a scientific project (Saunders *et al.*, 2023). Consistent with the qualitative study approach and interpretivist paradigm employed in this study, an exploratory design was adopted. Simon (2009) points out that an exploratory study provides an in-depth examination of content from varied perspectives, acknowledging complexity and uniqueness. Consistent with the research approach and the primary research question of this study, which is to explore the nature of infrastructure, metering, and administrative factors contributing to NRW in Hazyview within the City of Mbombela, an exploratory research design is best suited for this research.

3.7 Population

The population for a study is the group (usually people) about whom a researcher wants to conclude (Babbie, 2016, p. 116). The population in Hazyview, within the City of Mbombela, was selected for this study. The twelve units of analysis for focus groups (Table 3.1). Participants are those from whom enough rich, information-dense data can be collected to answer the research questions, often reaching a point of data saturation, where adding more participants yields no new insights (Ostenson, 2025). While twelve participants were interviewed, documents, including policy documents, previous NRW reports, and operational data from the water systems, were analyzed.

Table 3-1: Sampled participants

Focus group	Municipal staff	Consultants	Community
N	7	2	3
Interviews	Water and sanitation	Billing section	Water services development and planning
N	5	3	4

3.7.1 Sampling and Sample sizes

A purposive sampling strategy (criterion-based purposive sampling and maximum variation) was adopted to achieve the objectives of this study. According to the purposive sampling approach, the researcher selected a specific set of individuals as the study's population, in line with the intended results (Creswell & Creswell, 2018). Moreover, Patton (2023) explains that purposive sampling is the process of selecting cases with a wealth of information for a thorough investigation when one wishes to learn more about those situations without needing to or wanting to generalize to all of them. Purposive sampling is done to increase the utility of information obtained from a small sample.

Regarding document analysis, Bowen (2009) defines it as a systematic process for reviewing or evaluating documents, including both electronic and printed materials, to generate meaning, gain understanding, and develop empirical conclusions. For this study, the researcher reviewed policy documents, previous NRW reports, and operational data from the water systems. Moreover, the WC/WDM strategy, water tariff policy, water bylaws, Hazyview water balance, Hazyview billing, and water meter information were reviewed. This information is publicly available on the municipality's and DWS's websites.

3.7.2 Data collection techniques

The data collection method defines the strategies used to systematically gather information on variables of interest, enabling the researcher to answer formulated research questions (Kabir, 2016) comprehensively. This study employed document analysis, focus groups, and semi-structured interviews to collect data from purposefully sampled participants. Participants answered questions based on demographic information, aged infrastructure, water meters, billing systems, cost-effectiveness, extent, effects, and implications of NRW, as well as administrative factors.

- **Semi-structured interviews**

Maree (2007) asserts that an interview is a two-way dialogue that yields rich descriptive information, helping the researcher comprehend how the participant constructs their knowledge and social reality. In accordance with the qualitative methodology employed in this research, twelve municipal employees from water infrastructure, finance, and administration, ranging from supervisory to management level, participated in semi-structured interviews to gather primary data. Semi-structured interviews are ideal for this study because they enable the researcher to examine participants' data and supporting information in depth while remaining mindful of the study objective (Ruslin & Alhabsyi, 2022).

3.8 Data analysis

A thematic data analysis approach was employed in this study (Alhojailan, 2012). In addition to discovering meanings through interpretation, thematic analysis helped illustrate the data in detail. Alhojailan (2012) maintains that thematic data analysis provides a systematic approach to analyzing data while contextualizing it without pre-existing themes. The data were analyzed manually because the researcher felt it was manageable. Manual analysis of qualitative data provides deeper insight, flexibility, and a better understanding of nuance, enabling researchers to develop a close, reflexive relationship with the data, identify subtle meanings, and remain adaptable throughout the research process (Lim, 2025). This method fosters meticulous examination, strengthens the validity of the analysis (Koli, 2024), and helps ensure findings accurately represent participant perspectives, even though it is more time-consuming than automated analysis. The steps followed in the analysis of data collected through semi-structured interviews, focus groups, and document analysis are:

Step 1: The researcher familiarized himself with the data collected

Step 2: Generating initial codes

Step 3: Searching for themes

Step 4: Reviewing potential themes

Step 5: Defining and naming themes

Step 6: Producing the report

The researcher organised the data collected during interviews and arranged it in a logical order. The researcher then categorised the data, taking information and converting it into a format that facilitates analysis. The interpretation of specific documents, occurrences, and other data was examined for their intended meanings. The information and interpretations were scrutinized for underlying themes and other patterns that characterize the case more broadly, and the overall portrait of the case was constructed (Leedy & Ormrod, 2014).

Therefore, the thematic analysis followed a structured process to identify patterns in the qualitative data. It started with familiarisation, where the researcher immersed herself in the data by reading and taking initial notes. Next, code systematically labelled key data features inductively (data-driven) or deductively (theory-driven). These codes were then grouped into broader themes, meaningful patterns were identified, and hierarchical relationships were considered. The themes were reviewed for coherence and refined by merging, splitting, or discarding as needed. Once finalised, themes were defined and named with clear explanations. Finally, in the interpretation and reporting phase, themes were contextualised within the research question and existing literature.

In addition, percentages were used. Occasionally, qualitative research involves statistics or percentages, as these convey the essence a researcher is seeking to convey (Merriam & Grenier, 2019). For instance, an assertion may appear more credible and trustworthy if it shows that 75% of the focus group felt that, rather than the majority of the group, as it is far more direct (Merriam & Grenier, 2019; Nassaji, 2021). The percentage was used in the demographics section. Interviews, focus groups, and document data were triangulated and explained in Chapter 5. The results are reported collectively based on the themes that emerged from the qualitative data generated through each of the three methods, in relation to the study's objectives.

3.9 Trustworthiness

Validity refers to the extent to which an instrument measures what it is intended to measure (Leedy & Ormrod, 2014, p. 89; Collis & Hussey, 2014, p. 53). This study focuses on individuals who have experienced NRW. Validity comprises external and internal validity. External validity refers to the extent to which the conclusions drawn from the research findings can be generalised to the population as a whole (Salkind, 2018, p. 187). The results of this study can only be generalised to Hazyview, within the City of Mbombela. However, the findings of this study can apply to a similar setting. Table 3.2 presents the study's trustworthiness.

Table 3-2: Trustworthiness in the study

Member checking	Audit trail	Peer review,	Reflexivity
Yes	Yes	Yes	Yes

3.9.1 Credibility

In qualitative research, credibility refers to the believability of the study's findings from the participants' viewpoints (Creswell, 2014). In this study, the following strategies were employed to promote credibility. The participants were carefully selected to ensure they had the relevant knowledge and experience to give credible information. During the semi-structured interviews, with consent, an audiotape was used to record the interviews verbatim, ensuring more accurate transcripts for analysis. Before data collection, participants were informed of the research's purpose and procedures. Member checking, as referred to by several scholars (Lincoln & Guba, 1985; Creswell, 2014), was also done. The use of varied data-collection methods and instruments enabled the researcher to cross-validate responses, thereby enhancing the credibility of the results.

3.9.2 Dependability

According to Leedy and Ormrod (2014), this is the state of being dependable and trustworthy. When authentic and reliable, interpretive research can be trusted (Neuman, 2012). The researcher depended heavily on consistency as the main measure of reliability. This means that the same study procedure applied to a particular phenomenon can be repeated under the same conditions and yield the same results (Neuman, 2012). Since this study adheres to all pertinent research methodologies, other researchers may use different data and research techniques to reach the same conclusion.

3.9.3 Conformability

This is the section where the research's conclusion can be independently verified by the participants (Korstjens & Moser, 2018). Participants' data served as the foundation for the research's conclusion. The researcher ensured that every participant's input was taken into account, even when they disagreed.

3.9.4 Transferability

Transferability refers to the extent to which the results of qualitative research can be applied in various situations or environments (Creswell, 2014). Study participants from various municipal contexts will be able to relate to it in the same way (Lincoln & Guba, 1985). Because it addresses problems frequently encountered, the research presented here will apply to various municipal contexts.

3.10 Ethical consideration

During data collection, the following ethical considerations were followed:

Maree (2007) maintains that throughout the research process, the researcher should adhere to and follow ethical guidelines. To ensure that all data collection methods were ethical, the study adhered to a professional code of conduct that safeguards participants' safety (Fleming & Zegwaard, 2018). Even though it might be difficult to do so, recognizing it and using techniques such as reflexivity, peer debriefing, and triangulation can lessen its impact and ensure that study results are an objective and accurate reflection of participants' viewpoints. The following ethical principles were adhered to:

- **Informed consent and voluntary participation**

The researcher obtained written and verbal informed consent from all participants (Maree, 2017) prior to data collection, ensuring their availability and willingness to participate in the research process, specifically the semi-structured individual interviews and document analysis. The researcher presented participants with a consent letter on the first scheduled data collection date, which briefly explained the research process. During this engagement, participants gained clarity on the research process and signed the informed consent form. It is also important to note that participants were reminded that their participation is voluntary and that they may withdraw at any time without penalty.

- **Protection from harm**

The researcher made every effort to ensure that participants' participation in the study was free of any possible undue physical or psychological harm.

- **Privacy, confidentiality, and anonymity**

The data collected from the participants is kept confidential, and the results of this study will be shared anonymously to protect their identities. The data was securely stored in a lockable cabinet and on the hard drive of a computer for 15 years. In addition to the ethical aspects discussed above, this research study was conducted in accordance with the institution's ethics and clearance code.

The researcher is stationed at the Head of Office of the City of Mbombela in the Technical Department, and participants are not his subordinates; they hold various roles and responsibilities within the technical, administrative, and finance sections of the Hazyview office. The researcher intends to maintain a professional relationship during and after the meetings, which was addressed during the introductions.

3.11 Limitations and delimitations of the study

The study was limited to municipal workers at the supervisory and management levels in the water infrastructure, finance, and administration sections of Hazyview, under the City of Mbombela in Mpumalanga. Some of the participants were too busy or unavailable. The study was limited to Hazyview, in the City of Mbombela, Mpumalanga.

- Limitations: insider bias, limited generalisability, cross-sectional design, participant availability.
- Delimitations: geographic scope (Hazyview only), thematic scope (NRW not full water management).

3.12 Conclusion

In this chapter, the research process followed was explained. A discussion of the research methodology and design employed in this study was provided. The discussion started by focusing on the research methodology, including the research purpose, philosophy, methods, and strategies. This was followed by the research design, which focuses on the unit of analysis, population, sampling, data collection instruments, and data analysis, examining the factors influencing the level of Non-Revenue Water in Hazyview Town, Mbombela, Mpumalanga Province, South Africa. In Chapter Four, the presentation, interpretation, and discussion of the results are provided.

CHAPTER 4

RESEARCH FINDINGS REPORTING AND DISCUSSIONS

4.1 Introduction

This chapter presents the results obtained from participants in the Hazyview water supply system and documents in Mbombela, South Africa. The results reported include transcribed responses from a semi-structured interview guide, modified focus group discussions, individual interviews with purposively selected participants, and document analysis. These research tools were used to analyze the factors (infrastructure, metering, and administration) influencing Non-Revenue Water levels in Hazyview Town, South Africa. First, the findings obtained from participants through the three data collection tools were presented separately. The raw data from each group of respondents were transcribed and then analysed using an inductive coding process, which involved segmenting the text into meaningful sections, categorising the information, and developing descriptions, broader themes, and the final themes that emerged from the data. The results are reported collectively based on the themes that emerged from the qualitative data generated through each of the three methods. The discussion started with a focus on the demographic characteristics of the sampled participants, followed by the presentation of results aligned with the study's secondary objectives.

This chapter presents findings from semi-structured interviews, focus group discussions (FGDs), and document analysis. Data were transcribed, inductively coded, and organised into themes aligned to the study’s secondary objectives (infrastructure, metering, and administrative factors influencing NRW). The study first describes the sample, then presents themes from interviews, FGDs, and documents. A cross-source synthesis highlights convergences/divergences and links findings to the literature reviewed in Chapter 2. The chapter concludes with an integrated discussion that aligns with the research objectives.

4.2 Sample profile (staff & stakeholders)

Table 4.1 depicts the themes and subthemes that emerged from this study regarding staff and stakeholders. The themes and subthemes were discussed in this chapter.

Table 4-1: Themes and Subthemes of the participants

Theme	Subthemes
Examples of infrastructure failures that lead to NRW	Water leakage; unmonitored water levels (overflowing); illegal connections; meter tampering; meter reading not done correctly; stuck meters; aging infrastructure
Failure frequency	Over five times per week
Maintenance practices to prevent infrastructure-related NRW	Inspections; prompt response to leakages; Replacement of faulty and unauthorized meter connections; installation of Pressure Reducing Valves (PRV) and air valve
Administrative procedures to reduce NRW	Customer education programme; bylaws enforcement; WC/WDM strategy in place
Monitoring and managing NRW challenges	Budget constraints; Unauthorized water connections; meters not replaced on time; lack of accurate meter data; lack of skilled staff
Staff training and supervision linked to NRW management	Lack of supervision; lack of training on meter readings
Technologies to monitor or reduce NRW	Supervisory Control and Data Acquisition (SCADA)
Barriers preventing the adoption of advanced technologies	Budget
Success stories or failures with technological interventions	

In this section, the demographic profiles of the staff and stakeholders are discussed. It covers gender, age group, highest level of education, race, section name, and designation.

Table 4-2: Demographics of the two groups of respondents (n=12)

Demographics	***Individual interviews***	
	N	**%**
Gender		
Male	3	25
Female	4	33
Other	5	42
Total	**12**	**100.0**
Age group		
18-35	3	25
38-65	9	75
Total	**12**	**100.0**
Highest level of education		
Grade 12	0	0
Diploma	9	75
Degree	1	8
Honours degree	2	17
Total	**12**	**100.0**
Race		
Black	**12**	**100**
Total	**12**	**100.0**
Name of section		
Water and sanitation	5	42

Billing section	3	25
Water services development and planning	4	33
Total	12	100.0
Designation		
Admin	5	42
Senior Engineering Technician	3	25
Assistant Accountant	1	8
Plumber	3	25
Total	12	100.0

Gender: Other accounted for 42% of the realised sample in the individual interviews (Table 4.2). This was followed by females with 33%, and only 25% were male. This indicated that the distribution of gender among the sampled participants is skewed towards the other (participants did not specify). The reason for others not specifying could be that they are classified under Lesbian, Gay, Bisexual, and Transgender (LGBTQ) and experience discomfort in social situations. A study conducted by Mohale & Thobejane (2018) in Mpumalanga reported that LGBTI people face considerable levels of stigmatization, discrimination, and harassment in their daily lives. These challenges have a negative impact on the lives of LGBTI youth and also bring various emotions, which include intense sadness, anxiety, loneliness, and discomfort in social situations.

Age: The distribution of respondents by age group was more representative of older respondents (80% aged 36-65 years) than of younger respondents (18-35 years). These findings are not aligned with Chea (2022), who links water usage to those aged 40 years and below.

Education: Over half (57%) of the participants had only a diploma education, while a further 29% had an Honours degree, and only 14% had a bachelor's degree. These findings align with Chea (2022), who shows that participants with a diploma in education. The results indicate that the participants were knowledgeable about NRW management, as 71% (57 plus 14) had at least a three-year qualification, which is a prerequisite for working as a Technical Manager, Commercial Manager, or NRW Officer, who is instrumental in managing NRW in water companies.

Race: All respondents were black (Table 4.1). The population of Mpumalanga is predominantly black, in line with the national distribution.

Name of section: About the name of the section, most of the respondents (42%) were working in water and sanitation (Table 4.1). This study focused on NRW, and the section deals primarily with water, which is relevant.

Designation: The majority of respondents were administrative staff, followed by senior engineers. This is not surprising, since most participants had 3-year qualifications.

4.3 Interview findings

In this section, interview findings were presented and discussed. These included themes, quotes, and mini-interpretations.

- **Infrastructure failures that lead to NRW**

Seventy percent of participants perceived water leakage, illegal connections, and meter tampering as significant examples of NRW infrastructure failures. This means that there are illegal connections in the municipality. Illegal connections cause more damage to infrastructure than just non-revenue loss. It often leads to leaks and bursts in the infrastructure. These results are similar to those found by Ngabirano (2017), which show that Illegal connections affect the success of advanced metering.

P6:

> "*I must say examples of infrastructure failures that lead to NRW include broken water pipes, leaking meters, meter inaccuracy, aging infrastructure, e.g., old pipes and valves, as well as overflowing reservoirs.*"

- **Failure frequency**

Sixty percent of participants mentioned that infrastructure failures occur more than five times per week. This means that a bulk water resource infrastructure is struggling to cope with increased demand and is poorly maintained, making it vulnerable to failure. Mwangi's (2017) study revealed that aging infrastructure, such as numerous water supply systems, has been in place for long periods and is frequently in need of an upgrade. In addition, ongoing technological development renders the current infrastructure redundant and no longer meets consumers' needs and expectations.

P6

> "*We experience these failures as often as more than five times per week. Burst pipes and leaking meters are often reported, and leaks from old pipes occur occasionally. Also, overflows are not as frequent*".

- **Maintenance practices to prevent infrastructure-related NRW**

Participants agreed that most maintenance involves replacing faulty or unauthorized meter connections. Heymans, Eales, and Franceys (2014) reported that a performance audit of prepaid meters in Mogale, conducted 8 years after installation, revealed that 90% of the meters were faulty due to water meter failure, vandalism, and issues with electronics and other components.

P6

> "*The maintenance team and team on standby try to fix leaks and burst pipes as soon as they are reported. Reservoirs and tanks are closely monitored to prevent overflows, and malfunctioning valves and meters are replaced as soon as they are detected*".

P10

> *"Some of the maintenance practices include PRV. In terms of stuck meters, the billing department has identified all the stuck meters and has reported this to the technical department in order for these meters to be replaced".*

This means the pressure-reducing valve (PRV) must be maintained, as failure could cause damage. A leaking PRV may result in water damage, reduced water pressure, and safety hazards, such as system failure or explosion (Cană, Ripeanu, Diniță, Tănase, Portoacă & Pătîrnac, 2025). A study by Creaco and Walski (2017) found that PRV impacts include reduced system efficiency, increased operational costs, and potential damage to pipes and fixtures.

- **Administrative procedures to reduce NRW**

Participants agreed that the following are not active: the customer education programme, bylaws enforcement, and the WC/WDM strategy implementation. The reason for the lack of effectiveness of bylaws enforcement could be that the Court Roll is not sufficiently populated. Regarding the customer education programme and the WC/WDM strategy, one reason could be the municipality's capacity.

P4

“*Bylaws enforcement and meter reading are not effective*”.

- **Monitoring and managing NRW challenges**

Participants agree that the challenges of monitoring and managing NRW include budget constraints, unauthorized water connections, delayed meter replacements, inaccurate meter data, and a shortage of skilled staff. This implies that the municipality faces numerous factors in monitoring and managing NRW. These results are similar to those reported by Ngabirano (2017), which show that key challenges include water loss due to leaks, broken infrastructure, and billing system failures, as well as a lack of adequate skills to maintain the water infrastructure.

P6

“*Lack of accurate data and meter readings is a challenge that administrative teams face. A shortage of skilled staff is needed to reduce and manage NRW. Moreover, corruption is also a challenge because the public resorts to illegal connections or bypasses meters to avoid water bills*.

- **Staff training and supervision linked to NRW management**

Almost all participants reported a lack of supervision and training in meter readings. These results are supported by Mbadamana (2022), which shows that poor worker training and the lack of application of the latest technologies for leakage management are among the major contributors to unbilled and unmetered water.

P3

“*There is no link between staff training and management of NRW*”.

- **Technologies to monitor or reduce NRW**

Eighty percent of the participants agreed that SCADA is available but not yet fully implemented. The reason SCADA may not have been implemented could be the municipality's capacity, including the availability of trained staff with the relevant skills to operate this system. In a water system, SCADA stands for Supervisory Control and Data Acquisition. It is a computer-based system that utilizes hardware and software to remotely monitor, control, and collect real-time data from equipment such as pumps, valves, and sensors throughout the entire water network (Rao, Chakravarthi, & Jawahar, 2017). This allows operators to manage processes such as water quality, filtration, and distribution from a central location (Kumar, Metwally, Ashraf & Thamineni, 2023).

P6

> *Currently, control valves are used to monitor and regulate water pressure in the Hazyview distribution networks. This helps to reduce leaks and burst pipes. Data analytics is also used to monitor water levels, making it easy to detect leaks (unexplained water level drop*s).

- **Barriers preventing the adoption of advanced technologies**

All participants agreed that the budget is a barrier preventing the adoption of advanced technologies.Implementing an infrastructure meter involves costs for the meter, installation, and communication technology, with budgets influenced by the type of meter (e.g., smart meters, prepaid meters), the scale of the project, and the chosen provider (McHenry, 2013).

P6

“*Financial barriers such as high costs and the cost of implementation can prevent the adoption of advanced technologies. Organisational barriers, such as a lack of skills to manage and implement changes, employee resistance to change, and a lack of digital literacy, can also prevent employees from using technologies*.

- **Success stories or failures with technological interventions**

Most participants mentioned prepaid meters from other municipalities. Participants referenced experiences from nearby municipalities in Limpopo province. Mwangi (2017) revealed that a prepaid meter is a water meter that uses an in-built control system to control water consumption based on the amount of water paid for. A consumer pays for the amount of water upfront from a teller and is given an input code, which is then entered through the prepaid meter user interface. The processor then reads the code and activates the valve to release the purchased volume of water. Once the volume exceeds the amount paid for, the processor then turns off the valve, and the process is repeated.

4.4 Focus group findings (theme & quotes)

In this section, interview findings are presented and discussed. These include themes, quotes, and mini-interpretations.

- **Themes for focus group**

In this section, the themes and subthemes that emerged from the focus group are discussed. Table 4.3 presents the themes and their corresponding subthemes.

Table 4-3: Themes and Subthemes of focus groups

Theme	Subtheme
Infrastructure-related causes of NRW	Bypass connections, many contractors, stuck meters, bypass meters, and old infrastructure.
Maintenance strategies for addressing leaks and pipe bursts	Replace old meters with new meters, old information, and infrastructure
Technologies or innovations to reduce NRW	Real-time monitoring and leak detection.
Municipality challenges in adopting advanced leak detection systems	Funding, length of places, and the old meter model.
Integrated technology with administrative systems to improve NRW management	Smart Water Management (SWM)
Administrative practices	Smart meter reading and billing, and administer finance.
Weak administrative process contributes to water losses	Not proper meter monitoring and response to water leaks.
Collaboration of stakeholders to improve NRW management	Forum meetings on water uses.
Impact policy changes or investments	Bylaws implementation
Training or capacity-building addressing administrative inefficiencies	Meter training

- **Sampled population participants (focus group interview)**

In this section, the demographic profiles of the staff, consultants, and community are discussed. It covers only participants' gender. This is because participants were unwilling to share personal information during the focus group interview.

Table 4-4: Sampled population participants (focus group interview) (n=12)

Demographics	**Focus groups**	
	n	%
Gender		
Male	7	58
Female	5	42

Total	**12**	**100.0**
Representative		
Municipal staff	7	58
Consultants	2	17
Community	3	25
Total	**12**	**100.0**

Gender: Males accounted for 58% of participants in the realised focus group. These findings aligned with Kihumba (2013), who shows that the distribution of gender among participants is skewed towards males.

Representative: Municipal staff constituted 58% of sampled participants. This was expected, since the study focused on NRW and municipal staff handle water issues daily.

Infrastructure-related causes of NRW

Participants agreed that infrastructure-related causes of NRW include bypass connections, the presence of many contractors (which affects leak run times and data integrity, especially when contracts expire and replacements are time-consuming), stuck meters, bypass meters, and outdated infrastructure. These results are similar to those found by Kihumba (2013), which show that a large percentage of respondents (71.4%) attributed NRW to commercial causes such as illegal connections/water theft, unmetered public consumption, metering errors, unbilled metered consumption, and water use for which payment is not collected.

Municipal staff

P3

> *"The main problem in our municipality is the illegal water connections and old infrastructure. The municipality contracts one contractor after another, which really creates confusion"*.

Community P8

> "*People tamper with meters; this makes meters stuck, especially because pipes are very old. It is very concerning that these result in water leaks affecting other infrastructure, such as roads, in my area*".

Consultant P4

> *"Ageing infrastructure is something that municipality fails to address. This leads to pipe bursts and recurring water leaks".*

- **Maintenance strategies for addressing leaks and pipe bursts**

Participants indicated that the current maintenance strategies are not drastically addressing leaks and pipe bursts. These results are similar to those reported by Martins, Poleto, Jerônimo, and Batista (2017), who found that NRW resulting from physical losses from leaking and broken pipes may reflect failures in commercial operations to link with other components, which may also be due to poor operations and maintenance.

Municipal staff P2

> *"Municipality still uses old information and infrastructure for meters".*

Consultant P7

> *"The operational and maintenance section of the municipality contracted service providers to attend to emergency and planned maintenance".*

- **Technologies or innovations to reduce NRW**

All participants agreed that real-time monitoring and leak detection are technologies or innovations to reduce NRW. These results are similar to those reported by Mwangi (2017), which show that real-time data aided leak detection and enabled customer service representatives to answer questions about water consumption quickly.

Municipal staff

P1

> *"We are aware that technological solutions to reduce NRW are available, such as meters, consumption data, sensors, and pressure gauges, which provide real-time water flow and pressure. However, the old infrastructure makes it difficult to use some of these technologies"*.

- **Municipality challenges in adopting advanced leak detection systems**

Many participants indicated that funding is the main challenge in adopting advanced leak detection systems. While the effectiveness of advanced leak detection is apparent, funding is indeed a significant barrier to its widespread adoption (Farah & Shahrour, 2024), often alongside the lack of technical expertise and the difficulty in integrating new systems with existing infrastructure. However, the potential benefits, such as preventing water damage, conserving resources, and reducing costs associated with leaks, provide strong incentives for investing in these technologies, with the market for smart water leak detectors showing steady growth as more users recognize their value (Xu, Liu, Chen, & Li, 2014).

Municipal staff P3

> *"The funding is always a problem when one wants to explore advanced leak detection systems".*

- **Integrated technology with administrative systems to improve NRW management**

Many participants indicated that SWM helps transform shifts in urban water management by integrating advanced digital technologies. Smart water management leverages technologies such as IoT sensors and data analytics to efficiently monitor, control, and manage water resources (Gupta, Pandey, Feijóo, Yaseen & Bokde, 2020). Its goal is to promote sustainability by reducing water waste, improving system efficiency, and enhancing decision-making for water planning and distribution (Gupta *et al.,* 2020).

Municipal staff P4:

> *"The SWM may assist with integrating technology with administrative systems to enhance NRW governance"*.

- **Administrative practices**

Some participants agreed that enforcing compliance with the municipality's bylaws, such as payment of water bills and the use of smart meter reading, is necessary. This implies that requiring law enforcement to charge clients for services could reduce NRW. Moreover, implementing smart water meters can help reduce NRW. Smart water meters are advanced meters that cannot control the flow delivered to the consumer. However, they include advanced technology to communicate the meter reading to the municipality and/or the consumer (Ngabirano, 2017).

Municipal staff P1

> *"The community does not want to pay water bills, and the municipality is still using the old meter system, which needs to be improved".*

- **Weak administrative process contributes to water losses**

Many participants agreed that responding late to water leaks is a weak administrative practice that contributes to water losses. These results differ from those found by Mutikanga, Sharma, and Vairavamoorthy (2013), which indicate that commercial operators report leakage detections promptly to minimize the cost of water losses.

Community P1

> *The municipality has unresolved issues that compromise water management systems.*

- **Collaboration of stakeholders to improve NRW management**

All participants agreed that the forum meeting is the ideal venue for discussing water-related issues. A forum meeting related to water can refer to a broad range of gatherings that occur every three years, or to the more specific Water Sector Anti-Corruption Forum, established in South Africa in 2025, aimed at tackling corruption in the water sector.

Community P2:

> *"The collaboration may help as the community would be represented and receive feedback about the reduction of NRW. Some people would support interventions to improve NRW"*.

- **Impact policy changes or investments**

Some participants indicated that implementing bylaws may lead to changes. The implementation of a water management device precluded the aforementioned bylaws; their formulation paved the way for the mass roll-out of this device in various areas of Cape Town, for some of the reasons explained in the section below (Ngabirano, 2017).

Consultant P12

> *“There are no formal laws that I know of that are used to improve the situation of NRW"*.

- **Training or capacity-building addressing administrative inefficiencies.**

All participants agreed that training on meter reading and the repair of meters and pipes would have been helpful. Ngabirano (2017) revealed that due to the more advanced skill sets required to ensure the smooth operation and maintenance of the additional hardware and software components of an AMR system, the need for maintenance contracts was realised as municipal staff were trained and equipped to handle these systems.

Municipal staff P10:

> *"Training might assist, but the problem is that the municipality uses contractors. Even if staff are trained to address meter issues, it would not help because they cannot be allocated tasks to implement what they have learned. Unless the contractors train their staff"*.

4.5 Document analysis findings (themes with doc ids)

In this section, the documents analysed are depicted in Table 4.6. These include policy documents, previous NRW reports, or operational data from the water systems.

Themes for documents

In this section, the themes and subthemes that emerged from documents are discussed. Table 4.3 below depicts the themes and subthemes.

Table 4-5: Themes and Subthemes of documents

Theme	Subtheme
Examples of infrastructure failures that lead to NRW	Revenue recovery, the lack of capacity, and illegal connections.
Administrative procedures to reduce NRW	Meter guideline refers to the Service Provider (contractor).
Monitoring and managing NRW challenges	Proper billing and metering
Administrative procedures to reduce NRW	Block water tariffs, lack of political will, and cutting off the electricity supply
Weak administrative process contributes to water losses	Internal plumbing leakage
Municipality challenges in adopting advanced leak detection systems	Insufficient funds

Documents used in the study

In this section, the documents analysed are depicted in Table 4.6. These include policy documents, previous NRW reports, or operational data from the water systems.

Table 4-6: Documents used in the study

Title	Date	Issuing authority
City of Mbombela Water Balance Sheet	2025	Mbombela municipality
Water Services Development Plan	2023	City of Mbombela Local Municipality
Water market intelligence opportunity brief	2021	Mpumalanga green cluster agency
Water conservation, water demand management strategy, and action plan	2020	City of Mbombela
Provincial Gazette water bylaws	2017	The province of Mpumalanga

Only documents providing relevant data for the study's goal are selected. These documents must be no more than ten years old. These documents must be written and published in Mpumalanga.

- **Infrastructure failures that lead to NRW**

Each demand centre has its own unique challenges, although the main underlying issues are often similar. The demand centres are faced with myriad challenges, one of the most significant being the reduction of NRW and that of revenue recovery and illegal connections (Document 1, City of Mbombela Water balance sheet; Document 4, Water conservation, water demand management strategy and action plan, and Document 3, Water market intelligence opportunity brief). These results are similar to those found by Ngabirano (2017), which show that Illegal connections impact the success of advanced metering (section 4.3). The challenges are cross-cutting and reflect the state of water services across municipalities. One of the key problem areas that has been identified in the municipalities has not only been the deficient funding for implementation of (WC/WDM) measures, but more importantly, the lack of capacity to spend the grant funding and budgets allocated for these activities on appropriate interventions (Document 4, Water conservation, water demand management strategy and action plan). This is a crucial risk because, unless appropriately skilled individuals are appointed, the status quo of poor service delivery in some demand centres and high NRW will generally remain unchanged in the near future (Document 4: Water conservation, water demand management strategy, and action plan).

- **Administrative procedures to reduce NRW**

No person shall in any manner or for any reason whatsoever tamper or interfere with any meter or service connection or service protective device or supply mains or any other equipment of the Service Provider. (Offences regarding essential infrastructure may be handled according to the Criminal Matters Amendment Act, Act 18 of 2015) (Document 5, Provincial Gazette).

- **Monitoring and managing NRW challenges**

Worldwide, it has been demonstrated that billing and metering consumers is one of the most effective measures to encourage water conservation (Document 4, Water Conservation and Water Demand Management Strategy and Action Plan; Document 3, Water Market Intelligence Opportunity Brief). Whilst this is not feasible in certain areas, it has been observed that several demand centres are not billing and recovering revenue (Document 4, Water Conservation and Water Demand Management Strategy and Action Plan). Similarly, Mwangi (2017) found that unbilled metered consumption is not accounted for in the framework, as it is assumed to be negligible in high-income areas. Proper billing and metering are essential for the sustainability of a municipality and for the delivery of quality services. Unless metering and billing are implemented, municipalities risk that water demand will continue to rise, as consumers will not be encouraged to change or adapt their water-use practices in the absence of consequences for wasteful behaviour.

- **Administrative procedures to reduce NRW**

Lack of political will to support the implementation of WC/WDM (Document 4, Water conservation, water demand management strategy and action plan). The municipality does not have aggressively rising block water tariffs, which can help reduce NRW and SIV (Document 4, Water Conservation, Water Demand Management Strategy and Action Plan). There are credit control policies in place, but not enforced, especially in the area managed by the municipality. Credit control policies include cutting off electricity to consumers who do not pay for water (Document 4, Water Conservation, Water Demand Management Strategy and Action Plan). Administrative and capacity challenges make it very difficult to enforce these bylaws and policies.

- **Weak administrative process contributes to water losses.**

Informal and unauthorised connections, combined with internal plumbing leakage, contribute to high water losses and NRW (Document 1, City of Mbombela Water balance sheet). These results are similar to those in section 4.2, which show that NRW occurs through physical losses from leaking and broken pipes. The municipality is not repairing leaks in indigent households or unauthorised connections.

Internal plumbing leakage is found as a weak administrative process contributing to water losses (Document 2, Water Services Development Plan). Tabesh, Roozbahani, Roghani, Faghihi, and Heydarzadeh (2018) asserted that water losses are due to improper operation, inadequate maintenance management, ineffective active leakage management, and suboptimal asset management.

- **Municipality challenges in adopting advanced leak detection systems**

Insufficient funds to support maintenance of existing infrastructure (Document 2, Water Services Development Plan). These results are similar to those found in section 4.2, which show that funding is indeed a significant barrier to the widespread adoption of advanced leak detection systems.

4.6 Cross-source synthesis (matrix + narrative)

In this section, cross-source synthesis is depicted in Table 4.7 below. Major themes down the rows and sources across the columns are explained**.**

Table 4-7: Cross-source synthesis

Theme	Interviews	FGDs	Documents	Interpretation Convergent:
Illegal connections	Widely cited; drive bursts/pressure drops	Confirmed; "bypass meters" common	By-laws criminalise tampering; enforcement weak (Doc-05)	Enforcement capacity gap → persistent apparent + real losses

According to the table, illegal connections and outdated infrastructure pose challenges in the Hazyview Area of the Mbombela municipality. The findings reveal that consumers tamper with meters, which constitutes criminal activity, yet the municipality takes no action. Therefore, the unavailability of law enforcement led to high real water losses.

4.7 Integrated discussion (against chapter 2 literature & objectives)

This section discusses how the findings integrate with the literature in Chapter 2 and with the study objectives.

4.7.1 Objective One: Infrastructure Contributors to NRW

- **Infrastructure failures that lead to NRW**

Both the individual interviewed and the focus group results indicated that many participants perceived water leakage, illegal connections, and meter tampering as the main examples of NRW-related infrastructure failures. This aligns with Ngabirano (2017), who links illegal connections to a negative impact on the success of advanced metering. More effort should be directed at addressing infrastructure failures in NRW if the goal is to reduce them.

- **Failure frequency**

The results indicated that most participants reported infrastructure failures occurring more than five times per week. More effort should be directed toward new infrastructure if infrastructure failures are to be effectively addressed.

- **Maintenance practices to prevent infrastructure-related NRW**

The results indicated that the interviewed participants agreed that most maintenance involves replacing faulty or unauthorized meter connections. While focus group participants indicated that the current maintenance strategies are not drastically addressing leaks and pipe bursts. Ageing network and pressure issues extend the leak run-time. This aligns with Netshitanini *et al.* (2023) and Shushu *et al.* (2021), who have linked high pressures to increased burst frequency. In Hazyview, staff reports more than 5 incidents/week, compounded by slow repair cycles (administrative bottlenecks) and contractor turnover**.**

Implication: prioritise pressure management and SLAs that reduce Mean Time to Repair (MTTR). More effort should be directed at monitoring and security measures if faulty and unauthorised meter connections are to be addressed.

The first secondary objective was to understand the main infrastructural contributors to NRW in Hazyview. Based on this section, the first secondary objective was achieved, as data showed that water leakage, illegal connections, and meter tampering are the primary infrastructural contributors to NRW in Hazyview.

4.7.2 Objective Two: Administrative practices influencing NRW levels

- **Administrative procedures to reduce NRW**

The results indicated that participants agree that the following are not active: customer education programme, bylaws enforcement, and WC/WDM strategy. Focus group participants' results indicated that SWM can transform urban water management by **i**ntegrating advanced digital technologies. More effort should be directed to implementing the customer education programme, WC/WDM, and SWM, and to enforcing bylaws, if administrative procedures to reduce NRW are to be effective. This aligns with Kihumba (2013), who links the lack of implementation to the lack of enforcement.

- **Monitoring and managing NRW challenges**

The results indicated that participants agreed that the challenges of monitoring and managing NRW include budget constraints, unauthorized water connections, delayed meter replacements, inaccurate meter data, and a shortage of skilled staff. The results of focus group participants indicated that responding late to water leaks is a weak administrative practice that contributes to water losses. More effort should be directed toward funding if monitoring and managing NRW challenges are to be effectively addressed. The findings align with Mwangi (2017), who shows that a significant challenge for water utilities is the need to channel many funds towards renovations and construction.

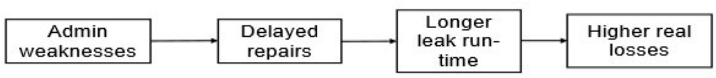

Figure 4-1: A theme map

Source: Own compilation (2025)

The figure shows that the weakness of the administrative system leads to greater real water losses. This implies that training is essential for the municipality to reduce actual water losses.

- **Staff training and supervision linked to NRW management**

The results indicated that almost all participants lacked supervision and received inadequate training on meter readings. This aligns with Ngabirano (2017), who links training to the efficient functioning of metering technologies. More effort should be devoted to training on meter readings if NRW management is to be improved.

The second secondary objective was to understand the administrative practices that influence NRW levels. Based on this section, the second secondary objective was achieved, as data showed that implementing customer education programmes, WC/WDM, SWM, and enforcing bylaws influence NRW.

4.7.3 Objective Three: Technological innovations that could mitigate infrastructure-related NRW

- **Technologies to monitor or reduce NRW**

The results indicated that many participants agreed that SCADA is available but not fully implemented. This aligns with Ngabirano (2017), who emphasized the need for feasibility studies before installing advanced meters. All participants in the focus group agreed that real-time monitoring and leak detection are technologies or innovations to reduce NRW. It seems that more effort should be directed at implementing SCADA, real-time monitoring, and leak detection if NRW is to be reduced.

- **Barriers preventing the adoption of advanced technologies**

Both the individual interviewed and the focus group results indicated that all participants agreed that the budget is a barrier preventing the adoption of advanced technologies. This aligns with Mwangi (2017), who links the barrier preventing the adoption of advanced technologies to a lack of funding. It seems that more effort should be directed toward making a budget available if the barrier to adopting advanced technologies is to be addressed.

- **Success stories or failures with technological interventions**

The results indicated that many participants mentioned prepaid meters from other municipalities. This aligns with Ngabirano (2017), who found that prepaid meters are associated with substantial savings in water consumption. It appears that more effort should be directed toward using prepaid meters if technological interventions are to be implemented.

The third secondary objective was to explore technological innovations that could mitigate infrastructure-related NRW. Based on this section, the third secondary objective was achieved because data showed that SCADA, real-time monitoring, and leak detection could mitigate infrastructure-related NRW.

4.8 Conclusion

The municipality's aging water infrastructure is a primary cause of significant water loss, with a substantial portion of the municipal water being lost through leaks, bursts, and inadequate maintenance of the water supply and distribution systems. Inadequate investment in upkeep and the deterioration of pipes, treatment plants, and drainage systems exacerbate these losses. Illegal water connections pose another challenge for the municipality. Illegal water connections are a criminal offense involving the unlawful tampering with a municipal water supply. These connections lead to reduced water pressure for legitimate users, contamination of the water supply, significant revenue losses for the municipality, and damage to water infrastructure. The lack of funding for water infrastructure is another problem the municipality faces. Insufficient funding stems from a significant investment gap: municipalities require funds annually to repair and upgrade aging systems, but fall short by hundreds of rands. Key factors include NRW from leaks and theft, tariffs that do not cover actual costs, ineffective municipal governance hindering revenue collection and borrowing, and delays in creating new funding models and institutional structures. This insufficient investment leads to widespread infrastructure failure, worsening the national water crisis and the ability to meet even basic needs.

In this chapter, the presentation and interpretation of the survey findings from interviews and focus groups were discussed. In the following chapter, conclusions and recommendations are made in light of the results presented in this chapter. The primary and secondary objectives are revisited, followed by an indication of the extent to which they were achieved.

Evidence from interviews, FGDs, and documents indicates three reinforcing drivers of NRW in Hazyview: (1) physical losses from ageing assets and pressure-related bursts with extended run-times; (2) apparent losses from illegal connections, meter tampering, and weak billing/credit controls; and (3) administrative constraints (skills, data quality, procurement delays) that slow detection and response. These findings converge across sources and align with regional evidence reported in Chapter 2. Transition. Chapter 5 translates these findings into prioritised, context-appropriate actions for the City of Mbombela, indicating expected impact pathways on NRW and feasibility in Hazyview's constraints (budget, skills, enforcement).

CHAPTER 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 introduction

This chapter synthesises the findings from Chapter 4 against the study objectives, draws conclusions, and presents a prioritised intervention plan to reduce NRW in Hazyview (City of Mbombela). It also outlines practical recommendations, study contributions, limitations and delimitations, and directions for future research.

5.2 Research problem

This study addressed a local evidence gap by qualitatively explaining how infrastructure condition, administrative practices, and technology readiness interact to sustain high NRW in Hazyview.

5.3 Primary objective of the study

Achievement: Achieved. Triangulated evidence from interviews, FGDs, and documents identified dominant contributors and their interaction pathways (pressure/asset age → bursts/leaks; weak billing/credit control → apparent losses; slow response/data gaps → extended leak run-time).

5.4 Objectives

DMA creation and minimum night flow checks; pressure management (PRVs) at hotspots; leak response SLA (48h) with contractor KPIs; targeted illegal connection regularisation and credit control; meter audit and fast-track replacements (top 10% under-registering).

B. Responsibility, timeline, cost band, KPIs

Table 5-1: Responsibility, timeline, cost band, KPIs

Action	Owner	Start–finish	Cost band	KPI / Target	Risk & mitigation
Establish 3 DMAs in Hazyview (priority zones)	Water Ops + GIS	M1–M4	Low–Med	Night flow baseline + 20% reduction by M6	Incomplete valves → pre-survey & valve rehab
Pressure management (PRVs + settings)	Water Ops	M2–M6	Med	Burst frequency ↓ 25% by M9	Wrong settings → monthly pressure profile
Leak response SLA (48h) + contractor KPIs	Ops + Supply Chain	M1–M3	Low	Median MTTR ≤ 48h by M6	Contractor delays → penalty clauses
Meter audit + replace top 10% under-registering	Revenue + Ops	M2–M8	Med	Apparent loss ↓; billed volume ↑ 5% by M9	Stockouts → framework contracts
Illegal connection regularisation + credit control	Revenue + Legal	M3–M9	Low	300 accounts regularised; arrears recovery plan	Social pushback → amnesty window
SCADA Phase 1 (levels/flows alarms)	Ops + IT	M4–M12	Med–High	Alarm-to-response < 2h	Skills gap → vendor training
AMR pilot (100–200 high-use)	Revenue + IT	M4–M10	Med	Read success ≥ 98%; real-time leak flags	Vandalism → tamper-proof install
Staff training (metering, leak detection)	HR + Ops	M2–M6	Low	90% field staff are certified	Attrition → refresher every 6 months

5.5 Intervention strategies

In the above section, a comparison is made between the individual interviewed and the focus group participants. In this section, intervention strategies for Hazyview are suggested.

The strategies presented in this section highlight the key roles that infrastructure contributors, administrative practices, and technological innovations can play in reducing NRW. Therefore, this contributes to the body of knowledge in environmental science. This would assist municipalities in understanding the specific constraints in reducing NRW. Moreover, this would assist municipalities by enabling cost savings and environmental benefits, such as reduced NRW. Other stakeholders and policymakers in the water sector would benefit from reading this study before engaging with strategies to reduce NRW. This research found that the Theory of Constraints and Managerial Efficiency could be valuable tools for reducing NRW; thus, it contributes to the literature on environmental sciences. The findings of this study highlight the complex and interconnected nature of the factors contributing to NRW in Hazyview, within the City of Mbombela Municipality. Based on the key infrastructural, administrative, and technological issues identified, several practical recommendations have been proposed. These recommendations aim to address critical weaknesses and enable more effective NRW reduction strategies.

Practical recommendations for Hazyview are based on the premise that, firstly, addressing infrastructural challenges such as frequent pipe bursts, illegal water connections, and faulty meters requires increased investment in infrastructure renewal, the establishment of routine maintenance schedules, and stronger enforcement mechanisms to prevent tampering and unauthorized connections. Strengthening infrastructure to reduce actual water losses and significantly improve service delivery is to be achieved.

Secondly, improving administrative practices is essential. The absence of active customer education campaigns, ineffective enforcement of bylaws, and the lack of comprehensive WC/WDM strategies have weakened the municipality's capacity to manage water losses. Enhancing administrative efficiency would require renewed focus on staff training, consistent supervision, adequate funding, and the formal adoption of strategic water management plans. Ensuring accountability in leak response times and resource allocation will further enhance operational effectiveness.

Thirdly, technological innovations such as SCADA, real-time monitoring, and leak detection systems were identified as promising tools for reducing NRW. However, limited budgets currently hinder their full implementation. To overcome this, the municipality should prioritize technology adoption by securing dedicated funding and, if necessary, exploring public-private partnerships. Additionally, the successful implementation of prepaid meters in other municipalities presents a viable model that could be replicated in Hazyview.

Overall, the recommendations emphasize the need for a multidimensional, integrated approach that combines infrastructure upgrades, improved governance, community engagement, and smart technology adoption. The successful implementation of these interventions requires a strong commitment to action, adequate funding, effective institutional capacity, and collaboration among municipal departments and external stakeholders. If these recommendations are acted upon, significant progress can be made toward reducing NRW, improving municipal revenue, and securing water sustainability in Hazyview and the broader City of Mbombela.

5.6 Recommendations

The section above discussed the implications of the results. In this section, possible interventions regarding the various contributors to NRW in Hazyview are recommended, focusing on infrastructure age, technological adoption, and management practices.

5.6.1 Objective One: Infrastructure contributors to NRW

In this section, possible interventions related to infrastructural contributors to NRW are discussed. Possible interventions to reduce NRW are suggested.

Infrastructural contributors

- Pressure and bursts: Implement PRVs in hotspots; verify settings monthly; track burst frequency per DMA.
- Leak run-time: Create DMAs; measure minimum night flow; introduce 48h repair SLA.
- Illegal connections: Pair enforcement with amnesty and fast regularisation; protect mains to reduce re-taps.
- Meters: Audit and replace under-registering top decile; fix stuck and inaccessible meters.

5.6.2 Objective Two: Administrative practices influencing NRW levels

Administrative practices

- Billing/master data: Clean and reconcile meter–account database; monthly exception reports (zero-use, constant-use flags).

- Bylaws and credit control: Enforce with clear processes, publish consequences, and use staged disincentives.
- Customer education: Focused campaigns on leak reporting and tampering risks; tied to bill messages and WhatsApp hotlines.
- Capacitation: Field training (leak detection, meter reading), supervisors coached on KPI use.

5.6.3 Objective Three: Technological innovations that could mitigate infrastructure-related NRW

Technological innovations

- SCADA Phase 1: Reservoir levels/flows and alarms to reduce detection time.
- AMR pilot: 100–200 high-use/ high-risk accounts; evaluate read success, leak flagging, and billing improvements before scale.
- Prepaid: Pilot only in specific segments (e.g., high arrears, communal standpipes) with social safeguards; do not generalise citywide without evaluation.

Procurement: Insist on open standards (e.g., STS compliance where relevant) and interoperability to avoid vendor lock-in. Table 5.2 below presents the prioritised recommendations.

Table 5-2: Prioritized recommendations table

Priority	Recommendation	Why (mechanism)	Owner	Start–Finish	Cost Band	KPI
1	Create 3 DMAs + night flow checks	Shortens detection, quantifies real losses	Ops + GIS	M1–M4	Low–Med	Night flow ↓ 20% by M6
1	48h leak-repair SLA + contractor KPIs	Cuts leak run-time (RL)	Ops + SCM	M1–M3	Low	MTTR ≤ 48h by M6

1	Pressure management (PRVs)	Lowers burst frequency	Ops	M2–M6	Med	Bursts ↓ 25% by M9
2	Meter audit + replace top 10% under-registering	Reduces apparent losses	Revenue + Ops	M2–M8	Med	Billed vol ↑ 5% by M9
2	Enforcement + regularisation campaign	Converts illegal use to billed	Revenue + Legal	M3–M9	Low	300 accounts regularised
3	SCADA Phase 1 (levels/flows + alarms)	Faster detection	Ops + IT	M4–M12	Med–High	Alarm→response < 2h
3	AMR pilot (100–200 accounts)	Better reads/leak flags	Revenue + IT	M4–M10	Med	Read success ≥ 98%

2) KPI mini-dashboard (define how you will know it worked)

- NRW (% and m³) per month (and by DMA once live)
- Burst frequency /100 km main / month
- Mean time to repair for leaks/bursts
- Minimum night flow by DMA
- Read success rate (%) and zero/constant-use anomalies (#)
- Illegal connection regularisations (#/month) and arrears recovered (R)

5.7 Significance of the study

- This study investigated the factors influencing NRW levels in Hazyview within the City of Mbombela, to suggest intervention strategies.
- It contributes to the body of knowledge on NRW in developing economies by providing possible interventions to the specific entities involved in NRW.
- It lays the foundation for broader research on NRW.
- Academic: Provides a qualitative, small-town SA case explaining the interaction of infrastructure condition, administrative capacity, and technology readiness in sustaining NRW.
- Methodological: Demonstrates a triangulated (interviews, FGDs, and

documents) approach and a TOC-informed operational framing for NRW reduction.

- Practical: Produces a prioritised, feasible intervention plan and KPIs that municipalities can adopt/adapt.

5.8 Limitations and delimitations

The following limitations were identified:

- Limitations: insider bias, limited generalisability, cross-sectional design, participant availability.
- Delimitations: geographic scope (Hazyview only), thematic scope (NRW not complete water management).
- Findings reflect the views of operations, admin, finance, and community stakeholders.
- Academic: Provides a qualitative, small-town SA case explaining the interaction of infrastructure condition, administrative capacity, and technology readiness in sustaining NRW.
- Methodological: Demonstrates a triangulated interview, FGDs, and documents: approach and a TOC-informed operational framing for NRW reduction.
- Practical: Produces a prioritised, feasible intervention plan and KPIs that municipalities can adopt/adapt.

5.9 Future research

- Future research should examine the use of advanced metering technology, as this would provide a more comprehensive economic and overall performance view at the municipal level.

- Future research should examine human behaviour in NRW.
- Longitudinal assessment of DMA and PRV impacts (seasonality).
- Comparative pilots: AMR vs prepaid outcomes (technical performance, equity, revenue).
- Behavioral economics of payment and tampering (design of incentives).
- Cost–benefit and financing models for small-town NRW programmes.
- Data governance for SCADA/AMR integration (cybersecurity, roles).

5.10 Conclusion

Convergent evidence shows that Hazyview's NRW is driven by (i) physical losses from ageing, pressure-stressed assets with extended leak run-time, (ii) apparent losses from illegal connections and meter/data weaknesses, and (iii) administrative constraints that delay detection and response. A staged plan of DMAs and PRVs, leak-repair SLAs, enforcement with regularisation, targeted meter replacement, and SCADA/AMR pilots offers a feasible pathway to reduce NRW and stabilise revenue. The next steps are to implement the high-impact/high-feasibility actions within six months, monitor KPIs monthly, and use the results to scale the technology components responsibly.

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APPENDICES

Appendix 1: Research Access Approval Letter

Civic Centre
1 Nel Street
Mbombela 1201
Republic of South Africa

CITY OF MBOMBELA
THE ULTIMATE DESTINATION

P O Box 45
Mbombela 1200
Republic of South Africa
Tel: +27 (0) 13 759-9111
Fax: +27 (0) 13 759-2070

OFFICE OF THE CITY MANAGER

Enq: Ms. Annah Chiloane
Tel: 013 759 2152

28 January 2025

Mr. KG Moabelo
The Researcher
City of Mbombela
1 Nel street
Mbombela
1201

Dear Sir,

RE: REQUEST FOR PERMISSION TO CONDUCT RESEARCH IN THE CITY OF MBOMBELA

Your letter dated 20 January 2025 on the above mentioned subject has reference.

The City of Mbombela hereby grants you permission to coduct research for the study titled: "***Analysis of Factors Infrastructure , Metering , and Administrative Influencing the Level of Non-Revenue Water in Hazyview Town , South Africa*** ".

Please take note that the municipality will not be liable for any financial responsibility on this study. Kindly ensure that the work of employees is not interrupted and consent is obtained from each participant before the actual data collection.

The City of Mbombela wishes you all the best with your research and would appreciate that you share with us an A4 size hardbound copy as well as an electronic copy of your final approved research report.

Regards,

[redacted]

W J KHUMALO
CITY MANAGER

Appendix 2: Ethical Clearance

THE INDEPENDENT INSTITUTE OF EDUCATION

Our Ref: M. 810325
Enquiries: research@iie.ac.za

04 March 2025

Outcome of Ethics Clearance for Master of Philosophy in Integrated Water Management.

Student name: Koena Given Moabelo
Student number: [redacted]
Brand and campus: IIEMSA

Dear Koena,

Thank you for submitting ethics clearance for the study titled: ***Analysis of Infrastructure, Metering, and Administrative Factors Influencing the Level of Non-Revenue Water in Hazyview Town, South Africa:***

We are pleased to inform you that your ethical clearance application has been approved. This means that you may proceed with data collection once you have addressed the comments shared by the HDC. You are reminded to inform the IIE's Higher Degrees Committee of any changes made to the research methodology or title of the research prior to examination. Kindly ensure that all ethical considerations are duly applied whilst collecting, analysing and interpreting the data for the completion of your research.

If you have any questions, please feel free to contact your programme team or supervisor directly.

All the best with your research studies.

[redacted]

Dr Reza Hosseini

Chair: Higher Degrees Committee

ADvTECH House: Inanda Greens, 54 Wierda Rd West, Wierda Valley 2196
P.O. Box 2369, Randburg 2125
Directors: GD Whyte (UK), JDR Oesch, MD Aitken, SCD Lurie
Group Company Secretary: CB Crouse

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Appendix 3: Participant or Respondent Informed Consent Form

THE INDEPENDENT INSTITUTE OF EDUCATION

Annexure H – PARTICIPANT OR RESPONDENT INFORMED CONSENT FORM

Explanatory information sheet and consent form for participants

To whom it may concern,

My name is Koena Given Moabelo and I am a student at The IIE's IIEMSA. I am currently conducting research under the supervision of Dr, YOLANDI SCHOEMAN to determine the factors that influence the level of NRW in Hazyview within City of Mbombela. I hope that this research will enhance our understanding of Non-Revenue Water (NRW) and its impact on water supply.

I would like to invite you to participate in my study. In order to explain to you what your participation in my study will involve, I have formulated questions that I will try to fully answer so that you can make an informed decision about whether or not to participate. If you have any additional questions that you feel are not addressed or explained in this information sheet, please do not hesitate to ask me for more information. Once you have read and understood all the information contained in this sheet and are willing to participate, please complete and sign the consent form below.

What will I be doing if I participate in your study?

I would like to invite you to participate in this research because the method I'm using require participants. If you decide to participate in this research, I would like to answer the questions which will be asked based on your outmost knowledge and experience.

You can decide whether or not to participate in this research. If you decide to participate, you can choose to withdraw at any time or to decide not to answer particular interview questions.

Are there any risks/ or discomforts involved in participating in this study?

Whether or not you decide to participate in this research, there will be no negative impact on you. There are no direct risks or benefits to you if you participate in this study. You might, however, indirectly find that it is helpful to talk about your discomforts. If you find at any stage that you are not comfortable with the line of questioning, you may withdraw or refrain from participating.

Detail the potential risks and how it will be managed by the researcher. Indicate how the ethical considerations will be applied in the context of the study.

Do I have to participate in the study?

- Your inclusion in this study is completely voluntary;
- If you do not wish to participate in this study, you have every right not to do so;
- Even if you agree to participate in this study, you may withdraw at any time without having to provide an explanation for your decision.

Will my identity be protected?

I promise to protect your identity. I will not use your name in any research summaries to come out of this research and I will also make sure that any other details are disguised so that nobody will be able to identify you. I would like to ask your permission to record the interviews, but only my supervisor, I and possibly a professional transcriber (who will sign a confidentiality agreement) will

have access to these recordings. Nobody else, including anybody at IIEMSA, will have access to your interview information. I would like to use quotes when I discuss the findings of the research, but I will not use any recognisable information in these quotes that can be linked to you.
What will happen to the information that participants provide?
Once I have finished all interviews, I will write summaries to be included in my research report, which is a requirement to complete my Masters of Philosophy Integrated Water Management You may ask me to send you a summary of the research if you are interested in the final outcome of the study.
What happens if I have more questions about the study?
Please feel free to contact me or my supervisor should you have any questions or concerns about this research, or if there is anything you need to know before you decide whether or not to participate. You should not agree to participate unless you are completely comfortable with the procedures followed. My contact details are as follows: Koena Given Moabelo [redacted] The contact details of my supervisor are as follows: Dr Yolandi Shoeman [redacted]

Participant or respondent Informed Consent – Audio and Visual Recordings.	
I agree to participate in the research conducted by Koena Moabelo about to determine the factors that influence the level of NRW in Hazyview within City of Mbombela. This research has been explained to me and I understand what participation in this research will involve. I understand that: • I agree to participate in this research and be recorded for the purpose of data collection. • My confidentiality will be ensured. My name and personal details will be kept private and confidential. • My participation in this research is voluntary and I have the right to withdraw from the research at any time. There will be no repercussions should I choose to withdraw from the research. • I may choose not to answer any of the questions that are asked during the research interview. • I may be quoted directly when the research is published, but my identity will be protected.	
Signature	**Date**

Appendix 4: Interview questions for individuals and Focus group

Research Questions

My name is Koena Given Moabelo and I am a student at The IIE's IIEMSA. I am currently conducting research under the supervision of Dr, YOLANDI SCHOEMAN to determine the factors that influence the level of NRW in Hazyview within City of Mbombela.

Research Title:

Analysis of infrastructure, metering, and administrative factors influencing the level of Non-Revenue Water in Hazyview Town, South Africa

<u>Section A: Biographical information</u>

1. **What is your age group?**

40-50

…………………………………………………………………………

2. **What is your gender?**

Male

…………………………………………………………………………

3. **What is your race?**

African

…………………………………………………………………………

4. **What is your highest level of education?**

National Diploma Water Care

…………………………………………………………………………

5. **What is the name of section?**

Water and Sanitation Operation and Mainatcne

…………………………………………………………………………

6. **What is your designation?**

    Senior Engineering Technician

…………………………………………………………………………

<u>Section B: Interview for individual interviews on Non-Revenue Water</u>

Objective 1: Understand the main infrastructural contributors to NRW.

Interview question: What are the main infrastructural contributors to NRW in Hazyview?

1. Can you provide specific examples of infrastructure failures that lead to NRW?

   ……Unauthorized water connections, Bypass of water meters

   Meter reading not done accurately

   …………………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   ……………………………………………………………………………

2. How frequently do these failures occur?

   ……Estimation…of meter readings happen frequently………………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   …

3. What maintenance practices are in place to prevent infrastructure-related NRW?

   ……Replacement of faulty and unauthorized/bypass of meter connections
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   ……………………………………………………………………………………

Objective 2: Understand administrative practices influencing NRW levels.

Interview question: How do administrative practices influence NRW levels?

1. Which administrative policies or procedures are effective or ineffective in reducing NRW?

   ………Bylaws enforcement and meter reading not effective……………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………

2. What challenges do administrative teams face in monitoring and managing NRW?

…Unauthorized water connections and bypass of meters…………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…….

3. How is staff training and supervision linked to NRW management?

……There is no link between staff training and management of NRW. Meter reading system should be improved

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………………

Objective 3: Explore technological solutions or innovations to mitigate infrastructure-related NRW.

Interview question: Which technological solutions or innovations could mitigate infrastructure-related NRW?

1. Are there any existing technologies used in Hazyview to monitor or reduce NRW?

……Not yet implemented.

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………………

2. What barriers prevent the adoption of advanced technologies?

…………………………………………………………………………………………………
…Financing those projects is the problem…………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
……

3. Have you encountered success stories or failures with technological interventions in other municipalities?

……Benchmarking still to be conducted
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………………