INVESTIGATING NON-REVENUE WATER IN URBAN WATER SUPPLY: A CASE OF BLANTYRE WATER BOARD

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Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirements for the Bachelor of Science degree in Water Quality and Management.

May, 2026

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ABSTRACT

Non-Revenue Water (NRW) poses a significant threat to the operational efficiency and financial sustainability of water utilities, particularly in developing countries. This study investigated NRW in urban water supply, a case study of Blantyre Water Board. Specifically, the study aimed to determine the trend of NRW, assess its financial impact on BWB, identify the causes of NRW, and evaluate the strengths and weaknesses of NRW reduction strategies implemented by the utility.

Mixed-methods approach was adopted to enhance the validity and reliability of the findings through triangulation of quantitative and qualitative data. Quantitative data covering the period 2015–2024 were analyzed using descriptive statistics, trend analysis, correlation, and regression analysis, while qualitative data were collected through key informant interviews to provide contextual explanations of the observed trends and operational challenges. Inferential statistical analysis was conducted at a 95% confidence interval, and statistical significance was determined at $p < 0.05$. The integration of qualitative findings helped explain relationships and patterns that could not be sufficiently interpreted through quantitative analysis alone.

The study employed purposive sampling in selecting key informants. Respondents were deliberately chosen based on their professional knowledge, technical expertise, involvement in procurement management, water supply management and NRW water control within BWB. The results indicate that NRW exhibited a fluctuating but increasing trend, rising from 40.8% in 2015 to 61.9% in 2024, with a mean of 49.82%, far exceeding recommended benchmarks.

A strong positive correlation of 0.681 was found between water production and NRW, indicating that increases in water production were associated with corresponding increases in water losses. In contrast, billed consumption showed a negligible negative correlation of 0.047 with NRW, suggesting minimal influence on NRW variation. Financial analysis further revealed that the BWB transitioned from operational surpluses to sustained financial deficits after 2020 due to rising production costs and escalating water losses. The study estimated

that the utility incurred cumulative financial losses of approximately MWK 31.3 billion between 2021 and 2024 as a result of NRW-related inefficiencies.

Qualitative findings identified key causes of NRW, including aging infrastructure, leakages, inadequate metering, illegal connections, and institutional inefficiencies. While existing strategies such as leakage control and metering improvements have yielded some benefits, their effectiveness is constrained by limited resources, weak monitoring, and lack of sustained implementation. The study concludes that persistently high NRW, driven by interconnected technical, administrative, and socio-economic factors, has significantly undermined the financial sustainability of BWB.

ACKNOWLEDGEMENTS

First and foremost, we express our sincere gratitude to almighty God for His guidance, strength, wisdom and protection throughout the course of this study.

we would also like to extend our heartfelt appreciation to our supervisor, Dr John Njalammano for his guidance, constructive criticism, encouragement and continuous support throughout the course of this research study.

Special appreciation is extended to Mr. Andrew Masiye, The Cooperate Planning Manager at the Blantyre Water Board, for his cooperation throughout the study. We are equally grateful to the management and staff of Blantyre Water Board for trusting us with necessary data and information used in this research.

Lastly, we sincerely thank the families of Kapyanga and Kajawo for their unwavering emotional, moral and financial support throughout our academic journey. Their encouragement and sacrifices made this achievement possible.

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List acronyms/abbreviations

Acronyms/ Abbreviations	Full Meaning
BWB	Blantyre Water Board
CRWB	Central Region Water Board
DMA	District Metered Area
IWA	International Water Association
JICA	Japan International Cooperation Agency
KPIs	Key Performance Indicators
LiSCaP	Lilongwe Service Level Improvement and Non-Revenue Water Capacity Development
LWB	Lilongwe Water Board
NRWB	Northern Region Water Board
NRW	Non-Revenue Water
PRVs	Pressure Reducing Valves
SCADA	Supervisory Control Data Acquisition
SDGs	Sustainable Development Goals
SIV	System Input Volume
SRWB	Southern Region Water Board
UfW	Unaccounted-for Water

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CHAPTER 1: INTRODUCTION

1.1. Background

Water is an essential natural resource that underpins human survival, public health, economic development and achieving sustainable development. (Silva et al., 2023). Access to safe and reliable water supply remains a critical challenge for many developing countries. Urban water supply systems play an important role in promoting public health, economic development, and environmental sustainability. However, many water utilities in developing countries face persistent challenges in managing water losses, particularly NRW, water that is produced but not billed to customers due to physical losses, commercial losses or unbilled authorized consumption. According to the IWA, many water utilities in developing countries lose up to 50% of their water as NRW, compared to less than 15% in developed nations(Yilmaz et al., 2021).

Nearly 45 million cubic meters of water is lost daily in developing countries, and close to 30 million cubic meters of water is delivered every day to customers but not paid for, costing water utilities about USD 6 billion every year(Nono et al., 2024). Malawi, like many countries in the Sub-Saharan region, faces significant challenges in managing NRW, One of its five water utilities, the BWB, which serves the city of Blantyre and surrounding areas has consistently reported high levels of NRW, with estimates ranging from 54% to 62% in the past 5 years. These losses not only translate into financial shortfalls for the utility but also hinder its ability to expand coverage and ensure sustainable service delivery to a rapidly growing urban population.

While previous studies done by Mapila (2021) and Banda et al.,(2018) identified individual factors, no recent study has quantified the trend, financial impact, and effectiveness of reduction strategies using a decade-long dataset combined with key informant interviews. This study was conducted to fill the gap by investigating the trend of NRW at BWB, drivers of NRW at BWB, financial impact of NRW at BWB and the effectiveness of strategies of reducing NRW adopted by BWB with an aim of suggesting solutions and recommendations for improving water loss management.

This will help to enhance the operational efficiency and financial stability of BWB and to the nation it will help in advancing national goals of equitable and sustainable water access, as outlined in Malawi Vision2063 and Sustainable Development Goal 6.

1.2. Problem Statement

NRW remains a major challenge affecting the operational efficiency and financial sustainability of water utilities in developing countries. NRW refers to water that is produced but not billed due to leakages, illegal connections, meter inaccuracies, and poor management practices. High NRW levels reduce revenue generation, increase operational costs, and negatively affect service delivery. The BWB has continued to experience high levels of water losses despite implementing interventions such as leak detection, meter replacement, and pipeline rehabilitation. Reports indicate that NRW levels at the utility remained between 41% and 62% from 2015 to 2024, which is above the recommended international benchmark of 25%. These losses have contributed to financial deficits, unreliable water supply, and challenges in meeting the increasing water demand in Blantyre City. Despite the persistence of the problem, there is limited research comprehensively examining the trends, causes, and financial impacts of NRW at BWB. Without adequate understanding of the technical, administrative, and socio-economic factors contributing to NRW, it becomes difficult to develop effective strategies for reducing water losses and improving service delivery. Therefore, this study seeks to investigate the trends, causes, and financial impacts of NRW at BWB and assess the strategies used to reduce NRW.

1.3. Objectives of the Study

Main Objective

To investigate causes and impacts of Non-Revenue Water at Blantyre Water Board.

Specific Objectives

The specific objectives are to:

1. Determine the trend of NRW at BWB from 2015 to 2024
2. Identify the technical, administrative, and socio-economic causes of NRW at BWB
3. Find out the financial impacts of NRW on BWB
4. Analyze the strategies employed to reduce NRW at BWB

1.4. Research Questions

1. What is the trend of NRW at BWB?
2. What are the technical, administrative, and social-economic causes of NRW at BWB?
3. What are the financial impacts of NRW on BWB?
4. What are the strategies employed to reduce NRW at BWB?

1.5. Significance of Study

This study is significant in improving the efficiency and sustainability of urban water supply systems in Malawi. For the Blantyre Water Board, the findings will provide practical insights into strategies for reducing NRW, improving revenue collection, and enhancing financial sustainability. The study will also highlight the importance of public awareness and community participation in addressing NRW challenges. Beyond BWB, the findings and recommendations may be adopted by other water utilities in Malawi and similar developing countries to strengthen operational performance and minimize water losses. At policy level, the Ministry responsible for water development can use the findings to formulate effective NRW management frameworks that support the objectives of Malawi Vision 2063 and the achievement of the SDGs, particularly those related to clean water and sanitation.

Academically, the study contributes to the limited local literature on NRW management in Malawi by providing empirical evidence on the trends, causes, financial impacts, and mitigation strategies of NRW in an urban water utility. The research therefore adds context-specific knowledge that can support future studies and policy decisions on sustainable urban water management.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This chapter reviews relevant literature related to NRW in urban water supply systems. The chapter discusses the concept and definition of NRW, its major components and causes, as well as its effects on the operational and financial performance of water utilities. It further examines the global perspective of NRW by highlighting trends, challenges, and management practices implemented in different countries. In addition, the chapter explores the status of NRW in Malawi and reviews the strategies adopted by the BWB to manage and reduce water losses. The reviewed literature provides the theoretical and empirical foundation for understanding the problem under investigation and identifying existing knowledge gaps that this study seeks to address.

2.2. Definition of NRW

NRW has become the internationally accepted terminology for describing the gap between water supplied and water billed, replacing the older term of UfW. Historically, UfW referred to the difference between system input volume and recorded consumption, but it lacked a standardized methodology for accurate estimation, often resulting in inconsistent figures across utilities (Liemberger & Wyatt, 2019).To address these inconsistencies, IWA developed a globally standardized water balance and set of performance indicators that remain the benchmark for assessing water losses (Saddiqa et al., 2022). Within this framework, NRW is defined as the difference between the total volume of water entering a distribution system and the volume of authorized consumption that is billed, whether metered or unmetered. NRW consists of two main components, real (physical) losses and apparent (commercial) losses (Liemberger & Wyatt, 2019).

The initial step in evaluating NRW involves preparing a standardized water balance, which enables utilities to determine the proportion of water that is billed and rightfully consumed, as well as the share that is lost and through which mechanisms. Although water balances have long been applied by utilities, inconsistent formats and differing approaches to classifying losses historically made it difficult to conduct meaningful comparisons across systems. To

address this, IWA established a globally accepted methodology for water balance preparation, accompanied by clear definitions of the various categories of losses and performance indicators (Liemberger & Wyatt, 2019). Building on this framework, recent studies highlight that the IWA's standardized structure has become the reference model for assessing NRW, providing utilities with a consistent basis for benchmarking, diagnosing loss patterns, and guiding interventions (Saddiqa et al., 2022).

Table 1 The IWA Standard Water Balance.

<table>
<tr><td rowspan="10">System Input Volume</td><td rowspan="3">Authorized Consumption</td><td>Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td rowspan="2">Billed Authorized Consumption</td><td>Billed Unmetered Consumption</td></tr>
<tr><td>Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non-Revenue Water</td></tr>
<tr><td rowspan="7">Water Losses</td><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="2">Commercial losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies and Estimations</td></tr>
<tr><td rowspan="4">Physical losses</td><td>Leakage on transmission and/or distribution mains</td></tr>
<tr><td>Leakage and overflows at utility storage tanks</td></tr>
<tr><td>Leakage on Service connections up to point of customer use</td></tr>
</table>

Source: Kingdom et al (2006)

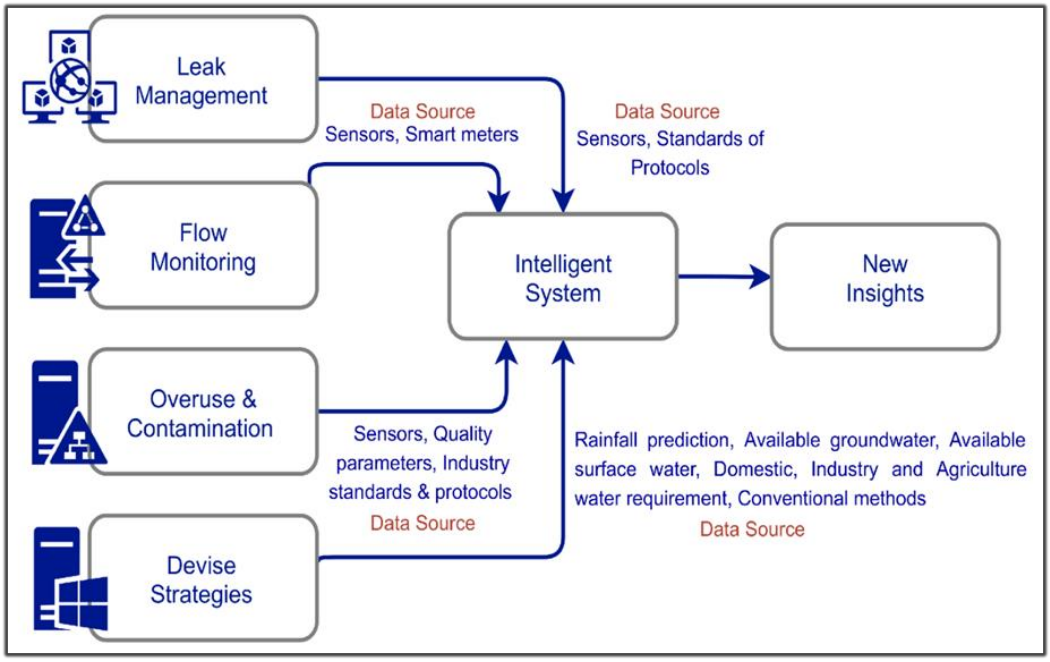
From Table 1, SIV includes all water supplied from sources like treatment plants and reservoirs. Part of this water is Authorized Consumption, which covers billed metered water, billed unmetered water, and unbilled but legitimate uses such as firefighting and system flushing.

The remaining water is NRW, which is split into real (physical) losses, water lost through leaks, bursts, or overflows, and apparent (commercial) losses, which occur when water is consumed but not billed due to meter inaccuracies, illegal connections, or data handling errors (Luo et al., 2020).

2.3. Modern Approaches to NRW

Modern approaches to NRW emphasize a transition from conventional reactive practices to integrated, data-driven management systems. The use of smart meters and sensor-based technologies enables real-time monitoring of water flow and consumption, thereby improving leak detection and reducing metering inaccuracies(Hamilton & Charalambous, 2020). These technologies are often embedded within IoT enabled systems, which facilitate continuous data collection on pressure, water quality, and usage patterns, enhancing operational efficiency and early fault detection. Furthermore, advanced tools such as GIS and machine learning allow utilities to integrate multiple data streams like the intelligent system to support predictive maintenance and informed decision-making.

Figure 1 Conceptual Framework for Intelligent NRW Management



Source*: Hong and Lee, 2019*

Strategies such as DMAs and SCADA based monitoring improve network control and enable precise localization of losses, reinforcing the need for a holistic approach that combines technical, commercial, and environmental data. The framework aligns with current academic consensus that effective NRW management relies on the integration of smart technologies and intelligent systems to generate actionable insights and optimize water utility performance. (Hong & Lee, 2019)

2.4. NRW on Global Perspective

Global trend analyses over the last decade show NRW remains a persistent and large problem, particularly in low and middle-income urban utilities. Quantitative syntheses and utility databases indicate many utilities continue to operate with NRW well above international benchmark of 25% of system input, producing large volumetric and monetary losses that undermine utility finances and service expansion (Liemberger & Wyatt, 2019). The NRW indicates the quality of the national water supply service, meaning huge amounts of NRW it shows that the water supply service is poorly managed.

NRW is most common in water stressed areas and it's a key driver that led to Water supply disruption which may end up increasing in cost and decline in productivity. It has become a thriving concern since the losses also affect the consumers because it may result in rising water tariffs to cover the lost revenue(Pathirane et al., 2024).

In Asia, especially In Malaysia it was noted that NRW was high with an average of 36% this was so due to poor organizational and management structures in the responsible agencies, insufficient funds to the water utilities, poor water network implementation. After a decade the NRW dropped to 23%(Farouk et al., 2023). Countries like Palestine where water is scarce, water loss is a major challenging and a serious issue, this huge levels of NRW reflects to huge amount of water that is being lost, this affects financial viability of water utilities, through lost revenue and increase in operational cost, this is so due to lack of good governance and inadequate technical skills (Pathirane et al., 2024).

Several studies published in Africa since 2019 estimate very high levels of NRW volumes and high percentages in many systems, highlighting a continued regional vulnerability. According to (Wainaina, 2016) NRW is increasing in an alarming rate in major water utilities companies in Kenya with an average of 40% making them lose about 44 million US dollars annually. These studies also document that NRW trajectories vary over time with operational decisions and external stresses, underlining the dynamic nature of NRW (Mubvaruri et al., 2022; Pathirane et al., 2024). Regionally relevant literature for Southern Africa and Malawi confirms the global pattern while offering useful methodological models. Case studies from Zimbabwe, Tanzania and other Sub-Saharan cities used utility production and billing records, DMA analysis, and minimum-night-flow approaches to decompose NRW components and to track trends(Mubvaruri et al., 2022; Shushu et al., 2021). These studies repeatedly show that apparent losses (metering and commercial issues) can be as large as, or larger than, physical losses in some contexts, and that DMA implementation combined with pressure management and meter replacement yields measurable short-term reductions, but long-term sustainability depends on institutional capacity and financing(Pathirane et al., 2024; Shushu et al., 2021).

2.5. NRW in Malawi

Malawi has been experiencing high levels of NRW water in all its five water utilities combined. The country's five water boards are losing close to MK60 billion annually due to NRW, which accounts for an average of 35 percent of water produced for their respective distribution systems(Banda, 2024).

The NRW loss has not improved since 2021, when a similar 35 percent in water losses across the five water boards was valued at K30 billion this is so due to losing huge volumes of water through illegal connections, vandalism of pipes and old piping networks and the recent studies show that BWB recorded the highest NRW of 50% followed by LWB of 35.8%, NRWB of 33%, SRWB of 30.9 while the CRWB of 27%. (Banda, 2024). BWB has the Highest NRW among boards, reflecting severe real and apparent losses. Intermittent supply and aging infrastructure aid up the leakage and bursting of pipe, high NRW depresses pressure at network extremities and erodes cost recovery and the other reason the BWB introduces the pre-paid metering system which end up making commercial loses since the meters were having some factory faults.

LWB also has higher levels of NRW but not as close to BWB. Earlier estimates suggested that LWB was losing over 35% of its potential revenue due to NRW, a financial drain that undermined both operational efficiency and the ability to invest in new infrastructure. In response, LWB has undertaken structured programs to address the problem, most notably the LiSCaP, supported by JICA (LWB, 2022). This program introduced DMAs across the city to localize monitoring, apply leak detection, and implement pressure management, while also strengthening institutional capacity through staff training, standard operating procedures, and improved production and sales reconciliation.

2.6. NRW Management at BWB

BWB was established in 1929 under the name Mudi Water Works, and it is one of the oldest water boards in Malawi. Like any other local utility, NRW at BWB has remained a persistent challenge. Estimates indicate wide fluctuations in NRW levels, ranging from about 20% in the mid-1990s to more than 50% in recent years, leading to significant financial losses for the

utility and the government (E. M. Banda & Mwale, 2018). These high figures expose long standing management gaps within BWB.

BWB has formally acknowledged NRW as a priority, participating in national NRW workshops and planning sessions. To address losses, the utility has adopted zonal structures and DMAs, assigning plumbers and caretakers to monitor and repair leaks. Task teams have also been created at different times to coordinate NRW activities (BWB, 2018). However, studies show that guidelines such as the Construction Management Manual, designed to standardize repair work, are inconsistently applied, resulting in varied repair quality and reliance on individual skills.

On technical approach, the utility has employed several strategies including active leakage detection, pipe repairs, meter replacement, and partial network rehabilitation. Diagnostic tools such as component analysis and minimum night flow have been used in some instances to assess losses, and DMA creation alongside pressure management has been recommended as best practice. Despite these efforts, implementation has been hampered by limited resources, aged infrastructure, and operational inconsistencies (Mapila, 2021). Apparent losses remain a challenge at BWB due to poor metering coverage, inaccurate customer records, and weak billing systems. Sector evaluations have emphasized the need for reliable meter asset management, systematic meter replacement, and improved revenue collection as core measures to address apparent losses (Blantyre Water Board, 2018).

According to (E. M. Banda & Mwale, 2018), the governance and financial challenges worsen the NRW problem at BWB. Low tariffs, limited cost recovery, and inadequate investment in infrastructure rehabilitation restrict BWB's ability to run systematic NRW programs. Parliamentary reports and independent reviews have highlighted how governance weaknesses and financial mismanagement amplify NRW and undermine service delivery.

CHAPTER 3: METHODOLOGY

3.1. Research Design

This study adopted a mixed method approach involving a descriptive research design based on secondary data analysis. The descriptive design is appropriate for the study as it allows the systematic examination and interpretation of existing information related to NRW, including its causes, trends, financial impacts and management strategies within the study area. By utilizing existing institutional records and documented datasets, the study provides a comprehensive overview of NRW dynamics and operational performance over time. The study also adopted an explanatory research design to identify and analyze relationships and potential causal linkages within the secondary data. Regression and correlation analyses are employed to examine the strength and direction of relationships among key variables influencing NRW levels.

3.2. Case Study

This study adopted a case study approach focusing on BWB as the unit of analysis. The case study design was selected to allow an in-depth examination of the NRW management strategies implemented by BWB within its real-life operational context. By concentrating on a single water utility, the study provided detailed insights into the specific practices, challenges, and institutional dynamics influencing NRW reduction.

However, a key limitation of this design is that the findings may not be fully generalizable to other water utilities in Malawi, due to differences in operational scale, infrastructure conditions, resource availability and institutional arrangements.

3.3. Desk Study

A desk study was employed in this research to systematically review and analyze existing literature, technical reports, and institutional records related to NRW management. This approach helped us to gather secondary data on established strategies, best practices, and documented challenges in water utilities, thereby providing a strong contextual and theoretical foundation for the study.

3.4. The Study Area

The research focused on the BWB, a public utility mandated to supply potable water to residents, institutions, and commercial customers within Blantyre City, Malawi. The BWB is a parastatal organization originally established in 1929 and reconstituted under the Water Works Act No. 17 of 1995 (BWB, 2018). It was founded following the construction of the Hynde Dam Scheme to provide piped water to the city. To meet rising demand, the Mudi Dam was commissioned in 1953, and subsequently, the Walker's Ferry scheme became the city's main water source. Guided by its vision to become a world class water utility in Malawi, the BWB has worked to ensure sustainable and equitable access to safe water (BWB, 2018).Its mission has been to provide reliable and affordable water supply services to all customers while addressing challenges such as water losses, aging infrastructure, and increasing urban demand.

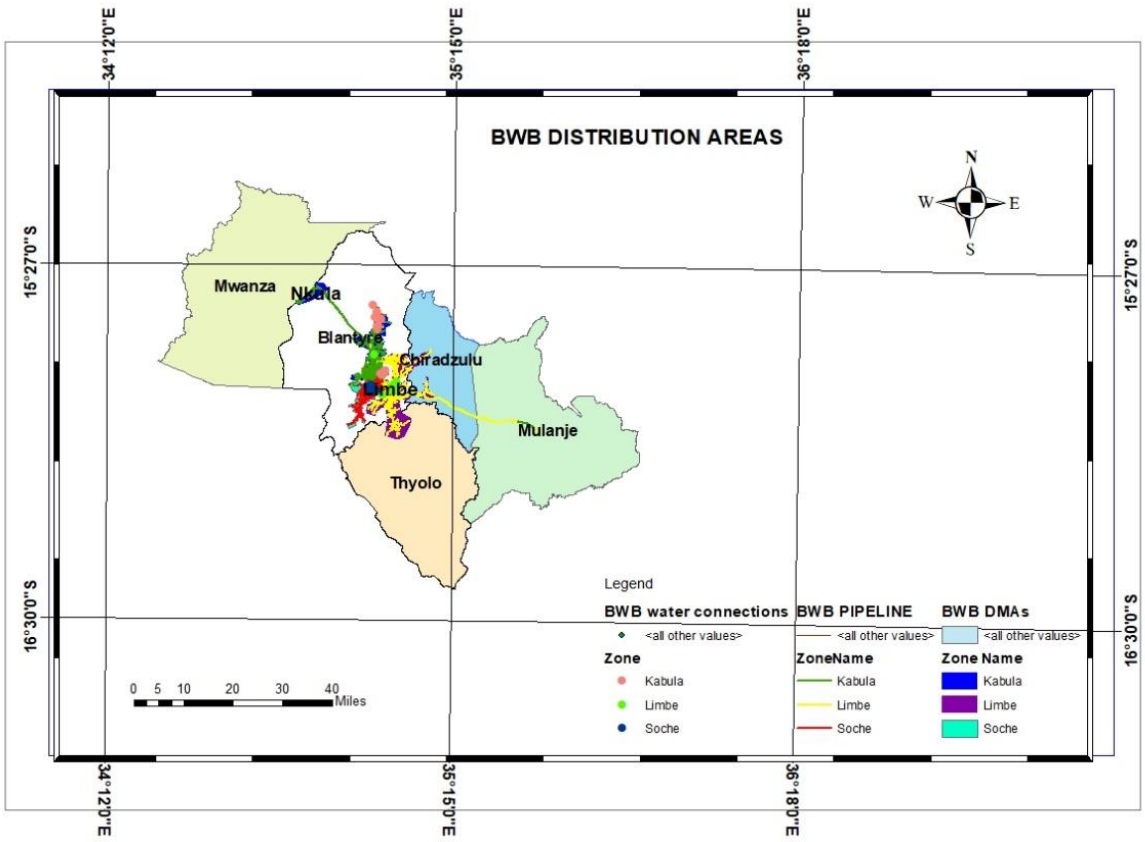


Figure 2 Showing Distribution Area of BWB

BWB abstracts raw water primarily from the Shire River at Walker's Ferry, located about 40 kilometers from Blantyre, it also abstracts from Likhubula River in Mulanje, and supplemented these supplies with water from the Mudi Dam within the city. The raw water undergoes treatment at the Walker's Ferry and Mudi treatment plants before being conveyed through pumping stations, reservoirs, and pipelines to consumers. The Board operates through three water supply zones of Kabula, Soche and Limbe, that ensure distribution across its service area. BWB's coverage extends over approximately 969 square kilometers, encompassing Blantyre City and parts of the surrounding districts of Chiradzulu and Thyolo, serving an estimated population of more than one million people (BWB, 2018).

3.5. Materials and Methods

Data was collected through a systematic review of documents. The process involved identifying, retrieving, and reviewing both published and unpublished materials relevant to NRW management at BWB. Sources were screened for credibility, reliability, and alignment with the study objectives. Documents obtained from institutional repositories and academic databases formed the core dataset. In addition to secondary data, interviews were conducted with 7 key informants drawn from the Blantyre Water Board. These included the Acting Procurement and Disposal Manager, Water Supply Manager, NRW Engineer, GIS Specialist, Billing Officer, Distribution Network Engineer, and Community Engagement Officer.

To ensure the credibility and reliability of the information obtained, only staff members with a minimum of 10 years of professional experience within the water utility sector or related technical fields were included in the study. This criterion was used to ensure that respondents had sufficient institutional knowledge and practical exposure to NRW-related operational challenges and management strategies.

3.6. Sampling Technique

The study employed purposive sampling in selecting key informants from the BWB. A total of 7 key informants were selected based on their direct involvement in water supply operations, distribution management, revenue administration, and NRW control activities within the utility.

Informants were included in the study based on a minimum of 10 years of professional experience within water supply or related technical fields, direct involvement in NRW-related activities or decision-making processes and active engagement in operational areas such as procurement, network management, billing, GIS mapping, and community water management

3.7. Data Collection Methods

Quantitative data such as water production, billed consumption, metered customers, revenue collection reports and production cost summaries were collected through institutional records.

In addition to documentary review, qualitative data were collected through semi-structured interviews with key informants selected using purposive sampling. This approach was appropriate because it targeted individuals with direct technical knowledge and operational experience in NRW-related functions within the utility. A total of 7 key informants were interviewed, and data collection continued until thematic saturation was reached, meaning no new substantial information was emerging from additional interviews.

The selected informants included the Acting Procurement and Disposal Manager, Water Supply Manager, NRW Engineer, GIS Specialist, Billing Officer, Distribution Network Engineer, and Community Engagement Officer. These participants were chosen based on their direct involvement in water production, distribution management, loss control, customer management, and infrastructure planning, all of which are central to NRW reduction efforts. Additional stakeholders such as the Finance Manager and Water Quality Officer were considered but were not included due to limited direct involvement in NRW operational control. The use of purposive sampling ensured that only information-rich cases were included, thereby enhancing the depth and reliability of qualitative insights.

3.8. Data analysis

The study applied both quantitative and qualitative analytical techniques to ensure a comprehensive interpretation of findings. NRW levels were determined using the formula obtained from BWB's NRW reduction manual (BWB, 2018), where NRW was calculated as

Equation 1 NRW

$$NRW[\%] = \left(1 - \left(\frac{M^3 of\ water\ billed}{M^3 of\ water\ supplied}\right)\right) * 100\%$$

Other quantitative data, including water production volumes, supply records and revenue collection rates, were analyzed using descriptive statistical methods such as percentages, averages, correlation, regression, minimum, maximum and trend analysis with the aid of IBM SPSS Statistics 20 and Microsoft 365 and Office version 16.0. The analysis enabled the identification of performance patterns, operational inefficiencies, and temporal variations in NRW levels. Qualitative data, including utility strategies, institutional reports, and interview responses, were analyzed using thematic analysis to extract key issues, management responses, and underlying factors influencing NRW. The integration of quantitative results and qualitative insights strengthened the robustness and reliability of the study findings and supported evidence-based conclusions.

3.9. Validity and reliability

To ensure validity and reliability, data were collected from credible institutional records and knowledgeable key informants. Interview questions were aligned with the research objectives and information obtained from interviews was compared with the existing literature for consistency.

3.10. Ethical consideration

Ethical standards were strictly observed throughout the research process to ensure transparency and responsible use of information. The study received ethical clearance from the Malawi University of Science and Technology Research Ethics Committee prior to the commencement of data collection.

Access to institutional and unpublished documents was granted through formal procedures. Relevant reports used in the study were obtained through the university and were presented to the BWB as supporting documentation to facilitate authorized access to operational information required for the research. All information obtained was used solely for academic purposes.

Confidentiality of sensitive institutional data was maintained by presenting results in summarized and aggregated form, thereby preventing disclosure of restricted or identifiable operational details. In addition, all secondary data sources were appropriately acknowledged to uphold academic honesty and avoid plagiarism.

3.11. Study limitations

The study is subjected to some limitations that may have influenced the scope and interpretation of the findings. Firstly, the research relied on a limited number of key informants, which may not fully represent the views of all stakeholders involved in NRW management. Secondly, the use of interview-based data collection introduces the possibility of response bias, as participants may have provided selective or socially desirable responses. Thirdly, the study utilized secondary data from existing reports and institutional records, which may be affected by issues of completeness and accuracy.

CHAPTER 4 : RESULTS

This section presents, analyses and discusses the findings of the study in relation to the research objectives. The results are presented using tables, figures and descriptive explanations followed by interpretation and comparison with existing literature.

4.1. Findings on the trend of NRW from 2015 to 2024.

This section focuses on findings on the determination of the trend of NRW at BWB over the period from 2015 to 2024. Understanding the trend is important in assessing whether NRW levels are improving, worsening, or fluctuating over time. The analysis uses annual data to identify patterns and variations in NRW percentages. Descriptive statistics and graphical representations are applied to visualize the trend clearly.

4.1.1. Trend Analysis of Non-Revenue Water

Table 2 presents the computed values of NRW and NRW percentages for the period 2015-2024 using water production and billed consumption data obtained from the BWB. NRW was calculated as the difference between total water produced and billed consumption, while NRW percentage was computed by expressing NRW as a proportion of total water production.

Table 2 Computation of NRW and NRW Percentage

Year	Water Production (M^3)	Billed Consumption (M^3)	NRW (M^3)	NRW (%)
2015	22,164,417	13,113,339	9,051,078	40.8
2016	27,604,659	12,213,425	15,391,234	55.8
2017	31,719,628	15,692,581	16,027,047	50.5
2018	29,414,433	17,374,772	12,039,661	40.9
2019	29,368,157	18,546,575	10,821,582	36.8
2020	33,497,833	15,551,274	17,946,559	53.6
2021	35,184,304	16,340,385	18,843,919	53.8
2022	24,297,825	11,524,413	12,773,412	52.6
2023	33,088,778	14,209,659	18,879,119	51.7
2024	37,788,374	14,387,520	23,400,854	61.9

The computed NRW values and percentages highlight notable variations and indicate persistent inefficiencies in water management.

4.1.2. Descriptive Statistics

Table 3 presents the descriptive statistics of water production, billed consumption, and NRW for the period 2015 to 2024.

Table 3 Descriptive statistics of water production

Statistic	N	Water Produced(M^3)	Water Billed (M^3)	NRW (M^3)	NRW (%)
Mean	10	30,412,840	14,895,394	15,517,447	49.82
Standard Deviation	10	4,592,982.053	2,123,499.04	4,173,492	7.43
Minimum	10	22,164,417	11,524,413	9,051,078	36.80
Maximum	10	37,788,374	18,546,575	23,400,854	61.90

Correlation Analysis

The correlation results show:

Water production and NRW: r = 0.681

Billed consumption and NRW: r = -0.047.

The results revealed a strong positive correlation between water production and NRW (r = 0.681, $p < 0.05$), indicating that increases in water supplied into the system were significantly associated with increases in water losses at a 95% confidence interval.

Regression Analysis of the trend of NRW at BWB

A linear regression model of NRW against time shows a positive slope, indicating an increasing trend in NRW over the study period. NRW increased from 40.8% in 2015 to 61.9% in 2024, confirming a worsening performance trajectory.

4.1.3. Trend of NRW at BWB from 2015 to 2024

Figure 3 illustrates the trend of NRW percentages at the BWB from 2015 to 2024. The graph shows fluctuations in NRW levels throughout the study period, with percentages consistently remaining above the internationally recommended benchmark of 25%.

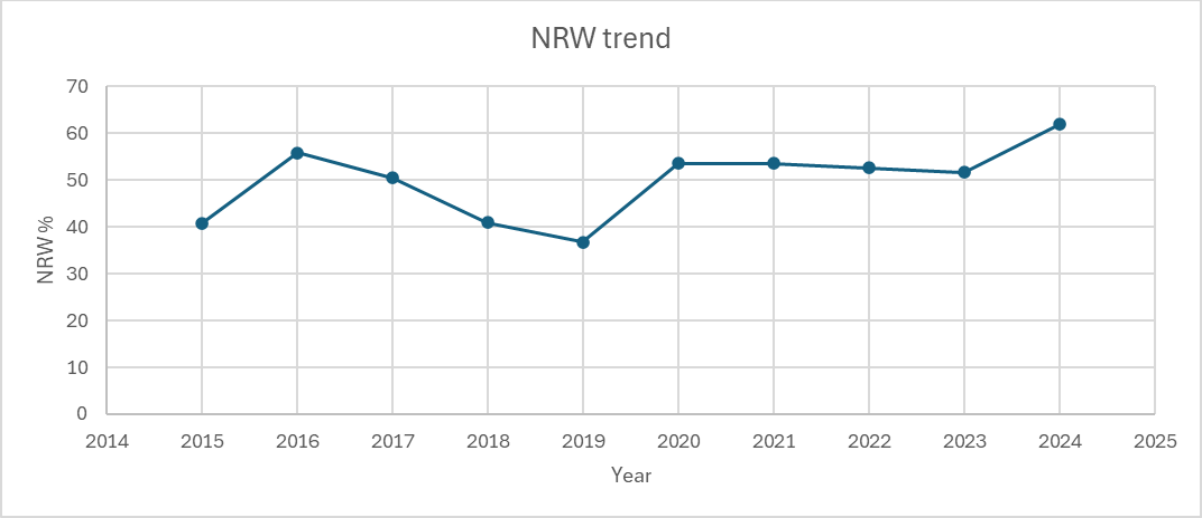


Figure 3 Graph 1 Trend of NRW at BWB (2015–2024)

4.1.4. Comparison of Water Production, Billed Consumption, and NRW

Water production shows an overall increasing trend, while billed consumption remains relatively stagnant. This widening gap results in increased NRW volumes, particularly after 2020.

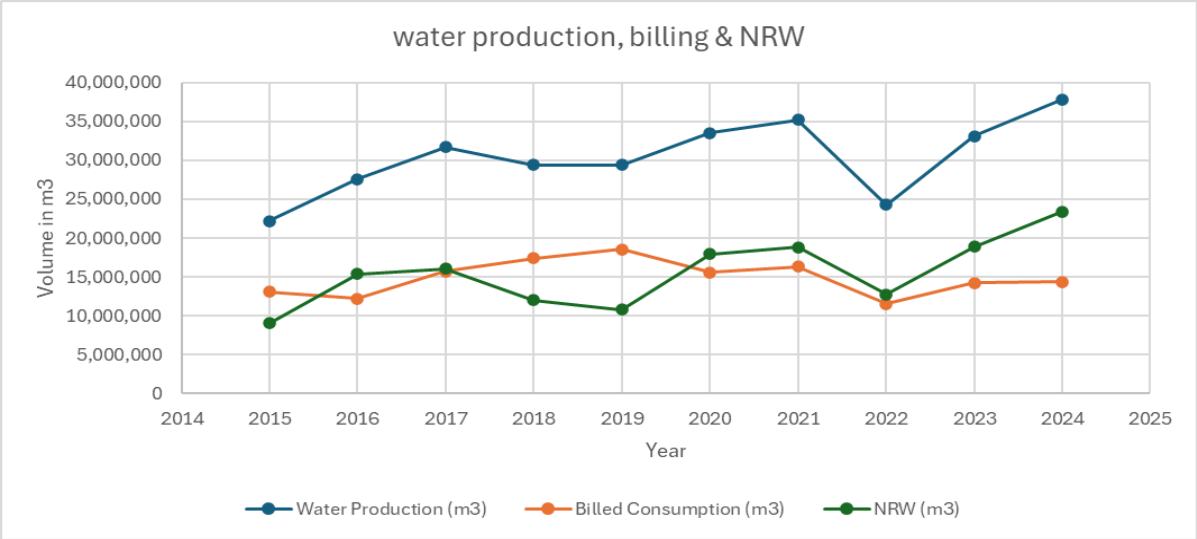


Figure 4 Graph 2 Comparison of Water Production, Billed Consumption, and NRW

4.2. Findings on the causes of NRW at BWB

This section presents the findings of technical, administrative and socio-economic causes of NRW at BWB.

4.2.1. Technical Causes of NRW at BWB

The study observed the following technical causes of NRW at BWB;

4.2.1.1. Increased Number of Faulty Meters

The study found that faulty and aging water meters significantly contribute to NRW at Blantyre Water Board. A total of 47,960 faulty meters were recorded between 2015 and 2024. These faulty meters were associated with under-registration of actual water consumption, resulting in substantial apparent losses.

4.2.1.2. Poor Pressure Management

The findings indicate that BWB relies mainly on pressure throttling without systematic monitoring. This results in fluctuating and excessive pressure levels that contribute to pipe stress, leak development, and frequent bursts.

4.2.1.3. Aged Infrastructure

Interview findings and infrastructure records show that more than 60% of distribution pipelines are over 30 years old, with a significant portion exceeding 40 years of service life. The system experiences frequent leaks and bursts due to material fatigue, corrosion, and joint failure.

4.2.2. Administrative Causes of NRW at BWB

The study observed the following administrative causes of NRW at BWB

4.2.2.1. Procurement and Supply Chain Inefficiencies

The study found that procurement delays for pipes, meters, and fittings affect timely maintenance and repair activities. Multiple approval layers and supplier delays result in prolonged system faults and extended water losses.

4.2.2.2. Poor Hydrant Management

The findings show that water abstraction through fire hydrants is not systematically measured or monitored. Weak coordination between BWB and the City Council contributes to unaccounted-for water use and possible illegal abstraction.

4.2.2.3. Inefficiencies in Detecting Illegal Connections

The study found that illegal connections and reconnections are mainly detected through random inspections and delayed customer reconnection requests. No real-time monitoring system is in place.

4.2.3. Socio-Economic Causes of NRW at BWB

The study observed the following socio-economic causes of NRW at BWB

4.2.3.1. Illegal Water Tapping in Peri-Urban Areas

The findings show deliberate pipe damage and illegal tapping in peri-urban areas, driven by limited access to affordable water services and economic hardship.

4.2.3.2. Illegal Connections and Meter Tampering

High-consumption households were found to engage in meter bypassing and tampering to reduce billing amounts.

4.2.3.3. Non-Payment of Water Bills

The study found that inability to pay water bills, particularly in low-income areas, contributes to revenue losses and increases NRW.

4.2.3.4. Influence of Scrap Metal Trade

The findings show that theft of metallic infrastructure components (meters, pipes, fittings) is driven by scrap metal markets, especially in high-density areas such as Ndirande and Chilomoni.

4.2.3.5. Informal Settlements and Encroachment

The study found that informal settlements built near or on pipelines hinder maintenance access and increase vulnerability to leaks, bursts, and illegal connections.

4.3. Findings on financial impact on NRW on BWB

This section presents results of the analysis of financial impact of NRW on BWB. NRW directly affects revenue generation and the financial sustainability of the institution. The analysis uses financial data to assess losses, revenue trends, and their relationship with NRW levels. Statistical tools such as correlation and regression are applied to determine the strength of this relationship.

4.3.1. Computation of Financial Impact and Financial Impact Percentage

Table 4 presents the computed financial impact and corresponding financial impact percentage derived from the comparison between water production costs and revenue collected by BWB from 2015 to 2024. The financial impact was obtained by calculating the difference between production costs and revenue collected for each year. Positive values indicate financial surplus, while negative values indicate financial loss.

Table 4 Computation of Financial Impact and Financial Impact Percentage

Year	Production Cost(MWK)	Revenue Collected(MWK)	Financial Impact (MWK)	Financial Impact (%)
2015	7,471,398,000	7,930,647,000	459,249,000	6.15
2016	6,403,362,000	8,076,578,283	1,673,216,283	26.13
2017	8,687,452,000	12,655,875,052	3,968,423,052	45.68
2018	15,327,623,444	15,686,035,553	358,412,109	2.34
2019	7,942,811,544	17,866,236,810	9,923,425,266	124.94
2020	15,561,902,345	17,096,128,316	1,534,225,971	9.86
2021	27,503,815,345	22,020,662,956	-5,483,152,389	-19.93
2022	18,589,161,171	14,721,774,520	-3,867,386,651	-20.80
2023	32,884,691,608	22,220,127,052	-10,664,564,556	-32.44
2024	42,435,331,266	31,042,857,090	-11,392,474,176	-26.84

Note*: Negative sign indicates financial loss*.

The results show that BWB experienced financial surpluses between 2015 and 2020, while persistent financial deficits were recorded from 2021 to 2024. The largest surplus was recorded in 2019, whereas the largest financial loss occurred in 2024.

4.3.2. Descriptive Statistics

Table 5 presents descriptive statistics for financial impact and financial impact percentage from 2015 to 2024

Table 5 Descriptive statistics of financial impact

Statistic	N	Financial Impact (MWK)	Financial Impact (%)
Mean	10	-349,615,009	11.91
Standard Deviation	10	6,804,000,000	48.72
Minimum	10	-11,392,474,176	-32.44
Maximum	10	9,923,425,266	124.94

The results indicate substantial variability in financial performance over the study period. The utility recorded an average financial deficit of approximately MWK 349.6 million, with considerable fluctuations over the years.

4.3.3. Production Cost versus Revenue Collected

Graph below shows the trends of the Water production cost and revenue collected by BWB over the study period.

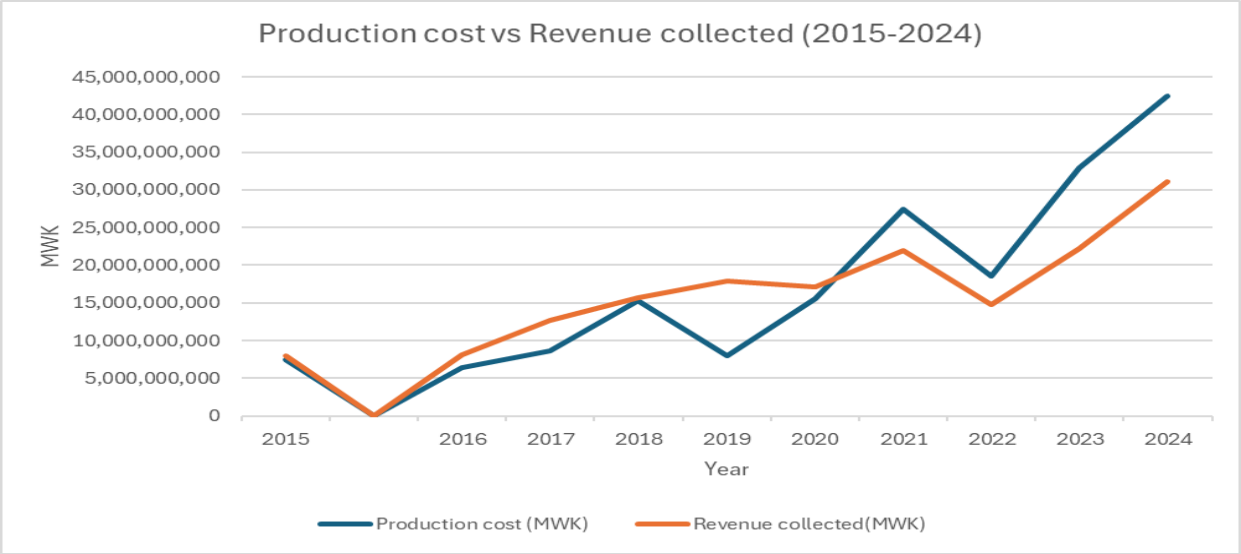


Figure 5 Graph 3 Production Cost vs Revenue Collected

The analysis of production costs and revenue collected shows that from 2015 to 2020, revenue consistently exceeded production costs. However, from 2021 onwards, production costs surpassed revenue collected, resulting in widening financial deficits. The gap between costs and revenue was greatest in 2023 and 2024.

4.3.4. Financial Impact of NRW

Graph 4 below shows the trends of the financial impact at BWB derived from the difference between total cost of water production and total revenue collected by BWB over the study period.

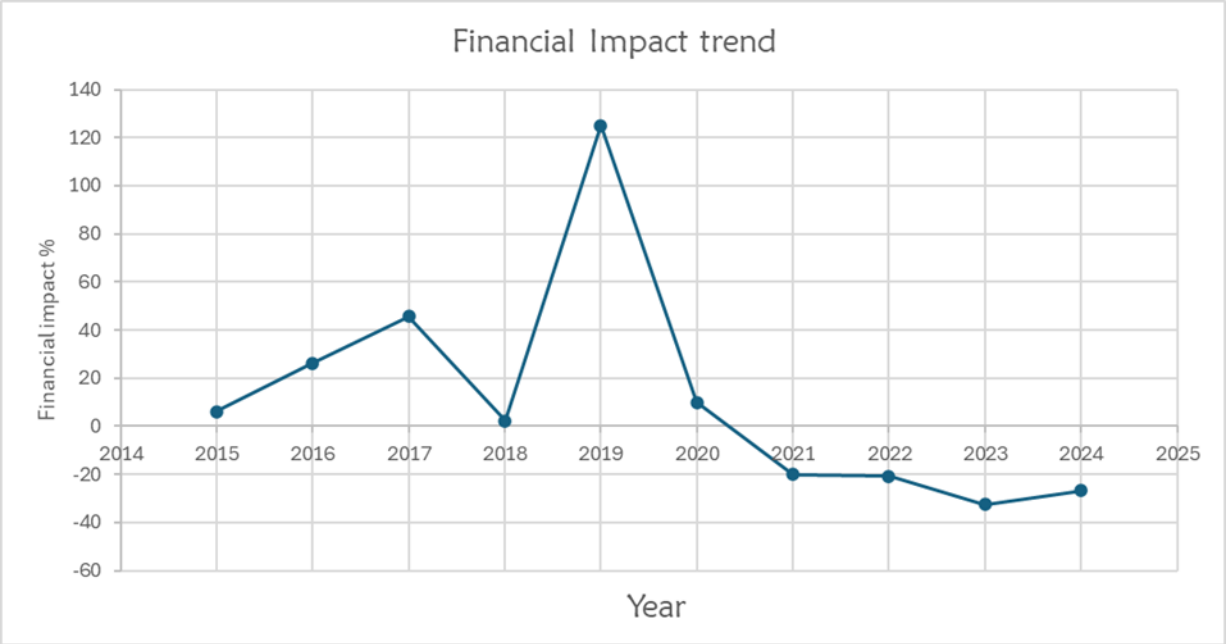


Figure 6 Graph 4 Analysis of financial impact of NRW

Analysis of financial impact trends shows that BWB maintained positive financial performance between 2015 and 2020, with the highest surplus recorded in 2019. From 2021 onwards, financial performance declined sharply, resulting in persistent deficits through 2024.

4.3.5. Relationship Between NRW and Financial Impact

The relationship between NRW and financial impact is presented in graph 5 to illustrate how variations in water losses influence the financial performance of the utility over time.

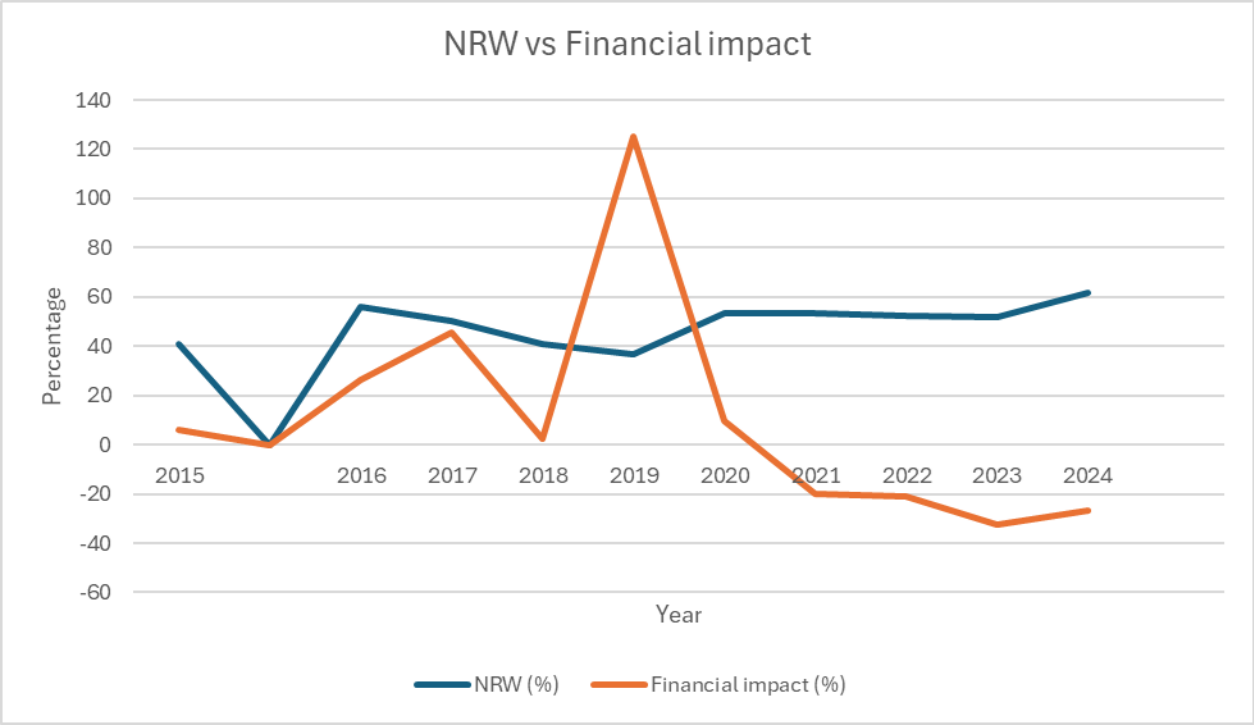


Figure 7 Graph 5 Relationship Between NRW and Financial Impact

The relationship between NRW and financial impact indicates that higher NRW levels were generally associated with worsening financial performance. During years with relatively lower NRW levels, the utility recorded positive financial outcomes. However, periods characterized by NRW levels above 50% corresponded with increasing financial deficits.

4.3.6. Correlation Analysis of NRW and Financial Impact

Pearson correlation analysis revealed a moderate negative relationship between NRW and financial impact, indicating that increases in NRW were associated with declining financial performance. Although the relationship was not statistically significant at the 5% level, the results suggest that NRW contributes to financial deterioration.

4.3.7. Regression Analysis of Financial Impact of NRW on BWB

Regression analysis showed a negative relationship between NRW and financial impact. The model indicates that higher NRW levels are associated with declining financial performance.

The regression further demonstrated moderate explanatory power, suggesting that NRW is an important determinant of financial outcomes.

4.4. Findings on NRW Reduction Strategies Implemented by BWB

This section presents findings on NRW reduction strategies implanted by BWB.

4.4.1. Caretaker Approach

The findings indicate that BWB adopted a caretaker approach comprising multiple NRW reduction interventions, including DMAs, active leakage control, pressure management, meter management, illegal connection control, infrastructure rehabilitation, and commercial management measures. The strategy was designed to address both physical and commercial losses through coordinated operational activities.

However, the study found that the strategy lacked clear prioritization of interventions according to dominant loss categories. DMAs were mainly used for water balancing and minimum night flow analysis, with limited use of continuous monitoring systems and real-time performance analytics.

Pressure management interventions existed but were limited in scope, with minimal use of advanced pressure control technologies such as automated pressure-reducing systems. Commercial loss management mainly focused on meter reading, verification, and customer disconnections, while advanced revenue analytics and integrated customer information systems were largely absent.

The study further established that the caretaker strategy lacked a comprehensive monitoring and evaluation framework, as measurable performance indicators, implementation timelines, and baseline NRW targets were not clearly defined. In addition, the strategy relied heavily on manual field operations and had limited integration of digital technologies such as smart metering, automated monitoring systems, and remote sensing tools.

4.4.2. Pipe Lowering and Replacement

The findings show that BWB implemented pipe lowering and replacement programmes targeting exposed pipelines, aged infrastructure, and sections experiencing frequent bursts. The interventions mainly focused on reducing physical losses by replacing deteriorated pipelines and relocating exposed pipes to safer depths.

The study established that pipeline replacement activities were largely reactive and concentrated on areas already experiencing repeated failures. Although burst-prone sections were prioritized, there was limited evidence of predictive maintenance planning or risk-based infrastructure assessment systems guiding rehabilitation activities.

The findings also indicate that pipe replacement programmes were constrained by high financial costs, technical requirements, and labor-intensive implementation processes. Resource limitations affected the pace and extent of infrastructure replacement activities.

4.4.3. Customer Satisfaction Initiatives

The study found that BWB implemented customer satisfaction initiatives aimed at improving customer engagement, complaint handling, and service responsiveness. These initiatives encouraged customers to report leaks, illegal connections, and billing anomalies.

The findings further show that improved communication and complaint resolution mechanisms contributed to increased customer cooperation in reporting operational problems within the network. However, customer satisfaction interventions were not directly linked to structured operational response systems for NRW reduction.

4.4.4. Meter Management

The findings reveal that meter management was a key NRW reduction strategy at BWB, focusing on reducing commercial losses arising from inaccurate billing, faulty meters, and unauthorized consumption. The utility emphasized meter availability, proper installation standards, calibration, auditing, and replacement programmes.

The study established that BWB maintained stocks of replacement meters and conducted periodic calibration, particularly for large customer meters and DMA boundary meters. Additional measures included installation of strainers and non-return valves to improve meter protection and accuracy.

However, several weaknesses were identified. Meter shortages and procurement delay occasionally resulted in prolonged unmetered consumption. Smaller customer meters were calibrated less frequently, with some intervals extending up to five years. The findings also indicate that reliance on manual meter reading created risks of human error, collusion, and inaccurate consumption recording.

4.4.5. Water Supply Management

The findings indicate that BWB implemented several water supply management measures to reduce NRW, including installation of ball valves in reservoirs to prevent overflows, routine flow measurements in transmission mains, reservoir drop tests, and periodic inspection of flow meters, valves, and pumping equipment.

These measures supported water balance analysis and system monitoring. However, the study found that most monitoring activities were periodic rather than continuous, limiting the utility's ability to detect leaks and operational failures in real time. The effectiveness of the strategy was also affected by challenges related to instrument calibration, technical capacity, and financial resource constraints.

4.4.6. Administrative Strategy

The study found that BWB implemented administrative measures aimed at strengthening institutional capacity and governance in NRW management. These included staff training, provision of safety equipment and operational tools, strengthening policies on illegal connections and borehole drilling, and enforcement measures against unauthorized water use. The findings indicate that the strategy improved institutional awareness of NRW management and strengthened enforcement efforts.

However, the strategy relied heavily on punitive approaches and lacked clearly defined performance monitoring indicators and evaluation frameworks. Resource limitations and inconsistent training programmes also affected implementation effectiveness.

4.4.7. Finance and Procurement Strategy

The findings show that BWB adopted finance and procurement interventions aimed at improving availability of NRW-related materials and strengthening operational support systems. Priority was given to procurement of pipes, fittings, meters, and maintenance materials required for NRW reduction activities.

The study established that timely supplier payments improved procurement responsiveness and emergency material availability. BWB also implemented incentive mechanisms encouraging reporting of illegal connections. However, financial constraints, procurement delays, and weak procurement risk management systems limited the effectiveness of the strategy. The study further found that the absence of clearly defined prioritization frameworks occasionally affected efficient allocation of resources.

4.4.8. Infrastructural Development Strategy

The findings indicate that BWB implemented infrastructural development measures focusing on rehabilitation and modernization of aging infrastructure. This included replacement of asbestos pipes, upgrading of burst-prone sections, and adherence to construction standards during new installations.

The study established that demand analysis was used to support infrastructure planning, while coordination with other service providers helped reduce accidental infrastructure damage during construction activities.

Despite these efforts, implementation was constrained by high financial requirements, temporary service disruptions during replacement activities, incomplete asset data systems, and institutional coordination challenges.

4.4.9. NRW Coordination

The findings reveal that BWB established an NRW coordination mechanism responsible for validating DMA data, consolidating operational information, and coordinating activities across departments.

The study found that centralized coordination improved data sharing and reduced duplication of operational activities. However, the effectiveness of the coordination framework was constrained by limited institutional authority, inconsistent data management systems, and inadequate analytical tools for performance monitoring and reporting.

CHAPTER 5: DISCUSSION

5.1. Discussion of findings on NRW trends at BWB

The study reveals persistently high NRW levels at BWB, averaging 49.82% over the study period. This is significantly above the internationally recommended threshold of 20–30% for efficient water utilities(Liemberger & Wyatt, 2019). Such elevated levels indicate deep structural inefficiencies in both physical infrastructure and operational management systems.

This finding is consistent with global evidence showing that NRW remains a widespread challenge in developing country utilities, where levels frequently exceed 40% and, in some cases, surpass 50% due to systemic constraints Their seminal World Bank study highlights that NRW in developing contexts is largely driven by a combination of physical losses and commercial losses, all of which reinforce each other in weak institutional environments.

Similar patterns have been observed across Sub-Saharan Africa. For example, a review by McKenzie and Seago (2019) found that many African utilities experience NRW levels ranging between 30% and 60%, largely attributed to aging pipe networks, inadequate maintenance, and insufficient investment in pressure management systems. These conditions closely mirror the situation observed at BWB, where infrastructure deterioration and operational limitations are key drivers of losses.

Case studies from Rwanda and Benin further reinforce these findings. In Rwanda, Water and Sanitation Corporation (WASAC) recorded NRW levels above 40%, despite ongoing reforms, with major contributing factors including leakage, metering inaccuracies, and weak network monitoring systems(Karamage et al., 2016). Similarly, a recent case study in Benin reported NRW levels of approximately 39%, driven by aging infrastructure, illegal connections, and institutional inefficiencies in loss management systems (Badou et al., 2026). These comparative cases demonstrate that high NRW is not an isolated issue but a regional structural challenge in water utility management.

5.1.1. Increasing Trend of NRW

The upward trend in NRW, particularly after 2020, suggests a progressive deterioration in system efficiency within the water distribution network. This pattern is consistent with Kingdom et al, (2006), who argue that NRW tends to accumulate over time in utilities that lack sustained investment in preventive maintenance, leakage control, and infrastructure rehabilitation. Their findings emphasize that without continuous intervention, losses become systemic rather than incidental, leading to long-term inefficiencies in water supply systems.

The results are further supported by (Mutikanga et al., 2011) who observed that many African water utilities experience rising NRW levels due to aging infrastructure, weak asset management practices, and limited operational monitoring systems. Similarly, (McKenzie & Seago, 2005) highlight that real water losses in distribution systems are strongly linked to deteriorating pipe conditions, intermittent maintenance practices, and inadequate pressure management, all of which are common challenges in developing country utilities.

Empirical evidence from Sub-Saharan Africa further demonstrates similar trends. McKenzie, Seago reports that utilities across the region frequently operate with NRW levels exceeding 40%, largely due to aging distribution networks and insufficient investment in pressure management systems. In a related study, Hamilton & Charalambous(2020)argue that the absence of systematic leakage management programs leads to compounding losses, where small undetected leaks develop into major system failures over time.

5.1.2. Water Production and NRW Relationship

The strong positive correlation between water production and NRW of 0.681 indicates that increases in water supplied into the system are associated with higher water losses. This suggests that expanding production without corresponding system improvements may intensify inefficiencies within the distribution network. This finding is consistent with the (Liemberger & Wyatt, 2019), which explains that higher production often increases system pressure, thereby accelerating leakage in aging infrastructure.

Similarly, McKenzie and Seago (2011) note that increasing production without parallel investments in leakage control and infrastructure rehabilitation typically worsens real losses in water distribution systems. Further supporting this, Mutikanga et al. (2011) found that many African utilities experience higher NRW when production increases are not matched with effective asset management and pressure control systems. Al-Washali et al. (2020) also emphasize that in developing country contexts, NRW is highly sensitive to system pressure and infrastructure condition, meaning that production expansion alone can exacerbate leakage.

5.1.3. Weak Relationship Between Billing and NRW

The negligible correlation of 0.047 between billed consumption and NRW indicates that improvements in billing alone have minimal effect on NRW reduction. This supports Hamilton & Charalambous (2020), who argue that NRW is driven by physical losses occurring before the metering stage. Similarly, Al-Washali et al. (2020) emphasize that commercial loss reduction must be combined with strong leakage control strategies to achieve meaningful NRW reductions.

5.1.4. Production-Consumption Gap

The widening gap between water production and billed consumption reflects increasing inefficiency within the water supply system. This divergence indicates that a growing proportion of treated water is not being converted into revenue, thereby contributing directly to higher NRW levels. Such a pattern is often symptomatic of both technical and commercial system weaknesses.

Mutikanga et al. (2011) explain that persistent gaps between production and consumption are typically driven by a combination of physical losses, such as leakages and bursts, and commercial losses, including meter inaccuracies, data handling errors, and unauthorized consumption. These issues tend to reinforce each other, particularly in systems with aging infrastructure and weak monitoring frameworks.

5.2. Discussion of findings on causes of NRW at BWB

This section discusses the findings on the technical, administrative and socio-economic causes of NRW at BWB.

5.2.1. Technical Causes of NRW

The high number of faulty meters identified in this study aligns with evidence that meter inaccuracy is a major contributor to apparent losses in water utilities. According to (Fontanazza et al., 2015), meter degradation over time leads to systematic under-registration, particularly at low flow rates, resulting in significant revenue losses when replacement programs are not effectively implemented. (Hamilton & Charalambous, 2020) further emphasize that metering errors can constitute a substantial share of NRW in systems where meters are aged, poorly maintained, or not regularly calibrated, especially in utilities with limited technical capacity.

McKenzie and Seago (2005) also note that uncontrolled pressure fluctuations significantly increase both background leakage and burst frequency, particularly in deteriorating networks. The International Water Association (Lambert, 2013) similarly identifies pressure management as one of the most cost-effective interventions for reducing NRW, especially when implemented through DMAs and PRVs. Without such controls, systems tend to experience accelerated pipe failures and higher leakage volumes.

A practical illustration of the effectiveness of pressure management is evident in the case of Johannesburg Water, where the implementation of pressure management zones led to substantial reductions in leakage and burst frequency in selected DMAs. Water Research Commission,(2017) reported that optimized pressure control resulted in significant water savings and reduced system stress, demonstrating that even aging infrastructure can achieve improved performance when hydraulic pressures are properly managed. This case reinforces the observation that the absence of structured pressure management at BWB likely contributes directly to persistent physical losses.

Comparable evidence is found in the case of Dar es Salaam Water and Sewerage Authority (DAWASA), Tanzania, where aging distribution networks and delayed rehabilitation programs were identified as major contributors to high NRW levels exceeding 40%. (Stephen et al., 2020)Despite improvements in management systems, persistent pipe deterioration continued to drive leakage losses, demonstrating that infrastructure age remains a structural constraint that cannot be addressed through operational measures alone without sustained investment in renewal programs.

The high number of faulty meters identified in this study aligns with evidence that meter inaccuracy is a major contributor to apparent losses in water utilities. According to(Fontanazza et al., 2015), meter degradation over time leads to systematic under-registration, particularly at low flow rates, resulting in significant revenue losses if replacement programs are weak.

5.2.2. Administrative Causes of NRW

Procurement inefficiencies identified in this study reflect broader governance and institutional challenges in water utility management. Al-Washali et al. (2020) emphasize that institutional inefficiencies particularly slow procurement cycles, weak contract management, and inadequate supply chain planning significantly undermine NRW reduction efforts in developing country utilities by limiting timely access to essential materials such as pipes, fittings, and meters.

A practical illustration of procurement-related inefficiencies contributing to NRW is evident in the case of Ghana Water Company Limited (GWCL), where delays in procurement of pipes and metering equipment were reported to slow down leakage repair programs and meter replacement initiatives(Sekyere et al., 2020). This resulted in prolonged system losses and reduced effectiveness of NRW reduction interventions, highlighting how administrative inefficiencies directly translate into physical and commercial water losses. This case reinforces the finding that delayed procurement processes at BWB likely contribute to the persistence of system inefficiencies.

Poor hydrant management identified in this study aligns with Alegre et al., (2016), who emphasize that all forms of authorized consumption including firefighting must be accurately measured and incorporated into water balance calculations to avoid hidden NRW. When hydrant usage is not monitored or quantified, it is often misclassified as losses, thereby distorting utility performance indicators. Liemberger and Wyatt (2019) further note that weak coordination between utilities and municipal authorities increases the risk of unaccounted-for water and weakens accountability systems, particularly in urban water supply networks where multiple institutions share operational responsibilities.

The inefficiency in detecting illegal connections reflects a widespread limitation in many developing water utilities. Hernández (2018) demonstrate that traditional inspection-based approaches are often insufficient because unauthorized consumption is typically intermittent, concealed, and strategically timed to avoid detection. As a result, illegal connections and reconnections can persist for long periods without being identified. In contrast, modern NRW management increasingly relies on data-driven approaches, including smart metering, pressure monitoring, and anomaly detection systems that enable real-time identification of abnormal consumption patterns (Berglund et al., 2020).

5.2.3. Socio-Economic Causes of NRW

Illegal water tapping in peri-urban areas reflects broader socio-economic inequalities in access to basic services. Karki (2023) notes that illegal abstraction is often driven by affordability constraints, irregular supply, and limited access to formal connections in low-income settlements. Similarly, (Williams et al., 2018) demonstrate that informal settlements are particularly vulnerable to water theft due to weak institutional enforcement and inadequate service coverage, which compels residents to rely on unauthorized means of access. Meter tampering in high-consumption households highlights the dual nature of NRW drivers. Kingdom et al. (2006) emphasize that illegal consumption is not limited to low-income groups but also occurs among higher-income users who manipulate meters or bypass billing systems to reduce financial burden. This indicates that NRW is shaped not only by poverty but also by opportunistic behavior across different socio-economic groups.

Non-payment of water bills aligns with findings by Al-Washali et al. (2020), who argue that affordability constraints, combined with unreliable service delivery, significantly reduce willingness to pay in many developing country utilities. This often creates a reinforcing cycle in which poor revenue collection limits investment in infrastructure, further worsening service quality and increasing default rates.

The role of the scrap metal trade in infrastructure vandalism is supported by global evidence linking illegal markets to increased theft of utility assets. Mutikanga et al.(2011) notes that informal and poorly regulated scrap markets create strong economic incentives for the theft of metallic infrastructure components. Williams et al. (2018) further explain that such markets contribute to systemic vandalism of public infrastructure, including water pipelines and meters, thereby increasing both physical and commercial losses.

Finally, informal settlement encroachment reflects rapid urbanization and weak spatial planning in many developing cities.(Ndawo et al., 2025) reports that unplanned urban growth often results in settlements expanding into utility corridors, increasing exposure of infrastructure to damage and restricting maintenance access. Berglund et al (2020) further highlights that such encroachment prolongs leak repair times, increases system vulnerability, and facilitates unauthorized connections, all of which intensify NRW levels.

A relevant case is the experience of Cape Town, where rapid expansion of informal settlements in peripheral urban areas significantly increased illegal connections and infrastructure damage, contributing to elevated NRW levels. Studies show that limited-service coverage and weak enforcement mechanisms in such areas made it difficult for the utility to control losses effectively, demonstrating how socio-economic pressures directly translate into system inefficiencies (McKenzie & Seago, 2005).

5.3. Discussion of findings on financial impact of NRW at BWB

This section discusses the findings on the financial impacts of NRW at BWB.

5.3.1. Financial Deterioration and Declining Cost Recovery

The findings reveal a progressive deterioration in the financial performance of BWB over the study period, particularly from 2021 onwards when production costs consistently exceeded revenue collected. The transition from financial surpluses in earlier years to persistent deficits indicates declining operational sustainability and weakening cost recovery capacity. This trend suggests that the utility increasingly struggled to recover the costs associated with water production and distribution, thereby exposing the institution to long-term financial instability.

These findings are consistent with global evidence showing that high levels of NRW significantly undermine the financial sustainability of water utilities. Liemberger & Wyatt, (2019) explain that NRW simultaneously reduces utility income and increases operational expenditure because utilities continue to incur costs for water abstraction, treatment, pumping, and distribution even when that water does not generate revenue. In such circumstances, utilities face growing financial pressure as operational costs rise faster than revenue collection.

Similarly, Al-Washali et al.(2019) argue that utilities experiencing persistent NRW often suffer from unstable financial performance due to inefficiencies in both technical operations and commercial management systems. High leakage rates, inaccurate metering, illegal consumption, and weak billing systems collectively reduce cost recovery efficiency and weaken the financial position of utilities. The situation observed at BWB reflects this pattern, where increasing NRW levels coincided with rising production costs and worsening financial deficits after 2020.The deterioration in financial performance may also indicate broader institutional and operational weaknesses.

According to IWA, utilities with inadequate infrastructure maintenance and weak asset management systems tend to experience escalating operational costs because aging networks require frequent repairs, emergency interventions, and higher pumping requirements. Without parallel improvements in revenue collection and NRW reduction, these rising costs become financially unsustainable over time. (Yilmaz et al., 2021)

Comparable findings have been reported in several African water utilities. At the Nairobi City Water and Sewerage Company in Kenya, persistent NRW levels above 40% significantly weakened cost recovery and reduced financial sustainability, as large volumes of unbilled water increased operational expenditure while limiting the utility's ability to finance infrastructure rehabilitation and service expansion (Obunga et al., 2025).

5.3.2. Variability in Financial Impact

The high standard deviation and wide fluctuations observed in the financial impact indicators demonstrate considerable instability in the financial performance of BWB throughout the study period. The large variation between the highest recorded surplus and the severe deficits observed after 2020 indicates that the utility's financial position was highly vulnerable to operational inefficiencies, rising production costs, and weaknesses in revenue recovery mechanisms. Such volatility suggests that financial outcomes were not stable over time but were strongly influenced by changes in system efficiency, particularly the persistent increase in NRW levels.

This finding is consistent with Alegre et al. (2016), who emphasize that utilities experiencing poor NRW management often face unstable financial conditions because water production costs continue to rise while substantial portions of produced water fail to generate revenue. In such systems, utilities incur treatment, pumping, and distribution costs for water that is ultimately lost through leakages, unauthorized consumption, or metering inaccuracies, thereby weakening cost recovery capacity. Similarly, Ociepa (2021) argue that persistent NRW significantly undermines the financial resilience of water utilities by increasing operational expenditure while simultaneously reducing billing efficiency and revenue generation.

The substantial transition from strong financial surpluses between 2015 and 2019 to severe financial losses from 2021 onwards further indicates the presence of structural inefficiencies rather than short-term operational fluctuations. Mutikanga et al. (2011) note that many African water utilities experience similar financial instability due to aging infrastructure, weak maintenance systems, and inadequate investment in NRW reduction programs. Where utilities fail to rehabilitate deteriorating networks or strengthen monitoring systems, operational costs tend to escalate progressively while revenue performance declines. A comparable situation was reported in the Dar es Salaam Water and Sewerage Authority (DAWASA) in Tanzania, where rising NRW levels combined with increasing operational costs contributed to persistent financial instability despite expansion in water production capacity (Stephen et al., 2023). Similar findings were also observed in Nairobi City Water and Sewerage Company in Kenya, where high NRW levels significantly reduced cost recovery efficiency and weakened the utility's financial sustainability due to growing expenditure on production and emergency maintenance (Isaac Murimi & of Nairobi, 2015). These case studies demonstrate that increasing production alone does not guarantee financial improvement when substantial volumes of water are lost before billing.

5.3.3. Production Cost and Revenue Imbalance

The widening gap between production costs and revenue collected reflects increasing inefficiency in converting produced water into financial returns at BWB. Although water production increased over the study period, revenue growth did not occur at the same rate, indicating that a substantial proportion of treated water failed to generate income. This imbalance suggests that increasing production alone cannot improve utility performance when large volumes of water are lost before reaching the point of billing. These findings are consistent with the IWA, which states that utilities with high NRW often experience escalating operational costs without corresponding revenue growth because significant portions of treated water are lost through leakages, unauthorized consumption, and metering inaccuracies (Ociepa et al., 2018). In such situations, utilities continue to incur costs related to abstraction, treatment, pumping, and distribution despite limited financial recovery from water sales.

Similarly, McKenzie and Seago (2019) argue that expanding production capacity without simultaneous investment in leakage reduction, infrastructure rehabilitation, and pressure management frequently worsens financial inefficiency. Increased production tends to raise system pressure, which may accelerate leakage rates and pipe bursts in aging distribution networks, thereby increasing operational expenditure while reducing revenue efficiency.

The imbalance observed at BWB also reflects the broader challenge of weak operational efficiency in many developing-country utilities. Al-Washali et al. (2020) explain that utilities experiencing persistent NRW often face rising production costs because additional water must be continuously produced to compensate for losses within the system. This creates a cycle where utilities spend more resources on production while financial returns remain constrained due to poor billing efficiency and unaccounted-for water. A comparable situation was reported at Johannesburg Water in South Africa, where increasing production costs associated with leakage and pressure-related losses significantly increased operational expenditure before pressure management interventions were introduced (McKenzie & Seago, 2005). Following the implementation of pressure control measures, the utility experienced notable reductions in leakage volumes and operational costs, demonstrating the importance of integrating production expansion with effective NRW reduction strategies. Similar findings were also observed in Kampala Water, Uganda, where rising production costs combined with high NRW levels reduced cost recovery efficiency despite increased water supply capacity (Mutikanga et al., 2017). The study showed that utilities may fail to achieve financial gains from production expansion when system losses remain uncontrolled. Therefore, the findings from BWB suggest that sustainable financial improvement requires not only increased water production but also substantial investment in leakage reduction, infrastructure rehabilitation, pressure management, and commercial efficiency improvements.

5.3.4. Relationship Between NRW and Financial Performance

The observed inverse relationship between NRW and financial performance demonstrates that increasing water losses contributed significantly to declining financial outcomes at BWB over time. The persistence of NRW levels above 50% after 2020 coincided with escalating financial deficits, indicating that excessive water losses had become financially unsustainable for the utility. This pattern suggests that a substantial proportion of water produced by the utility failed to generate revenue, thereby weakening cost recovery and increasing operational strain. These findings are consistent with Liemberger and Wyatt (2019), who explain that NRW represents both a physical and financial loss because utilities incur the full costs of water abstraction, treatment, pumping, and distribution for water that is not billed or paid for. As NRW increases, utilities experience declining revenue efficiency while operational expenditure continues to rise, thereby undermining financial sustainability. Similarly, Al-Washali et al. (2020) emphasize that persistently high NRW levels significantly reduce cost recovery capacity and weaken the long-term financial sustainability of water utilities, particularly in developing countries where institutional and financial resources are already constrained. High NRW reduces the ability of utilities to finance infrastructure maintenance, service expansion, and operational improvements, creating a cycle of deteriorating performance and increasing inefficiency. The non-linear relationship observed in this study is also supported by existing literature. Kingdom et al, (2006) argue that the financial impact of NRW is often influenced by other operational and economic factors such as tariff structures, energy costs, subsidy arrangements, and billing efficiency. As a result, utilities may temporarily maintain positive financial performance despite moderate NRW levels through tariff adjustments or external financial support. However, when NRW remains persistently high over extended periods, operational costs eventually exceed revenue generation capacity, leading to sustained financial deficits. A similar situation was reported in Kampala Water, Uganda, where NRW levels exceeding 45% contributed to declining operational efficiency and increasing financial pressure despite efforts to expand production and adjust tariffs (Mutikanga et al., 2017).

The study found that continued water losses significantly reduced revenue recovery and increased expenditure on water production and emergency maintenance. Comparable

findings were also reported in Tanzania's Dar es Salaam Water and Sewerage Authority (DAWASA), where persistent NRW reduced financial sustainability by increasing operating costs while limiting revenue collection efficiency (Stephen et al., 2025).

5.4. Discussion of findings on NRW Reduction Strategies Implemented by BWB

This section discusses the findings of the implemented strategies of reducing NRW at BWB.

5.4.1. Caretaker Approach

The caretaker approach adopted by BWB reflects internationally recognized integrated NRW management principles, which emphasize combining technical, commercial, and administrative interventions to address water losses holistically. Studies show that NRW is multidimensional and requires coordinated interventions involving leakage management, pressure control, metering improvement, and institutional strengthening (Hoțupan et al., 2019). However, the findings suggest that BWB's approach lacks strategic prioritization and analytical integration. Contemporary NRW literature emphasizes that utilities achieve better outcomes when interventions are tailored according to dominant loss components rather than applying generalized approaches (Alegre et al., 2016). Utilities that separate physical losses from apparent losses during intervention planning are more capable of allocating resources efficiently and achieving measurable reductions. The limited exploitation of DMAs beyond water balancing also constrains effectiveness. According to the International Water Association, modern DMA systems should support continuous monitoring, anomaly detection, and rapid operational response. Similar limitations were observed in utilities in Zambia and Tanzania, where DMAs existed physically but lacked digital monitoring systems, reducing their operational value in NRW reduction (Ferrari & Savic, 2015). The reliance on reactive maintenance rather than predictive asset management further weakens sustainability. Studies indicate that predictive maintenance systems supported by condition monitoring and asset analytics significantly reduce burst frequency and operational costs (Shabangu et al., 2020).

In Singapore's Public Utilities Board, predictive monitoring combined with smart analytics contributed to NRW levels below 5%, demonstrating the effectiveness of proactive infrastructure management (Hoțupan et al., 2019).

5.4.2. Pipe Lowering and Replacement

The findings on pipeline lowering and replacement are consistent with global evidence showing that aging and exposed infrastructure are major drivers of physical water losses. Pipe deterioration caused by corrosion, material fatigue, and operational stress significantly increases leakage frequency in distribution systems (Liemberger & Wyatt, 2019).

The reactive nature of replacement activities observed at BWB reflects a common challenge among utilities in developing countries. Studies emphasize that effective infrastructure management requires risk-based asset planning and predictive rehabilitation rather than responding only after bursts occur (Kanakoudis & Muhammetoglu, 2014). Utilities relying heavily on reactive maintenance typically experience recurring failures and higher long-term operational costs. A comparable case was reported at the Nairobi City Water and Sewerage Company in Kenya, where recurrent pipe bursts persisted until the utility introduced risk-prioritized rehabilitation programmes targeting high-failure zones identified through asset condition analysis (Obunga et al., 2025)

5.4.3. Customer Satisfaction Initiatives

Customer engagement initiatives implemented by BWB align with literature emphasizing the importance of public participation in NRW management. Studies show that customer cooperation improves leak reporting, detection of illegal connections, and overall operational responsiveness(Ociepa et al., 2019). However, the findings indicate that these initiatives remain weakly integrated into operational workflows. Research demonstrates that customer engagement contributes meaningfully to NRW reduction only when linked to structured response systems, digital reporting platforms, and rapid repair mechanisms(Kanakoudis & Gonelas, 2014), For example, utilities in Turkey and Greece achieved improved leak detection rates after integrating customer reporting systems with centralized maintenance dispatch platforms, enabling faster response to reported

faults(Kanakoudis & Muhammetoglu, 2014). Without such operational integration, customer satisfaction initiatives mainly improve public perception without significantly reducing actual water losses

5.4.4. Meter Management

The findings confirm that meter management remains a critical component of commercial loss reduction. Literature consistently identifies inaccurate metering, under-registration, and delayed replacement as major contributors to apparent losses in water utilities (Karema et al., 2025). The calibration programmes and installation standards implemented by BWB align with the best international practices. According to IWA guidelines, regular calibration and auditing of customer and DMA meters are essential for maintaining billing accuracy and protecting utility revenue (Alegre et al., 2016). Nevertheless, long calibration intervals for smaller meters and continued reliance on manual meter reading significantly weaken the strategy. Studies show that older residential meters progressively under-register consumption, especially at low flow rates, leading to cumulative revenue losses over time (Karki, 2023). A similar challenge was reported in Uganda's National Water and Sewerage Corporation (NWSC), where manual meter reading and delayed meter replacement contributed to apparent losses before the introduction of automated meter reading technologies (Mutikanga et al., 2017). Utilities adopting smart metering systems have reported improved billing accuracy, reduced collusion, and enhanced consumption monitoring capabilities (Fontanazza et al., 2015).

5.4.5. Water Supply Management

The water supply management interventions implemented by BWB are consistent with NRW management frameworks emphasizing flow monitoring, reservoir management, and system auditing. Preventing reservoir overflows and conducting flow measurements are recognized as important measures for controlling real losses and improving operational efficiency (Kumpel & Nelson, 2016). However, the study demonstrates that periodic monitoring remains insufficient for effective leak management. Modern NRW management increasingly relies on continuous monitoring technologies capable of detecting anomalies in real time

Intermittent inspections often allow leaks to persist undetected for extended periods, increasing cumulative losses.(Horbatuck & Beruvides, 2024), for example, utilities in Denmark and the Netherlands achieved substantial reductions in water losses through deployment of continuous pressure and flow monitoring systems linked to centralized control platforms(European Environmental Agency, 2021). The absence of such systems at BWB limits rapid operational response and reduces the effectiveness of water balancing efforts.

5.4.6. Administrative Strategy

The administrative interventions implemented by BWB demonstrate recognition that NRW management is also an institutional and governance issue. Literature emphasizes that utilities with strong organizational structures, staff capacity development, and regulatory enforcement mechanisms generally achieve better NRW performance (Kingdom et al., 2006). The emphasis on staff training and enforcement of illegal connection policies is consistent with findings that human resource capacity significantly influences operational efficiency and revenue protection (Liemberger & Wyatt, 2019). However, the heavy reliance on punitive approaches may negatively affect staff motivation if not balanced with incentives and supportive supervision. Studies in South African utilities found that performance-based incentive systems were more effective in sustaining operational improvements than purely disciplinary approaches (Ndawo et al., 2025). The lack of clearly defined performance indicators also limits accountability. Modern NRW programmes emphasize KPIs, benchmarking systems, and data-driven performance evaluation as essential management tools (Stephen et al., 2025.). Without measurable targets, utilities struggle to assess intervention effectiveness and identify operational weaknesses.

5.4.7. Finance and Procurement Strategy

The finance and procurement strategy aligns with literature emphasizing the importance of timely material availability for effective NRW management. Delays in procurement of pipes, fittings, and meters frequently prolong leak durations and maintenance backlogs in developing country utilities (Santos, 2024).

The study findings also support evidence that procurement quality directly influences infrastructure reliability. Poor-quality materials contribute to premature pipe failures, recurrent bursts, and increased NRW levels (Ngolo & Kidere, 2023).

However, procurement inefficiencies and financial constraints observed at BWB are common institutional challenges in many African utilities. Similar problems were documented in Ghana Water Company Limited, where delayed procurement cycles and funding shortages undermined maintenance efficiency and prolonged system failures (Vicario et al., 2025).

5.4.8. Infrastructural Development Strategy

The infrastructural development strategy reflects long-term NRW reduction principles centered on network rehabilitation and modernization. Global evidence consistently identifies aging infrastructure as one of the most significant drivers of physical water losses (Liemberger & Wyatt, 2019).

Replacing asbestos and burst-prone pipes aligns with international recommendations advocating proactive infrastructure renewal to improve system reliability and reduce leakage (Kanakoudis & Muhammetoglu, 2014). Demand analysis and coordination with other service providers further support integrated infrastructure management approaches.

However, the financial and institutional constraints affecting implementation reflect common barriers in developing countries. Large-scale infrastructure rehabilitation requires substantial investment, which many utilities struggle to sustain (Luo et al., 2020).

A comparable example is the experience of Johannesburg Water in South Africa, where phased infrastructure rehabilitation combined with pressure management significantly reduced burst frequency and operational costs, although implementation was slowed by financial limitations (McKenzie & Seago, 2005).

5.4.9. NRW Coordination

The establishment of a centralized NRW coordination mechanism at BWB aligns a study by (Kingdom et al., 2006) whichemphasizes the importance of integrated institutional coordination in NRW management.

The findings demonstrate that centralized data validation and interdepartmental collaboration reduced duplication of operational activities. Similar approaches have proven effective in utilities such as Manila Water in the Philippines, where integrated NRW coordination significantly improved monitoring and operational response times (Adedeji et al., 2022).

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

This study investigated NRW in urban water supply systems using BWB as a case study, with the aim of determining NRW trends, assessing its financial implications, identifying its causes, and evaluating the effectiveness of existing NRW reduction strategies. The findings demonstrate that NRW remains a critical challenge that continues to undermine the operational efficiency and financial sustainability of the utility. The study established that NRW levels at BWB have shown a fluctuating but increasing trend over the period 2015 to 2024, rising far above internationally recommended benchmarks. This indicates persistent inefficiencies within the water distribution and management system.

The study further established a strong positive relationship between water production and NRW, suggesting that increases in water supplied into the system were accompanied by corresponding increases in water losses. At the same time, billed consumption showed minimal influence on NRW variation, implying that the major contributors to NRW are associated more with system inefficiencies and losses than with revenue generation capacity. Financial analysis revealed that escalating NRW levels, combined with increasing production costs, contributed significantly to the transition of BWB from operational surpluses to sustained financial deficits after 2020. The substantial cumulative financial losses incurred during the study period highlight the severe economic burden posed by NRW on the utility.

Qualitative findings revealed that NRW at BWB is driven by a combination of technical, administrative, and socio-economic factors. Aging infrastructure, frequent leakages, inadequate metering systems, illegal connections, and institutional inefficiencies were identified as major contributors to water losses. Although the utility has implemented several NRW reduction measures, including leakage control initiatives and metering improvements, the effectiveness of these interventions remains limited due to inadequate resources, weak monitoring mechanisms, and inconsistent implementation.

Overall, the study concludes that NRW constitutes a major obstacle to sustainable urban water supply management at BWB. Unless comprehensive, data-driven, and sustainable NRW

management strategies are strengthened and consistently implemented, the utility will continue experiencing operational inefficiencies, reduced revenue generation, and increasing financial instability. The study therefore underscores the need for integrated interventions that combine infrastructure rehabilitation, technological modernization, strengthened institutional capacity, and improved monitoring systems in order to achieve long-term NRW reduction and enhance the sustainability of urban water service delivery.

6.2. Recommendations

6.2.1. Implement a Comprehensive Meter Replacement and Calibration Program

Based on the findings that a high number of faulty and aging meters (47,960 between 2015 and 2024) contribute significantly to apparent losses through under-registration, it is recommended that BWB establish and implement a structured meter replacement and calibration program. This program should prioritize replacing old and malfunctioning meters with modern, high-accuracy meters and introduce routine testing and calibration schedules. Accurate metering directly improves revenue collection, reduces apparent losses, and enhances billing fairness, thereby strengthening the financial sustainability of the utility. To ensure effectiveness, BWB should adopt a meter asset management system, maintain a database of meter age and condition, and set a replacement cycle supported by periodic audits.

6.2.2. Establish an Integrated Pressure Management System

Given that poor pressure management characterized by reliance on uncontrolled throttling leads to excessive and fluctuating pressures, it is recommended that BWB develop and implement an integrated pressure management system. This should include the installation of PRVs, pressure transducers, and real-time monitoring systems to regulate and stabilize network pressure. Stable and optimized pressure reduces pipe bursts, minimizes leakage rates, and extends the lifespan of infrastructure, lowering real losses and operational costs. For practical implementation, BWB should conduct pressure mapping and establish standard operating pressure ranges with continuous monitoring and reporting.

6.2.3. Develop and Implement a Planned Infrastructure Rehabilitation Program

In response to findings that aged and deteriorating infrastructure contribute significantly to leaks and bursts, it is recommended that BWB design and implement a long-term infrastructure rehabilitation and replacement program. This program should prioritize high-risk and frequently failing pipeline sections identified through maintenance records and field assessments. Proactive rehabilitation reduces recurring maintenance costs, minimizes water losses, and improves service reliability, as opposed to reactive repairs that perpetuate system inefficiencies. To ensure practicality, BWB should establish a pipe condition assessment framework, allocate an annual rehabilitation budget, and adopt modern, durable pipe materials suited to local conditions.

6.2.4. Strengthening Preventive Maintenance and Asset Management Systems

Considering that reliance on temporary repairs contributes to recurring failures, it is recommended that BWB strengthen its preventive maintenance strategy by adopting a formal asset management system. This should include scheduled inspections, condition-based maintenance, and timely replacement of critical components. Preventive maintenance reduces the frequency of bursts and leaks, improves system efficiency, and ensures optimal utilization of infrastructure assets. For effective implementation, BWB should deploy a digital maintenance tracking system, train staff in predictive maintenance techniques, and establish key KPIs for maintenance response and asset reliability.

6.2.5. Reform Procurement and Supply Chain Management Systems

Based on the findings that procurement delays and supply chain inefficiencies hinder timely repairs and replacement of critical materials; it is recommended that BWB streamline and reform its procurement and supply chain management processes. This should include the adoption of framework contracts for frequently used materials, reduced approval layers for emergency procurements, and improved supplier performance management systems. Timely availability of materials enables rapid response to leaks, bursts, and meter faults, thereby reducing both physical and commercial losses. To ensure practicality, BWB should establish

minimum stock levels, introduce digital inventory management systems, and conduct periodic supplier evaluations to improve reliability and reduce delays.

6.2.6. Strengthening Quality Assurance in Procurement

Given the identified gaps in quality assurance and technical specification enforcement, it is recommended that BWB institutionalize strict quality control mechanisms in its procurement processes. This should involve standardized technical specifications, prequalification of suppliers, and mandatory inspection and testing of materials before acceptance. Poor-quality materials lead to premature infrastructure failure, increasing leaks, bursts, and meter inaccuracies, which ultimately elevate NRW. For effective implementation, BWB should develop procurement guidelines aligned with engineering standards, enforce contract compliance, and introduce penalties for substandard supplier performance.

6.2.7. Implement a Hydrant Metering and Monitoring System

Considering that unmonitored hydrants contribute to unbilled authorized consumption and illegal abstraction, it is recommended that BWB install meters on all operational hydrants and establish a monitoring system to track water usage. Additionally, hydrants should be secured using lockable covers and inspected regularly. This responsibility should be shared between the Operations Department of BWB and Blantyre City Council, with a formal coordination framework established between the two institutions. To ensure effectiveness, BWB should implement joint reporting protocols, hydrant usage logs, and periodic audits of hydrant activity.

6.2.8. Establish Formal Inter-Agency Coordination Mechanisms

In response to weak coordination between BWB and Blantyre City Council, it is recommended that a formal inter-agency coordination framework be established.

This should include MOUs, defined roles and responsibilities, and regular data sharing mechanisms regarding water usage and infrastructure management. Effective coordination ensures accountability for authorized water use, improves monitoring, and reduces institutional gaps that contribute to NRW.

For practical implementation, BWB should establish joint committees, regular coordination meetings, and shared digital reporting platforms.

6.2.9. Deploy Data Driven Systems for Detecting Illegal Connections and Reconnections

Given the reliance on manual and reactive detection methods, it is recommended that BWB adopt data driven monitoring systems to detect illegal connections and unauthorized reconnections. This should include smart metering technologies, consumption data analytics, and anomaly detection models capable of identifying irregular usage patterns in real time. Real-time detection significantly reduces unbilled consumption by enabling prompt identification and disconnection of illegal users, thereby improving revenue collection and system integrity. For effective implementation, BWB should integrate customer consumption databases, train staff in data analytics, and establish automated alerts for suspicious consumption patterns.

6.2.10. Regulate and Monitor Scrap Metal Trade to Prevent Infrastructure Vandalism

In response to the role of scrap metal markets in driving infrastructure vandalism, it is recommended that BWB collaborate with government authorities to regulate and monitor scrap metal trading activities. This should include licensing of scrap dealers, mandatory verification of material sources, and enforcement of penalties for trading stolen infrastructure components. This initiative should involve local authorities, law enforcement agencies and BWB management. Controlling the market for stolen materials reduces incentives for vandalism, thereby protecting infrastructure and minimizing both physical and commercial losses. For practical implementation.

6.2.11. Strengthening Infrastructure Protection and Surveillance Systems

Given the prevalence of vandalism and illegal access to pipelines, it is recommended that BWB enhance infrastructure protection through surveillance and physical security measures. This should include installation of protective barriers, routine patrols, and use of technologies such as GIS mapping and remote monitoring systems. BWB, in collaboration with local authorities, should oversee this implementation.

Improved surveillance reduces unauthorized access, enables early detection of vandalism, and minimizes prolonged leakages, thereby reducing NRW. To ensure effectiveness, BWB should prioritize high-risk areas such as peri-urban settlements and exposed pipeline zones.

6.2.12. Develop and Enforce Land Use and Infrastructure Protection Policies

In response to encroachment on water infrastructure by informal settlements, it is recommended that BWB work with urban planning authorities to develop and enforce land use regulations that protect water infrastructure corridors. This should include demarcation of pipeline routes, restriction of construction near critical infrastructure, and relocation strategies where necessary. This initiative should be led by local government authorities, urban planning departments, and BWB management. Protecting infrastructure corridors ensures accessibility for maintenance, reduces pipe damage, and prevents illegal connections, thereby improving overall system efficiency. For practical implementation, authorities should adopt GIS-based mapping systems and enforce building regulations in high-risk zones.

6.3. Recommendations on Strategies for Reducing NRW adopted by BWB

6.3.1. Caretaker Approach

BWB should restructure the caretaker approach into clearly separated NRW intervention packages targeting physical and commercial losses independently. This can be achieved by developing a framework that classifies NRW issues by DMA data and allocates dedicated budgets, teams, and performance targets for each category.

In practice, this requires establishing a decision matrix and monthly review meetings that ensure interventions are focused, measurable, and resource-efficient rather than broadly distributed.

6.3.2. Pipe Lowering and Replacement

The pipe replacement strategy should shift from reactive replacement to a predictive, risk-based asset management system. BWB should develop a pipeline risk map using historical burst data, soil conditions, and pipe age to prioritize replacements before failures occur.

Implementation should involve creating an asset register linked to GIS, followed by phased annual replacement plans focused only on high-risk segments, ensuring cost efficiency and reduced recurrence of bursts.

6.3.3. Meter Management

Meter management should be strengthened through continuous auditing and digitalization of meter reading processes. BWB should transition gradually from manual reading to automated or handheld digital systems while reducing calibration intervals for all customer categories. Implementation should also include a rolling meter replacement program based on performance data rather than fixed time intervals, supported by a centralized meter database for tracking accuracy, age, and anomalies.

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APPENDICES

Appendix I: Questionnaire

The following questionnaire is designed to gather information on root factors that cause NRW at BWB, trend of NRW at BWB over the recent years, financial impact of NRW at BWB and strategies of reducing NRW adopted by BWB.

Questionnaire no……

Date……..

SECTION A: RESPONDENT INFORMATION

1. Department/Section
2. Position/Job Title
3. Number of years worked at Blantyre Water Board
    - ☐1–5 years
    - ☐6–10 years
    - ☐11–15 years
    - ☐Above 15 years
4. Main responsibilities related to water operations or NRW

SECTION B: TREND OF NON-REVENUE WATER

1. How has NRW changed at BWB between 2015 and 2024?
2. What factors have contributed to the increase or decrease in NRW over the years?
3. Which areas or zones experience the highest NRW levels?
    - ☐Limbe
    - ☐Soche
    - ☐Kabula

4. What operational challenges are associated with increasing NRW?
5. How does NRW affect water supply reliability?

SECTION C: TECHNICAL CAUSES OF NRW

1. What technical causes contribute most to NRW at Blantyre Water Board?
    - ☐Pipe leakages
    - ☐Aging infrastructure
    - ☐Faulty meters
    - ☐Pressure fluctuations
    - ☐Burst pipes
    - ☐Unauthorized hydrant usage
    - ☐Other:
2. How do faulty meters contribute to NRW?
3. Does the institution conduct regular meter calibration?
    - ☐Yes
    - ☐No
4. What challenges affect pressure management within the distribution system?
5. How effective are leak detection and pipe maintenance programs?
6. How do power failures affect water production and distribution monitoring?
7. What challenges are faced in monitoring hydrant water usage?
8. Are GIS and hydraulic models effectively used in managing NRW?
    - ☐Yes
    - ☐No Explain:

SECTION D: ADMINISTRATIVE CAUSES OF NRW

1. How do procurement delays affect NRW management?
2. What procurement challenges affect the supply of pipes, meters, and fittings?

3. Are there adequate monitoring and reporting systems for NRW?
    - ☐Yes
    - ☐No
4. How effective is coordination between departments in reducing NRW?
5. How does limited funding affect NRW management activities?
6. What institutional weaknesses contribute to NRW?
7. Are there policies guiding meter replacement and NRW reduction?
    - ☐Yes
    - ☐No
8. What administrative reforms are needed to improve NRW management?

SECTION E: SOCIO-ECONOMIC CAUSES OF NRW

1. How do illegal connections contribute to NRW?
2. How common is meter tampering and bypassing?
    - ☐Very common
    - ☐Common
    - ☐Rare
    - ☐Not common
3. How does non-payment of water bills affect NRW?
4. How do informal settlements contribute to water losses?
5. What role does vandalism play in NRW?
6. How has scrap metal trading contributed to theft of meters and pipes?
7. Do communities adequately understand the impacts of illegal water use?
    - ☐Yes
    - ☐No
8. What social factors encourage illegal water connections?
9. How does NRW affect water availability in high-demand areas?

SECTION G: STRATEGIES USED TO REDUCE NRW

1. What strategies are currently used to reduce NRW?
    - ☐Meter replacement
    - ☐Leak detection
    - ☐Pressure management
    - ☐Public awareness campaigns
    - ☐GIS mapping
    - ☐Routine inspections
    - ☐Law enforcement collaboration
    - ☐Other:
2. How effective are the current NRW reduction strategies?
3. Does the institution use SCADA, DMA, or AMR systems?
    - ☐Yes
    - ☐No
4. What challenges affect implementation of NRW reduction strategies?
5. What role does community awareness play in reducing NRW?
6. What improvements would you recommend to reduce NRW to acceptable levels?

SECTION H: RECOMMENDATIONS

1. What technologies should BWB adopt to reduce NRW?
2. What policy changes are needed to strengthen NRW management?
3. Should Malawi regulate scrap metal trading related to water infrastructure?
    - ☐Yes
    - ☐No