Institute for Water
and Energy Sciences
(incl. Climate Change)

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PAN AFRICAN UNIVERSITY INSTITUTE FOR WATER AND ENERGY SCIENCES (including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfilment of the requirements for the Master degree
in

WATER ENGINEERING

Presented by

Ciniso Sizwe GINA

ANALYSING THE ADOPTION OF A DIGITAL APPROACH FOR NON-REVENUE WATER MANAGEMENT IN AFRICAN WATER UTILITIES: A CASE STUDY FOR BURKINA FASO, MALAWI AND ETHIOPIA WATER UTILITIES

Defended on 20/04/2024 Before the Following Committee:

Chair			
Supervisor	Simeon KENFACK	Dr.	African Water and Sanitation Association, AfWASA
External Examiner			
Internal Examiner			

TITLE PAGE

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By

Ciniso Sizwe GINA

April, 2024

STATEMENT OF AUTHOR

I, Mr. **Ciniso Sizwe GINA**, hereby certify that, in all of my knowledge, this thesis is a result of my own personal work. In addition, I affirm that, in compliance with academic standards and ethics, any data, materials, techniques and software from other works that are presented here have been properly acknowledged, cited and referenced.

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CERTIFICATION

I, the undersigned, **Dr. Simeon KENFACK**, Director of Programs at the African Water and Sanitation Association (AfWASA), hereby certify that Mr. Ciniso Sizwe GINA conducted his Master's Thesis research under my supervision.

………………………………………………………………………………05 April 2024……

SIGNATURE **DATE**

BIOGRAPHICAL SKETCH

Name: Ciniso Sizwe GINA

High School: Evelyn Baring High School, Nhlangano, Eswatini

Birth Place: Lubombo, Eswatini

Universities:

1. University of Eswatini, Luyengo Campus
2. Pan African University Institute for Water and Energy Sciences (including Climate Change), Algeria

ABSTRACT

Non-Revenue Water (NRW) remains a great threat to African water utility operations and sustenance, stalled by outdated infrastructure, rapid urbanisation and climate change. As such, this study investigated NRW management in three African water utilities: ONEA in Burkina Faso, Wolaita Sodo Water in Ethiopia and Lilongwe Water Board in Malawi, with NRW levels of 19.3% in 2018, 35.4% in 2024 and 42% in 2021 respectively. The research aimed to analyse the adoption of digital approaches for NRW management by identifying key operational challenges through literature reviews and questionnaires and specifically examining the impact of operational activities on NRW levels and exploring the potential of digital solutions for effective NRW management. The reviewed literature indicated main operational activities (technical management, customer management, financial management and institutional management) as the major factors influencing NRW levels in the utilities. Other factors affecting the NRW management are the overarching factors (leadership, management strategy, culture and governance) and the enabling environment (regulation, sector policy, institutional arrangement and legislation). The findings highlight significant gaps in teams in place, technical capacity building for staff and the deployment of technologies such as SCADA systems and proactive leak detection and repairs for NRW management. Benchmarking of African water utilities with utilities in other regions like Europe (Denmark) demonstrated the effectiveness of digital solutions and regulatory measures in NRW reduction as NRW was less than 10%. The recommendations include adopting proactive leak detection, data management analytics, network management and advanced metering infrastructure (AMI) as strategic approaches for African water utilities. Additionally, developing a digital model is proposed for utility benchmarking to facilitate tactical decision-making and intervention to manage NRW in water utilities.

Keywords: Non-Revenue water, Digitisation, Water Utility

RÉSUMÉ

L'eau non facturée (ENF) demeure une grave menace pour les opérations et la pérennité des services d'eau en Afrique, entravés par des infrastructures obsolètes, une urbanisation rapide et le changement climatique. Cette étude a scruté la gestion de l'ENF dans trois services d'eau africains : l'ONEA au Burkina Faso, Wolaita Sodo Water en Éthiopie et Lilongwe Water Board au Malawi, avec des niveaux d'ENF respectifs de 19,3 % en 2018, 35,4 % en 2024 et 42 % en 2021. L'objectif était d'analyser l'adoption de solutions numériques pour la gestion de l'ENF en identifiant les principaux défis opérationnels par le biais d'analyses de la littérature et de questionnaires, tout en explorant le potentiel des solutions numériques pour une gestion efficace de l'ENF. La littérature examinée souligne que les principales activités opérationnelles (gestion technique, gestion des clients, gestion financière et gestion institutionnelle) sont les principaux facteurs influençant les niveaux d'ENF. Les résultats révèlent des lacunes significatives dans les équipes en place, soulignant la nécessité de renforcer les compétences techniques du personnel et de déployer des technologies telles que les systèmes SCADA ainsi que des méthodes proactives de détection et de réparation des fuites. L'analyse comparative avec d'autres régions comme l'Europe (Danemark) a mis en lumière l'efficacité de l'innovation technologique et des mesures réglementaires dans la réduction de l'ENF à moins de 10 %. Les recommandations suggèrent l'adoption de mesures telles que la détection proactive des fuites, l'analyse de la gestion des données, la gestion des réseaux et une infrastructure de comptage avancée (AMI) comme stratégies pour les services d'eau africains, avec l'introduction d'un modèle numérique pour faciliter la prise de décision et l'intervention tactiques.

Mots-clés : L'eau non facturée, Numérisation, Service de l'eau

DEDICATION

Navigation is great with clear directions, but with support and the people you love, it's a worthwhile episode.

This work is dedicated to:

My father, Velaphi Gina and my cousin Dumisani Mathenjwa for being a source of inspiration in my academic pursuit and life in general.

My family and friends for their continual support, academically and otherwise.

ACKNOWLEDGEMENT

I would like to thank everyone who contributed in this journey. Firstly, I would like to thank the African Union Commission for offering me the opportunity to pursue my MSc. In Water Engineering at the Pan African University in Algeria.

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Great thanks to my research supervisor and the Director of Programs at AfWASA, Dr. Ing. Simeon KENFACK for his careful guidance throughout the research period and concern on my wellbeing in Abidjan. The efforts from my research mentor Ms. Djalia UMUNTANGAMPUNDU through carefully crafting standard will not go unnoticed. May God greatly bless all my colleagues in the office for their support and assistance throughout the entire internship period.

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ABBREVIATIONS AND ACRONYMS

AfWASA	African Water and Sanitation Association
AI	Artificial Intelligence
API	Application Programme Interface
AWM	Automatic Water Metering
AWWA	American Water Works Association
DMA	District Metering Area
GIS	Geographical Information Systems
GSMA	Global System for Mobile communications Association
IBNET	International Benchmarking Network for Water and Sanitation Utilities
ICT	Information and Communication Technology
IoT	Internet of Things
IWA	International Water Association
MCM	Million Cubic Metres
NRW	Non-Revenue Water
NWSC	Uganda National Water and Sewerage Corporation
ONEA	Office National de l'Eau et de l'Assainissement (Burkina Faso)
PLC	Programmable Logic Controller
SADC-GWP	Southern Africa Development Corporation - Global Water Partnership
SAUR	Société d'Aménagement Urbain et Rural
SCADA	Supervisory Control and Data Acquisition System
SDE	Sénégalaise des Eaux (Senegal)
SWM	Smart Water Metering
USD	United States Dollar
WDN	Water Distribution Network
WSCSSE	Wolaita Sodo City Water Supply and Sewerage Services Enterprise
WSS	Water Supply and Sanitation
WUP	Water Utility Partnership

CHAPTER 1: INTRODUCTION

1.0. Introduction

This chapter introduces the project fundamentals. It first gives an overview of the entire status of water resource management, it's significance and thus deriving the problem statement from that information. The chapter further specifies the aim of the project with supporting research questions and the hypothesis. It then gives a clear justification of the study highlighting obstacles in the study and lastly the tentative thesis chapter outline.

1.1. Background Information

Water is a fundamental human right as declared by the UN. It is essential for economic development and linked with nearly all the SDG's. Target 1 of the 2030 agenda for attaining SDG 6 places a strong emphasis on providing everyone with equitable access to safe and affordable drinking water. The UN SDG's Report (2023), states that billions of people still lack access to safe drinking water and basic sanitation. The report further states that in 2022, 2.2 billion people lacked access to safe drinking water, 3.5 billion lacked safe sanitation and 2.2 billion lacked basic hand washing facilities. This overview hence means that in order to meet the 2030 targets, the progress rates will have to accelerate by 6 times for drinking water, 5 times for sanitation and 3 times in the hygiene sector.

For water utilities, population growth, rapid urbanization and climate change present substantial challenges. As such, water loss and water theft concerns in non-revenue water management have become a costly challenge for the under-capacitated and financially constrained water utilities within Africa. Shim et al. (2022) suggests that to effectively and financially address the water concerns, there is a growing need for smart water solutions and water digitalisation. Furthermore, while there is growing promotion of digital technologies in water utilities globally, there is still a gap in the evaluation of the potential of these new digital technologies within non-revenue water management and more especially so in Africa. According to Charalambous & Hamilton (2015), Non-Revenue Water (NRW) refers to water that is produced and supplied but is lost without generating any revenue for the water utility.

A study by Umutangampundu (2020) on NRW effect on water utility operation, recommends the enforcement of policies on improvement of water revenues for cost recovery; capacity building for NRW management, adoption of ICT tools for data acquisition, community engagement, institutionalisation of NRW within African water utilities and an innovative management model. The conceptual model details on an enabling environment, overarching factors and main operational activities. This research has been formulated following the adoption of Umutangampundu's conceptual framework with a particular focus on the main operational activities (Technical, financial, commercial and institutional management) for NRW management.

1.2. Problem statement

Water utilities across Africa grapple with a complex challenge in the proficient management of NRW (Ortega-Ballesteros *et al,* 2021). This complex issue involves both physical losses (e.g. leaks, overflows) and commercial losses, including meter inaccuracies and theft. These factors lead to substantial financial losses, resource inefficiencies and disrupt effective water service delivery. Makaya & Hensel. (2014), claim that heightening the aforementioned problem is the inadequate water infrastructure in these regions thus intensifying water scarcity in areas with limited access. Outdated systems, leaks and inefficient water distribution contribute to a staggering annual global water loss of approximately 126 billion m^3, accompanied by 11.9 billion kg of CO_2 emissions resulting from the treatment of non-revenue water (Burke *et al,* 2023).

Despite the potential benefits offered by digital interventions, such as remote sensing, asset management, predictive analytics, and artificial intelligence, the adoption of these solutions in African water utilities is slow and uneven. This lethargic uptake is attributed to a lack of understanding of factors influencing technology adoption, governance weaknesses and various technical and financial challenges that further compound NRW-related issues.

According to Kingdom et al. (2006), the consequences of this slow adoption include inadequate water services, financial losses amounting to nearly 6 billion USD yearly and a persistent inability to address the rising water demand aging infrastructure and the environmental impact of the sector's carbon footprint. Adding on to the great challenge is the global volume of NRW estimated at 364 MCM/ day, equivalent to $39 billion/ year as stated by Liemberger & Wyatt. (2019). The above-mentioned factors make it imperative to assess and improve how digital approaches are being adopted by African water utilities for NRW management hence the urge to conduct the study.

1.3. Research Objectives

1.3.1. General objective

The general objective of the study was to analyse the adoption of a digital approach for non-revenue water management in African water utilities.

1.3.2. Specific objectives

1. To identify operational activities influencing Non-Revenue Water management in utilities.
2. To quantify the impact of any specific operation on the total Non-Revenue Water levels of the utility.
3. To create a digital model for Non-Revenue Water management in water utilities.

1.4. Research Questions

1.4.1. Main Research Question

How can a digital approach be effectively adopted and utilized to improve non-revenue water (NRW) management in African water utilities?

1.4.2. Specific Research Questions:

1. What are the operational activities that increase Non-Revenue Water in utilities?
2. What is the value of impacts of the specific operations on the total NRW levels?
3. What would a digital model for NRW management in water utilities look like?

1.5. Working Hypothesis

1.5.1. Main Hypothesis

The main hypothesis states that the adoption and utilization of digital approach can significantly support the improvement of NRW management in African water utilities.

1.5.2. Specific Hypotheses

1. Operational activities have significant impact on total NRW level of a water utility.
2. The design and implementation of a digital model on operational activities can significantly enhance NRW management in a water utility.

1.6. Justification of Study

The study's importance lies in its potential to provide insights into the current status of digital approaches adoption for NRW management in African water utilities. The study will determine the aspects that impact the adoption of digital approaches and evaluate the benefits as well as obstacles associated with them. Digitalization of utility processes, such as billing, has shown a reduction in NRW for many utilities. The paper fills a research gap by developing a digital approach for NRW management comprehensively in the water sector, which was previously understudied.

1.7. Research Obstacles

No research obstacles encountered within the project.

1.8. Tentative Thesis Chapter Outline

The research is formatted in the following order:

Chapter 1: Introduction. This chapter outlines the background information of the research highlighting the effect of digitisation in NRW management. It further delves into the main problem at hand and details on the research questions and as such the objectives of the study. It details also on the research significance that is to benchmark the adoption levels of digitisation for NRW management and develop a clear way forward in the latter sections.

Chapter 2: Literature Review. This chapter provides the foundation required to understand the dynamics of NRW management in Africa, digitisation in the water sector and the adoption levels in African water utilities. This is accompanied by literature on the possible barriers to adoption of digitisation for NRW management and best practices and also an overview of NRW management from the analysed water utilities.

Chapter 3: Materials and Methods. This chapter outlines the materials used, methodologies, their justifications and also the research project setting. The attention is placed on the suitability of the particular method for data collection, cleaning and analysis.

Chapter 4: Results and Discussion. The chapter presents and discusses the findings of this study and comparing them with previous digital measures.

Chapter 5: Conclusion and Recommendations. This chapter sums up the whole research work and if they meet the set objectives. It indicates how objectives were achieved and what implications or future propositions the project has.

References, Bibliography and Appendix. These sub-parts are also crucial parts for the research as they reflect the used bibliography and many appendices as well.

Below is a simplified schematisation of the thesis chapter outline.

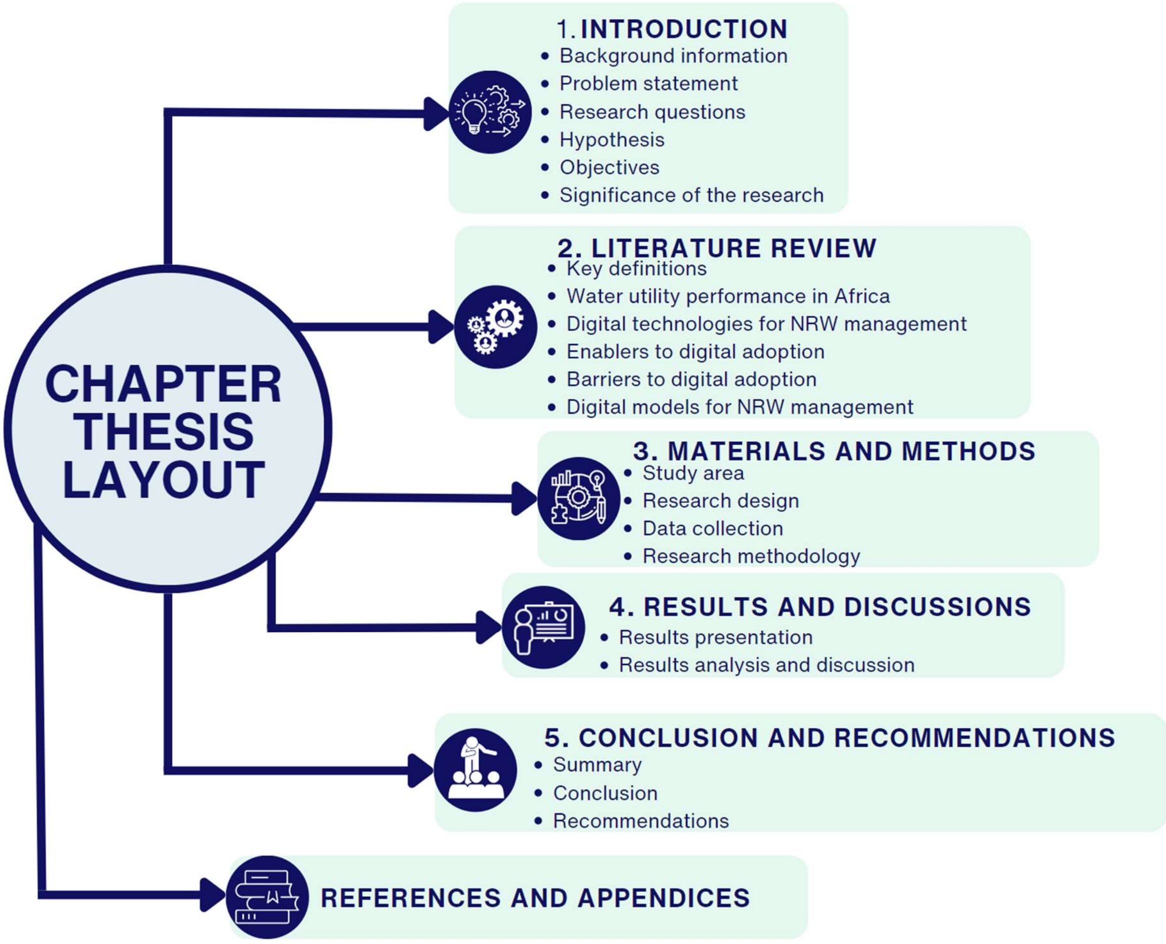

Figure 1.8: *Schematisation of thesis chapter layout*

1.9. Conclusion

The introductory part of the project highlighted all the principles guiding the project placed in their suiting order. The chapter outlined the strong correlation between the background information, problem statement, objectives, hypothesis to clearly justify the need for the study. To further justify the need for the study, in chapter 2, literature review was conducted as follows.

CHAPTER 2: LITERATURE REVIEW

2.0. Introduction

Many approaches have been done in an attempt to solve the problems of NRW losses faced by many water utilities in Africa. The literature review aims to analyse the adoption of a digital approach for non-revenue water management in African water utilities. The objectives are identifying operational activities influencing Non-Revenue Water management in utilities and to quantify the impact of any specific operation on the total Non-Revenue Water levels of the utility.

The topic was chosen due to the gap in research on assessment of the adoption of digital solutions for non-revenue water management in the African context. The literature review highlights the key definitions as used in the project, overview of African water utilities and digital approaches used for NRW management in African water utilities with their enablers and barriers. The literature review asserts the need for the digital model through detailed overview of the current digital approaches utilised, the NRW levels and management in place in the utilities with a comparison to better performing water utilities outside Africa.

2.1. Key Definitions

The standard definitions listed below have been used for the research extracted from Pearson, (2019).

Water Abstracted: is the volume of water obtained for input to raw water mains leading to water treatment plants or production units.

Water Produced: is the amount of treated or purified water.

Water Imported and Exported: relates to the volumes of bulk transfers across operational boundaries.

System Input Volume (SIV): is the volume of water input to a transmission system or a distribution system. Liemberger et al., (2007) opine that system input volume equals value of metered system input recorded in the entire system. Meter accuracy should be thoroughly verified to reflect the real situation.

Water Supply Coverage: It delineates the area and properties that are connected to the water supply system. In an area where only part of the population is served this refers to the ratio between the supplied population and total population in the administrative area of the utility.

Water Supply Network: A collection of assets, such as in reservoirs, boreholes, treatment works and any necessary associated pumps and pumping station delivering raw water to the treatment works for purification. It usually includes the treated water assets down to and including the service reservoirs prior to the water distribution network. This would include trunk mains and possibly pumping stations.

Water Distribution Network: a collection of assets, primarily mains and service pipes but may include booster pumping stations, which deliver water from a water supply network to customer premises.

Authorised consumption: includes water used in flushing of mains and sewers, filling water tankers, firefighting and for hydrants. These can be classified as billed, metered, unmetered, or unbilled depending on local customs (UN-Habitat, 2012).

Real Losses: are physical water losses from the pressurised system, up to the point of customer metering. The volume lost as a result of leaks, bursts, and overflows varies according to the frequency, flow rate and average length of each leak.

Apparent Losses: Unauthorised consumption and any kinds of metering errors.

Non-Revenue Water (NRW): Water that is produced and delivered but lost without obtaining any money for the utility (Charalambous & Hamilton, 2015). It is the difference between the System Input Volume and Billed Authorised Consumption. It can be expressed in three ways: as a percentage (%), as per the number of connections and per the distance of the pipeline as expressed below in equations 2, 3 and 4.

Supply Reliability: is the capacity of a utility to provide a consistent supply of water at the required time and can be assessed using head room.

Headroom: the difference between available supplies and demand within a water resource zone. The balance between actual headroom and design headroom defines the supply reliability.

Supplied Population (P_s): is the total number of people supplied with water by the utility

Per capita consumption (PCC): is the water consumption by a single person per day. It is measured in (l/c/d).

Domestic consumption (C_D): the amount of water consumed or used per day (m^3/d).

Some of the considerable equations for non-revenue water are computed as follows:

Equation 1

Water Losses = System Input Volume — Authorised Consumption

Equation 2

$NRW = SIV\text{-}C_T$

Equation 2: *NRW expressed as a percentage (%)*

$$NRW\ (\%) = \frac{Q_L}{Q_P} \times 100$$

Where: Q_P: Water produced

Q_C: Billed water consumption

Q_L: Total water losses

Equation 3: *NRW expressed in terms of length*

$$NRW = \frac{Q_L}{Total\ pipe\ length\ in\ area, L}$$

Equation 4: *NRW expressed in terms of number of connections*

$$NRW = \frac{Q_L}{No. of\ connections\ in\ target\ area}$$

2.1.1. The Water Balance Theory for water audit

According to Pearson (2019), IWA developed a standard water balance and standardised terminology and definitions for the components of the water balance. In order to ensure consistency of assessment and reporting of losses, it is paramount that this water balance and respective definitions of the components are adhered to when undertaking any form of water loss study, auditing or reporting. Below is the importance of calculating the water balance:

- Framework for assessing the situation of the water utility,
- Reveals availability/ reliability of data and level of understanding,
- Creates awareness of problems/ issues,
- Directs necessary improvements,
- Tool for benchmarking and comparison among utilities and
- Aids in taking sound investment strategies and decisions.

The water balance theory is based on the water balance concept developed by IWA. According to Charalambous and Hamilton (2015), understanding the water balance concept is the foundation on which water losses management techniques are based. Based on this theory, water consumption in a utility system comprises water losses and authorized consumption. Authorized consumption is further broken down into unbilled authorized consumption and billed authorized consumption. Water losses according to the theory are also categorized as commercial (apparent losses) and real losses. Mastaller and Klingel (2017) point out that the theory thus holds that non-revenue water is the sum of real losses, commercial losses, and unbilled authorized consumption while revenue water comprises only billed authorized consumption. Therefore, according to IWA, the calculation for NRW can be achieved as follows: NRW= System Input Volume - Billed Authorized Consumption globally per year (Liemberger et al., 2006).

The IWA water balance model

<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th></tr>
<tr><td rowspan="10">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption (Including Water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>UnBilled Metered Consumption</td><td rowspan="8">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses</td><td rowspan="3">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td>Systematic Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer metering</td></tr>
</table>

Figure 2.1.1: *IWA Water balance Concept (Source: Hirner & Lambert, 2000)*

2.2. Water utility

A water utility is defined as an entity, such as a government unit, a private or municipal corporation, an association, a partnership, or an individual, engaged in providing safe water to the public for domestic or drinking purposes. Its principal duty is to ensure a safe and adequate water supply for its users. Thus, a proficient utility is one that efficiently delivers clean, safe water to its customers in a sustainable manner, focusing on reliable water supply, water quality, infrastructure maintenance, financial sustainability, environmental responsibility, customer service, compliance with regulations, innovative technology use, community engagement, and emergency preparedness. Utilities may be managed by city or regional authorities, or private companies (Roeger & Tavares, 2018; Lufingo, 2019; Stephenson & Pollard, 2015). Different groups may own and manage the systems for water distribution, collection and treatment (Van den Berg & Danilenko, 2017). The scope of its responsibilities can extend to wastewater treatment and promoting the circular economy (UN Water, 2021).

2.2.1. An overview of African water utilities performance

According to Dos Santos et al. (2017), from 2000 to 2015, Africa experienced significant urban population growth, with urbanisation driving substantial socio-economic, environmental and health changes. This necessitated an understanding of urban growth dynamics to prepare for such changes (Linard, Tatem, & Gilbert, 2013). During the same period, the challenge of providing access to water supply and sanitation became more pronounced as urban populations grew. Studies found wide variability in coverage levels and trends in water supply and sanitation across 31 cities, with a notable increase in the prevalence of open defecation, highlighting areas needing improvement (Hopewell & Graham, 2014). Furthermore, the rapid growth in urban populations outstripped the capacity of cities to provide adequate services, particularly in low-income and informal settlement areas, creating a crisis of access with serious potential political costs if not addressed (Chitonge, 2014). This hence means that the performance of water utilities has been seriously lagging behind as there seems to be no lack of demand for improved water supplies (Danilenko et al, 2014).

Many African utilities face challenges due to inadequate coverage of operation and maintenance costs, hindering their ability to expand access. African water utilities exhibit significant variations in institutional setup, organisation and reporting requirements (Dos Santos et al., 2017). The lack of specific research often leads professionals in the sector to apply findings from one utility or country (usually developed countries) to utilities in other countries. However, these other countries often have very different institutional, political, and economic conditions (Danilenko et al, 2014). To clearly outline the performance of African water utilities, six have been selected with their NRW performance and management solutions in place.

Eswatini Water Services Corporation being the sole water utility in Eswatini, is solely responsible for the production and supply of potable water for domestic water countrywide and also for wastewater treatment. For Eswatini Water Services Corporation in Eswatini the NRW yearly levels were 25%, 37% and 34% for the years 2017, 2021 and 2023 respectively. In the year 2021, the NRW in accordance to pipe length was found at 6 m^3/km/day as compared to the standard of 3 m^3/km/day. The infrastructure leakage index was found to be 2.5 as opposed to the standard of 1 and the water use was 287 l/c/day as opposed to the standard of 150 l/c/day. Below is a graph for the NRW levels in the utility in 2017, 2021 and 2023.

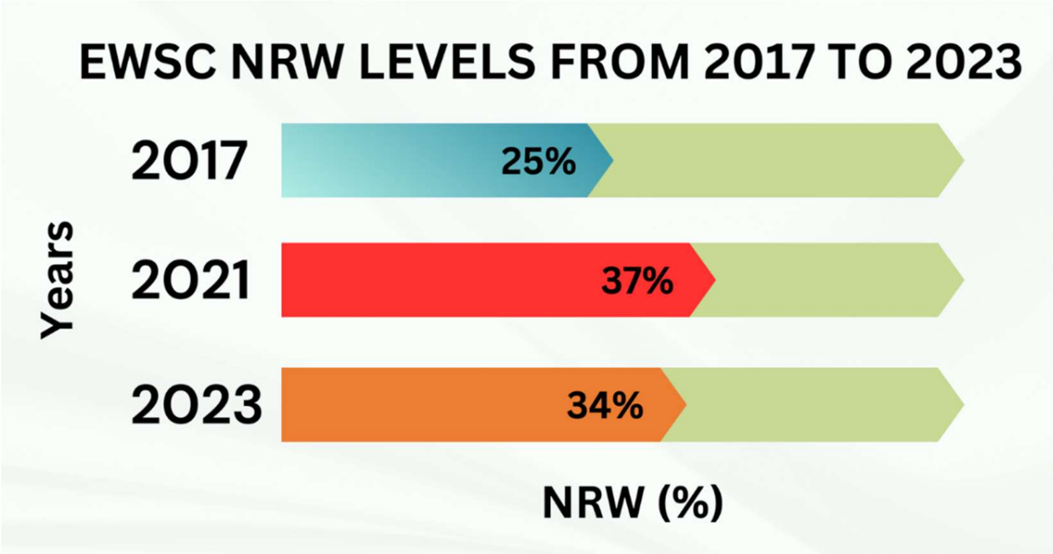

Figure 2.2: *Graph for Eswatini Water Services Corporation NRW levels from 2017 to 2023*

This significant rise in the NRW levels in the water utility are related to the challenges outlined by the Eswatini Water Services Annual Report of 2021 and 2022 which are:

- Revenue collection,
- Increase in energy costs,
- Technological changes,
- Imbalance of water supply and demand,
- Governance and regulation,
- Inadequate water storage infrastructure (reservoirs),
- Illegal connections, water network vandalism and theft of meters,
- Economic impact of COVID-19,
- Old aging infrastructure and its budget constraints and
- Difficulty of compliance with environmental regulations.

Evident from the two consecutive years (2021 and 2022), the challenges for the utility remain similar. These directly contribute to the rising NRW levels in the utility thus affecting the overall operational capacity.

The Uganda National Water and Sewerage Corporation (NWSC) had a total water supply coverage of 71% within Uganda and had its NRW levels with the corresponding years as depicted below:

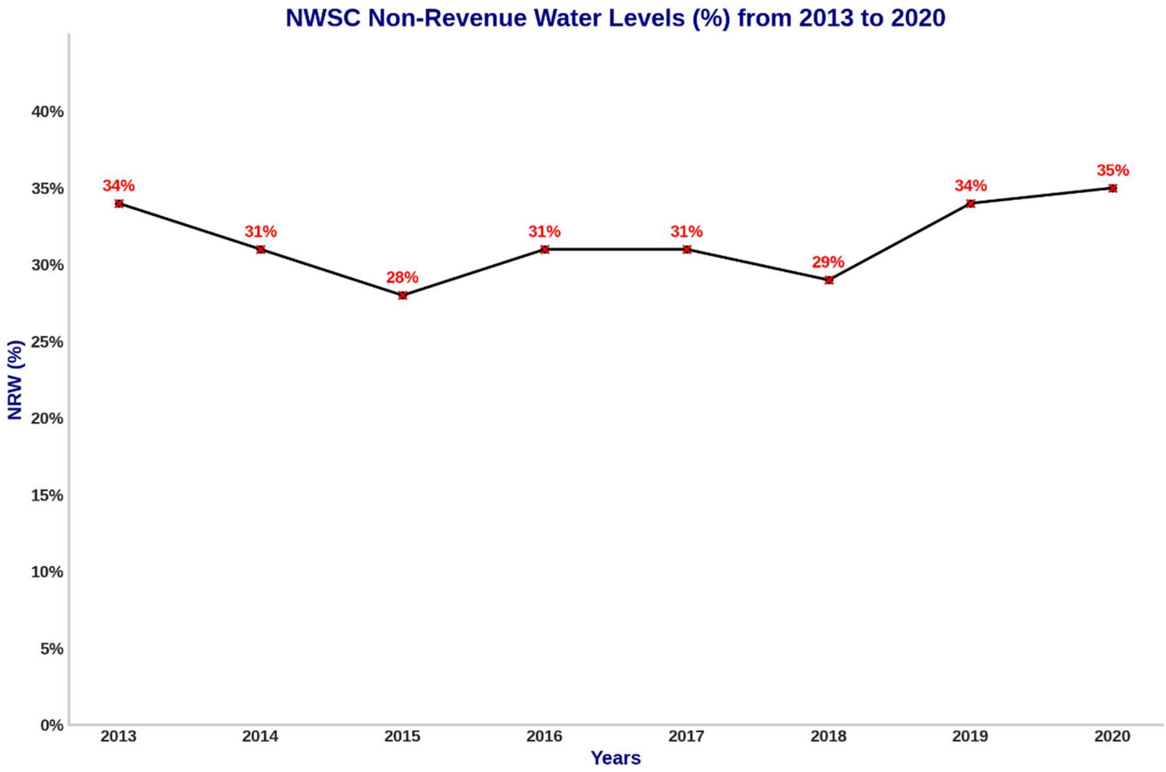

Figure 2.2.1: *NWSC Non-Revenue Water levels (%) from 2013 to 2020 (Source: NWSC, 2022)*

From the yearly collected NRW levels, it is evident that the NRW levels are worsening every single year. The losses are more acute in Kampala Water at a staggering 41% attributed by:

- Old water networks prone to leaks and bursts,
- Illegal water usage by some customers and
- Old water meters that under register the total consumption (NWSC, 2022).

2.2.2. Comparison of NRW levels and technical solutions in Africa to other parts of the world

A comparison of the levels with their respective digital solutions was conducted from different literature sources for Africa against other parts of the world (Europe, Asia and America). A further comparison table was formulated with data sources from the Nordic region to highlight their NRW levels and digital solutions in place. Below is a graph showing the NRW levels for selected African water utilities compared to others from other parts of the world.

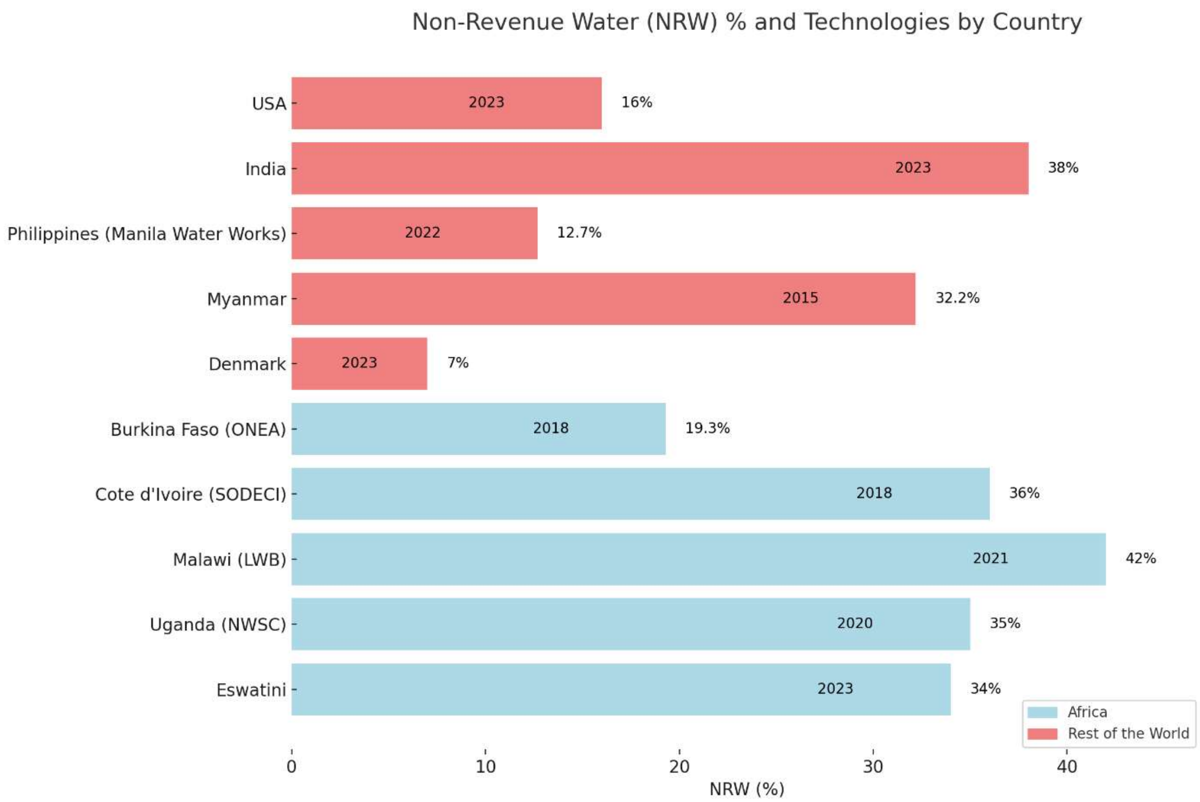

Figure 2.2.2: *Graph showing the NRW (%) in Africa compared to other parts of the world.*

Further below is the overview of the NRW levels in selected African water utilities in comparison with utilities from the rest of the world and a comparison of NRW levels and solutions in the Nordic region.

Table 2.2: Comparison of NRW levels and digital solutions in Africa and other parts of the world

Digital solutions in Africa	Rest of the world
Eswatini (NRW= 25% in 2017, 37% in 2021 and 34% in 2023). Technologies: • Visual inspection for leaks • Optimising efficiency to minimise real water losses • Remote operation and real-time systems (Telemetry, Automatic Meter Reading)	Denmark (NRW= 7.33% in 2020, 7.22% in 2021, 7% in 2023): Sample from a benchmarking exercise with 76 water companies evaluated. Due to strict legislation. Heavy fines/ payments for any utility with NRW levels exceeding 10%. Technologies: • Flow & Pressure management in sections • Online remote metering and reading • Leak detection technology (listening method). Acoustic leakage detector coupled

	with correlators. Done proactively with repairs. • Hydraulic modelling • Water balance (water audits) • Segmenting pipe network
(NWSC) Uganda (NRW= 29% in 2018, 34% in 2019 and 35% in 2020). Technologies: • Customer Relationship Management System (for leak reporting, billing, database) • Prepaid water meters • Capacity building	Myanmar (NRW= 76.6% in 2014 and 32.2% in 2015). After a NRW reduction project. Technologies • Leakage monitoring, pipe repair & meter replacement • Water quality improvement (sedimentation tank with filters) • Technical knowledge transfer • Pressure management (booster pumps)
(LWB) Malawi (NRW= 37.2% in 2019, 39.2% in 2020 and 42% in 2021). Technologies: • Prepaid water metering systems • Remote water monitoring and water management system (SCADA) • DMA management • Data loggers for flow and pressure data collection and management • Leak detection technology • Water meter management programs • Water balance calculations conducted regularly	Manila Water Works, Philippines (NRW= 12.69% in 2022). Technologies: • Reconfiguration (demarcation) of water network • Accurate measurement of supply volumes • Active leakage control and active repairs • Water supply and pressure management • Water meter management programs • Modern and innovative systems and equipment • Active reporting platforms for leaks and illegal connections • Regular repairs and maintenance
(SODECI) Cote d'Ivoire (NRW= 33% in 2016, 35% in 2017 and 36% in 2018). Technologies: • Smart meters • Leak detection system	India (NRW= 38% in 2023 (around 60% in 2023)). Technologies: • Replacing old pipes in network • House to house connections • Meter testing • Smart water metering • SCADA systems

	• Pressure management systems
(ONEA) Burkina Faso (NRW= 19.3% in 2016, 19.3% in 2017 and 19.3% in 2018). Technologies: • Water balance calculations conducted regularly • Pressure reducing valves • Maintenance manuals developed	USA (NRW= 16% in 2016). Technologies: • Advanced Metering Infrastructure (AMI) • Acoustic Leak Detection • Pressure Management • Data Analytics • Geographic Information Systems (GIS)

Manila Water, 2022; EWSC, 2021; LWB, 2021; Water in figures, Denmark, 2022; Eranove, 2018; Indian Infrastructure, 2023; Umutangampundu, 2020

Table 1.2.1: A comparison of NRW levels in the Nordic region

Countries	**Denmark**	**Sweden**	**Norway**	**Finland**
NRW/ leakage	<10%	10-25%	25-40%	?
Laws/ rules on leakage	Yes	No	No	No
Cost of 1 m^3 of drinking water	Ca.40 DKK (CPH)	10-15 DKK (Skane)	50 DKK (Norway)	20-30 DKK (Helsinki)
Proactive leakage prevention	Yes	No	Under discussion	
Software used	MIKE+	WaterGEMS, GEMS+	Mike+	
Transparency of dist. network data	Public	Private	Private	Private

Wei, 2024

Table 1 above compares NRW levels and the digital solutions implemented to tackle water loss between African nations and other parts of the world (Asia, Europe and USA). It highlights the importance of technological innovation and regulatory measures in improving water management efficiency globally as evident in the countries with low NRW levels. Denmark showcases the lowest NRW levels from the above data attributed to strict legislation, highlighting the role of regulatory frameworks in effective water management even in comparison to counterpart countries in the Nordic region also indicated in table 2. There is a prominent trend towards the integration of smart technologies, such as SCADA and smart metering in Africa and other parts of the world (Asia, Europe and USA) to facilitate real-time monitoring and efficient water management.

Below is a comprehensive overview of the common digital solutions for utilities in both Africa and the rest of the world with the specific countries indicated.

Table 2.2.2: Common digital solutions for utilities in both Africa and the rest of the world

Digital Solution	Applied in Africa	Applied in Rest of the World
Remote water monitoring and management	LWB (Malawi), Eswatini	Denmark, India
Leak detection technology	LWB (Malawi), SODECI (Cote d'Ivoire)	Denmark, USA, Myanmar, Manila Water (Philippines)
Pressure management systems	LWB (Malawi), Eswatini	India, USA, Myanmar, Manila Water (Philippines)
Smart water metering	SODECI (Cote d'Ivoire)	India
Water balance (water audits)	LWB (Malawi), ONEA (Burkina Faso)	Denmark
Water meter management program	LWB (Malawi)	Manila Water (Philippines)
Customer relationship management system	NWSC (Uganda)	Manila Water (Philippines)

The common digital solutions for NRW management found in the African water utilities and from other parts of the world are highlighted in the above table, with their relevant countries where they are utilised. The solutions range from remote water monitoring and management, leak detection technology, pressure management systems, smart water metering, water balance calculations (audits), water meter management program and customer relationship management system that lessen the NRW levels as supported by the LWB (2021) annual report; Water in figures, Denmark (2022); Eranove (2018) and Indian Infrastructure (2023).

2.3. NRW Management in Lilongwe Water Board, ONEA and SODECI

2.3.1. NRW Performance in Lilongwe Water Board, Malawi

Lilongwe Water Board developed a five-year NRW reduction strategy beginning in 2029 to 2025. According to the Lilongwe Water Board. (2021) annual report, from a mid-evaluation assessment exercise, the targets had not been met by the year 2021. The NRW levels escalated from 37.2% in 2019 to 42% in 2021 against the target of 35.5% and 30% respectively as presented in the figure below.

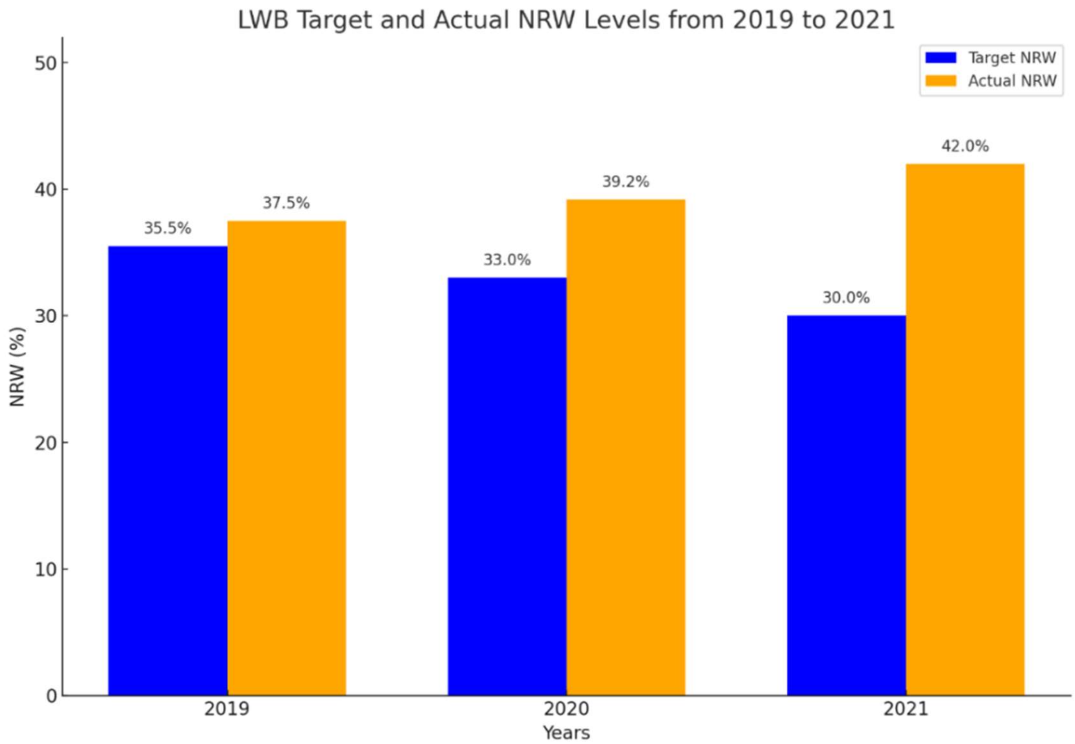

Figure 2.3.1: *Lilongwe NRW trends post NRW strategy implementation (Target vs Actual) (source: LWB, 2021)*

From the evaluation exercise, the NRW reduction strategic plan laid out six strategic focus themes to ease implementation and monitoring of activities of the board. The themes are outlined below;

- Reliability of Water Supply
- Non-Revenue Water reduction
- Customer Satisfaction
- Financial Capacity for infrastructure development
- Institutional and Human Capacity Development
- Wastewater Management

The board further has more innovations that could be effective in lowering the NRW levels. The innovations are: Mobile water treatment plant, Prepaid water metering system, Remote monitoring and water management system, Meter testing and the E-Madzi facility (Lilongwe Water Board, 2021). The main accomplishments and challenges observed during the mid-term evaluation exercise are summarised in the table below.

Table 2.3.1: Key Achievements and Challenges faced during implementation of NRW strategy between 2019 to 2021

COMPONENT	OUTPUT	ACHIEVED	CHALLENGES
System Input Volume	Accurate production figures	• Bulk meter accuracy tests done in areas registering inconsistencies • 4 Bulk meter replacements done • 3 Bulk meters serviced	• Bureaucratic procurement processes
DMA Management	Hydraulically balanced DMAs	• Monthly desk reconciliation of Billing and GIS customer data conducted. 15% of customers included in the billing system with DMA code numbers Monthly Zonal DMA balance analysis reports prepared.	• Customer Meter Validation exercise delayed due to COVID19. • Other DMAs still presenting negative NRW due to undocumented interconnections and boundary valves
	Reduction in Bulk meter under registration	• Meter policy drafted to guide implementation of routine inspections andstandard bulk meter installation.	• Delayed approval of Meter policy which would empower and guide implementation of activities.
	Reduced number of illegal connections	• Awareness program instituted, including naming and shaming. • 310 cases investigated; 101 cases confirmed • Revisit on previously confirmed illegally connected customers Improved adherence and monitoring of physical new water connection procedure	• Minimal prosecutions of confirmed cases due to COVID19
	Reduce meter inaccuracies to maximum permissible errors	• Meter age detail included in Billing	• Faulty and programmed meter replacement not intensified
	Reduce data handling errors	• Trainings conducted • Data analysts conduct monthly validation of billing information	• Inability to conduct frequent physical meetings due to impact of covid-19 • Increase in estimated accounts due inaccessible meters
	Eliminate unbilled accounts	• new water connection process guards hired to enhance the new water	• Billing system inefficiencies Increase of Newly Connected Areas

		connection workflow • Conducted campaign for voluntary connection to Billing for unbilled • customers	
	Reduce estimated accounts to 1% of the total customer base	• Enhance contract management for the outsourced meter reading firm • Enhanced analysis for estimated accounts including analysis of estimates from inaccessible meters	• Conflicting policy direction Intensive Meter replacement exercise failed due to Covid 19
	Consolidated faults data	• SCADA under procurement	• Integration between call centre faults and staff reported faults not implemented
	Updated inventory management system	• 89.7% of all new connections installed Georeferenced and updated in GIS • 100% of all newly pipe installations georeferenced and updated in GIS.	• Some new water connection being misallocated in DMAs • Lack of appreciation by other users of need for 100% georeferencing of new water connections
	Reduction of Bursts and leaks	• Enhanced burst analysis reports highlighting hot spots and indicative causes 13 kms of frequently burst and aged pipes replaced through Zones • 49km replaced	• Pipe replacement program not fully implemented, especially for aged asbestos cement pipes Pressure management system resulting in Unregulated pressures
	A motivated workforce	• Incentive scheme for NRW introduced	• Absence of corporate ownership for NRW reduction initiatives, especially non-technical members
	Availability of repair materials	• Additional repair materials and equipment procured	• Frequent stockouts of fastmoving repair materials
	Reduction of unauthorised valve Operations	• Developed preventive maintenance program for the zones	• Lack of commitment to actualize the plans.
	Accurate measurement of unbilled authorized volumes	• All active Fire hydrants' consumption under monthly scrutiny through	• Only 58% burst forms filled to calculate volume of water loss during repair/ flushing of pipes

		• the water balance computations	
	Reduction in unbilled consumption volumes	• Automatic taps installed in some LWB facilities	• Continuous use of treated water for lawn watering instead of raw water
	Improved approaches to NRW reduction	• Basic training on leak detection conducted • DMA management capacity built at all levels	• Scheduling of some trainings affected by COVID-19

LWB, 2021

As indicated in the table above, the project made significant strides in improving system accuracy, reducing illegal connections, enhancing data management and updating infrastructure as a means to reduce the NRW. However, the board had setbacks. It faced bureaucratic challenges, negative impacts of COVID-19, operational and technical issues and grappled with engagement and resource limitations.

2.3.2. NRW Management in SODECI, Côte d'Ivoire and ONEA, Burkina Faso

ONEA in Burkina Faso has become a benchmarking point for African water utilities due to its good performance in water management (AfWA/USAID, 2010). This is because of its total coverage, low NRW levels, institutional, technical and financial performance that has been constantly good over the years. The data for NRW levels from research work by Umutangampundu (2020) showed the following levels in the consecutive years:

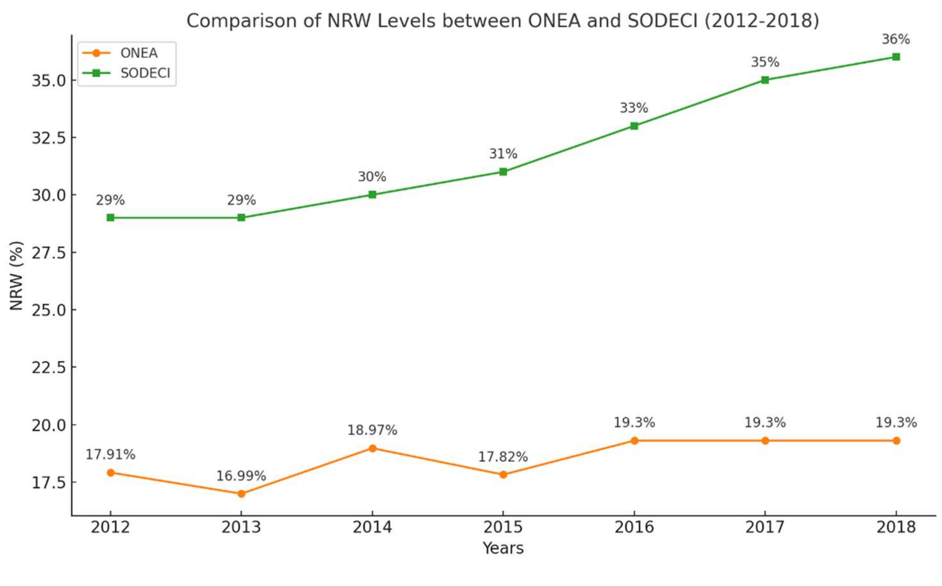

Figure 2.3.2: *Comparison of NRW levels between ONEA, Burkina Faso and SODECI, Côte d'Ivoire (Source: Umutangampundu, 2020)*

The comprehensive dataset from Umutangampundu (2020) provides an insightful comparison of technical, financial, customer, and institutional performances between two water utilities: SODECI (Côte d'Ivoire) and ONEA (Burkina Faso). Analysing technical performance indicators, it is evident that ONEA surpasses SODECI in several areas, including water supply coverage (92.44% vs 71%) showcasing its superior efficiency in managing water losses and ensuring broader access to water. Both utilities have high metering efficiency, but ONEA's commitment to water quality stands out with a 100% score in physico-chemical and bacteriological tests for 2018, compared to SODECI's 96%. This highlights ONEA's effective measures in ensuring water safety and reliability.

Financial performance metrics further delineate the two utilities' operational efficiencies and strategies in managing resources and revenue. ONEA demonstrates a stronger operating cost coverage ratio of 1.23 in 2017 compared to SODECI's 1.06 in 2014, indicating a more sustainable management of operational expenses relative to revenue from water services. Additionally, ONEA's lower unit cost of production ($0.73/m^3) versus SODECI's ($0.94/m^3) points to more efficient production processes. However, both utilities maintain high collection efficiencies, with ONEA slightly leading at 98%. These financial indicators underline the critical balance between operational efficiency, cost management and revenue collection in sustaining water utility services.

The customer and institutional performance indicators reveal a detailed view of the utilities' service delivery and organizational strengths. ONEA exhibits superior customer satisfaction at 90% in 2017 and higher continuity of water supply (23 hours/day) than SODECI (20 hours/day), reflecting its effectiveness in maintaining reliable water services and addressing customer needs. Institutional performance shows ONEA investing significantly in capacity building with 100% annual staff training, compared to SODECI's undisclosed training data. Despite both utilities employing a similar staff-to-connection ratio, ONEA's explicit focus on NRW management through dedicated leadership underscores its strategic approach to reducing water losses. These dimensions of performance highlight the importance of customer-centric services, continuous staff development and strong institutional frameworks in enhancing the sustainability and reliability of water utilities. It is from the above detailed project findings that further support the lower NRW levels in ONEA as opposed to SODECI.

2.4. Digital technologies for NRW management

Digital transformation, defined as the change in processes or products influenced by the advancement of digital technologies, is categorised into four primary areas: processes, technology, people and data. In the water industry, this transformation is guided by the need for data-driven solutions, leading to the adoption of technologies such as digital twins, smart asset management, GIS and AI (Ciliberti et al., 2021). These innovations empower utilities globally to collect insights, make informed decisions, and enhance services rapidly (Sacoto-Cabrera et al., 2022). For Non-Revenue Water (NRW) management, tools like GIS monitoring systems, SCADA, and active and passive leakage control strategies are vital.

Zafra-Gómez et al. (2024) states that digitalisation in water utilities promotes transparency, traceability and accountability, thus enhancing customer trust and willingness to pay. For example, predictive control and AI-powered predictive analytics tools in wastewater networks allow for the prediction and early warning of high-water levels, pollution events and blockage detection, thereby improving operational efficiency and reducing costs. Digital tools and processes, adaptable to various segments of the water value chain, can enhance access to safe and clean water (Zafra-Gómez et al., 2024).

2.4.1. GIS monitoring systems and databases

GIS are systems for the acquisition, processing, organisation, analysis and presentation of spatial data. According to (Ziemendorff, 2022), GIS's usefulness lies in providing information that is easy to obtain and process for almost all areas of a utility, including many commercial and operational uses linked directly to the reduction of NRW and some of its uses are:

- Every component of the network is geolocated to aid field workers in finding them promptly. For example, meter boxes for reading meters, and valves for maintenance, properties for invoice distribution,
- Instant access to information about materials, diameters and other characteristics of leak sites, enabling leak repair staff to assemble the suiting materials and replacements,
- Real-time calculation of the budgets and materials necessary for new connections, enabling applications without prior inspection, saving time and money and
- Provision of thematic maps for commercial inspections to find illegal connections, under- registration.

Water utilities can also use GIS monitoring system and database to reduce water loss in their networks. GIS monitoring system and database can help water utilities to measure and control the flow and pressure of water in their pipes, and to detect and repair leaks quickly. This is by segmenting the network into sub-zones or districts that have different water pressure and metering. By monitoring the minimum night-time flows in each zone, water utilities can identify the zones that have high water loss and locate the leaks more easily (Lambert et al., 1999).

2.4.2. Passive leakage control

Passive leakage control is a technique for handling water losses in water supply systems that relies on customers or staff to report leaks or pressure problems. This method may be suitable for areas where water is abundant or cheap, but it does not prevent leakage from increasing over time. Passive leakage control is often used in less developed systems where the effects and causes of underground leakage are not well understood (Farley, 2003; McKenzie et al., 2002).

2.4.3. Active leakage control

Active Leakage Control (ALC) is a program that water utilities use to locate leaks that are not reported by customers or other sources. ALC usually involves checking for leaks regularly and measuring the lowest water flow at night in areas that have different water pressure or metering (Mathis et al, 2008). The usage of the DMA approach to leakage detection and localisation has become an international best practice. Sturm and Thornton (2007), showed that the network's features and the local environment, which may include available resources, equipment and budget, will largely determine the best leakage control strategy. The approach to leakage control in many developing nations, especially, is typically passive or minimal activity, fixing only apparent leaks (McKenzie, 2004).

2.4.4. Supervisory Control and Data Acquisition System (SCADA)

SCADA is an industrial control system pivotal for monitoring and controlling water supply processes that leverages sensors, actuators and communication networks to optimise use and monitor essential parameters such as water pressure, flow rate, levels and energy consumption based on algorithms (Irvawansyah & Rahmansyah, 2018). SCADA combines hardware and software elements to collect, monitor and analyse real-time data, enabling plant operators to control processes while providing meaningful, automatic data. This system allows system operators to remotely record events and control industrial processes. HMI (Human-Machine Interface) software facilitates interaction with devices like pump stations, tanks, sensors, valves and meters.

SCADA's ability to collect data and send commands plays a crucial role in optimising water network operations and reducing Non-Revenue Water (NRW) loss. By using data points, operators can use SCADA to identify operational problems in real-time, thus offering a system of controls that provides instant access to operational data and production information, enabling informed decision-making regarding operations (Gouthaman, Bharathwajanprabhu, & Srikanth, 2011). Computers along with digital networks monitor the entire treatment process, which is now the standard (eLynx Water Solutions, 2023).

SCADA, first introduced in the 1970s, utilised new computer systems for industrial and electrical processes (Anton et al., 2017). SCADA systems have been utilised in developed countries for decades, but their adoption in developing countries, particularly in Africa, has been limited due to challenges such as high costs and lack of technical skills (Mwenge Kahinda et al., 2018). As technology has advanced over the years, more reasonably priced options are now accessible. SCADA has been successfully used in African water utilities, such as the Aqaba Water Company (AW) and Nairobi City Water and Sewerage Company (NCWSC), to improve operational performance, customer service and NRW management. However, SCADA systems need to be complemented by other measures and adapted to the local context to achieve sustainable water service delivery and NRW reduction (Farley & Trow, 2003; Mwenge Kahinda et al., 2018).

SCADA for water management ensures the following functionalities in water systems:

- Communications with equipment (numerous native protocols or via OPC server).
- Remote control of hydraulic installations.
- Data logging.
- Presentation of data by graphic editor.
- Management of alarms and events.

2.4.5. Smart Water Meters

Verma. (2020) defines a smart water meter as a technology that measures the very least volume of water consumed over time and that can transfer real-time data remotely. A smart water meter can have more advanced functionality as well, such as the ability to send alerts when a leak has been detected, but it at least needs to collect and transfer data automatically. The system consists of three types of technologies for:

- data capture,

- data transfer and
- data analysis.

Data collection technology consists of water meters that measure water flow and data loggers that store measurements (Giurco et al. 2008). There are different types of smart water meters suitable for different purposes such as domestic water meters that measure domestic water consumption and regional water meters that can measure drinking water in an area or part of a city, providing important information about water use in the network (Kamstrup, 2021b). IoT-based smart water meters allow users to monitor drinking water and pay accordingly. Below is an example of a smart water meter.

Figure 2.4.5: *A smart water meter device (Source: Kamstrup)*

The system allows utilities to better monitor and control water demand, helping to reduce overall water loss. These smart meters use sensors to quickly detect water leaks, helping water companies quickly eliminate waste by restricting the flow of water. By detecting and repairing leaks early, water pollution can be prevented and the water can be made drinkable. Smart water meters allow customers to pay for exactly the water they use. The meter also plays an important role in reducing water revenues due to theft, leakage or incorrect delivery before customers lose water. With precise water metering and payment sharing, utilities can generate enough revenue to help improve infrastructure. This can improve collection and tax collection and reduce wastewater from seepage (Drabble et al., 2020). SWM technology also increases the efficiency of water companies in providing safe water to consumers. Through water monitoring and instant detection, utilities can optimise water networks, reduce water waste and improve water reliability.

2.5. Framing Digital Adoption

Digitisation in water may be a suiting solution to combatting the challenges related to population growth, urbanisation, climate change and inequality by ensuring urban resilience. The technology domains guiding the digital adoption are briefly defined comprehensively by White & Lemasagarai, (2023) below:

Table 2.5: Technology domains guiding digital adoption

Domain	Definition
Data acquisition	The infrastructure needed for digital data collection (e.g. sensor networks, smart pipes, smart meters, mobile devices and other tools)
Connectivity and network infrastructure	The availability of suitable network infrastructure for communication (e.g. transmitters, data, voice, SMS, USSD, etc)
Data processing and storage	The systems and processes used to manage data from different sources (e.g. ERP systems, cloud computing)
Management and Control	Technologies that use two-way control to allow for remote operation (e.g. SCADA and IoT solutions for process automation)
Modelling and Analytics	The combination of datasets to produce specific analytics and tools used to present data for decision making.
Customer relationships	Tools that modify customer-utility relationships (e.g. billing and payments, customer complaints and social media)

White & Lemasagarai, 2023

2.6. Enablers to digitisation

There are several catalysts to digitisation in the water sector. For the sake of the discussion, three have been highlighted and discussed below basing its relevance to the water sector in then African context.

2.6.1. Regulations and Public Policy

Buafua (2015) finds that private-sector participation and economic regulation, particularly through performance contracts, enhance the technical efficiency of urban water utilities more effectively than regulation by independent agencies. This underscores the importance of regulatory frameworks that promote private management while ensuring public ownership and oversight (Buafua, 2015). Foster et al. (2020) emphasises the critical role of groundwater for resilient urban water supply in the face of rapid urbanisation and climate change, arguing for a proactive approach from water utilities towards groundwater resource management and quality protection (Foster et al., 2020).

The study by Van den Berg and Danilenko (2017) on the performance of water utilities across Africa reveals that despite significant investments, the rapid urbanisation has outpaced the ability of African utilities to provide reliable water services, indicating a need for innovative governance and regulatory approaches to improve utility performance (Van den Berg & Danilenko, 2017). Hope et al., (2020) suggest that to address the water challenges in rural Africa, policies need to focus on networking rural services at scale, creating value to unlock rural payments, and designing performance-based funding models (Hope et al., 2020). These studies collectively highlight the potential of regulatory and policy frameworks to facilitate the digitisation of water utilities in Africa, pointing towards the necessity of integrating private sector efficiency with public sector oversight and community engagement for sustainable water management.

2.6.2. Data Structuring Solutions

Water utilities are now dealing with large volumes of data that are both structured and unstructured coming from disparate sources. Most utilities report that accessing information from outdated systems still presents a challenge. The key to maximising the use of big data is accessing the right data when it is needed by the applications. Raatikainen et al. (2021) highlight that an increase in the use of application programming interfaces (APIs), which provide a way for retrieving data programmatically by any software application is greatly observed. Karmous-Edwards & Sarni (2018) further assert that the required data can then be accessed via APIs by a variety of software programs throughout the business from existing legacy systems, sensors and other applications regardless of data location, utility department or functionality needed. The same data sets can be used and reused for multiple purposes, thereby increasing the value of digital solutions.

2.6.3. Demographical Shift

The demographic shift towards a more digitally savvy customer and workforce is likely to be a significant driver for the digitisation of African water utilities. The digital customer and workforce, fuelled by generational changes, are increasingly expecting and demanding that core services such as water embed digital innovations into their offerings. Adam, (2019) strongly supports that the advent of a no-collar workforce, combined with these generational forces, suggests that the transformation to digital water utilities is not just desirable but inevitable.

The digital revolution, marked by the widespread adoption of information and communication technologies, holds the potential to radically transform Africa, similar to the impact of the first industrial revolution on the western countries in the 19th century. Despite challenges, the digital revolution in Africa harbours bright future opportunities, particularly in poverty alleviation and business development. The diffusion of digital technologies across the continent, albeit at varying speeds, is reshaping the landscape for service delivery in essential sectors like water and electricity supply.

In Nairobi, Kenya, for instance, telecommunications and urban water and electricity utility systems are increasingly interlinked, with ICT deployments for urban utilities being strategically employed to navigate the city’s fragmentation and to target services towards underserved communities. This approach not only demonstrates market-led priorities to maximize returns and expand networks but also engages with the micro-political dynamics of service delivery in urban contexts (Guma, 2019). The drive towards digital transformation in African water utilities, therefore, must navigate both the opportunities presented by a digitally literate population and the infrastructural and regulatory challenges inherent in the continent's diverse contexts.

2.7. Digital adoption barriers

According to White & Lemasagarai (2023), some telling data on the barriers to digital technology adoption include a lack of resources (budget) accounting for 23%, a lack of skills and knowledge (18%), a lack of a clear return on investment (13%), governance (11%), resistance to change (10%) and complexity to change (10%). According to additional data, two-thirds of utilities have not formalised their digital vision or adapted their structure to facilitate their journey and smart practices adoption is low. More than two-thirds of water utilities either do not use data for maintenance or performance management, or use data only in a reactive mode to detect defects or anomalies, with less than 10% embracing big data analytics, AI and machine learning. The barriers to digital adoption in water utilities are outlined and briefly explained below.

2.7.1. Systems integration

Systems integration involves the process of combining various technological systems, software and processes into a cohesive, functioning whole. Systems integration and interoperability present significant barriers to digitisation in African water utilities, impacting the efficient management of water resources and the delivery of services. The complexity of integrating disparate technological systems and ensuring they can work together seamlessly is a challenge, as evidenced by the study of urban infrastructure focusing on telecommunications and urban water and electricity utility systems in Nairobi, Kenya, which reveals challenges in ICT deployments aimed at maximising returns on investment and expanding networks within the fragmented urban contexts of African cities (Guma, 2019).

Similarly, institutional barriers to the integration, interoperability and information sharing of e-government systems in South Africa highlight the broader implications of system integration challenges across government services, which could hinder efforts to digitise and integrate services within the water utilities sector (Manda, 2017). Additionally, the operational and financial risks associated with implementing innovative technologies in water utilities underline the importance of stakeholder involvement and the complexities of introducing systems integration and interoperability in environments with varying field conditions (Zoric & Heusinkveld, 2020).

Furthermore, identifying barriers to e-government integration, such as strategy, technology, policy, and organisation, including challenges related to architecture interoperability, data standards, and legacy systems, is essential for advancing the digitisation of water utilities (Lam, 2005). These studies illustrate the multifaceted challenges of systems integration and interoperability in the context of African water utilities and underscore the need for technological innovation, policy reform, and stakeholder engagement.

2.7.2. Human resources impact

The impact of human resources on digitisation efforts in African water utilities emerges as a critical barrier. One of the most significant challenges is the lack of skilled personnel to manage and implement new technologies effectively. This gap not only slows down the pace of digital adoption but also affects the sustainability and efficiency of water services. The rapid growth of Africa's urban population further worsens these challenges, demanding a more significant expansion of basic services infrastructure that the current workforce cannot meet (Chitonge, 2014; Berg & Danilenko, 2017).

Additionally, the transition towards digitalization in the water sector requires a workforce that is not only technically skilled but also adaptable to the rapidly changing technological landscape (Kuteyi & Winkler, 2022). Investing in human capital, therefore, becomes imperative, including training and capacity building, to harness the potential of digital technologies for improving water utilities. This approach aligns with broader efforts across the continent to leverage digitalization for economic growth, where the usage of digital technology by individuals shows a positive impact, underscoring the importance of human resource development in realizing the benefits of digital transformation (Solomon & van Klyton, 2020).

2.7.3. Financing

Financing emerges as a pivotal barrier to digitisation in African water utilities, primarily due to the vast infrastructure needs that significantly exceed the continent's capacity for investment. Beck, Maimbo, Faye, and Triki (2011) highlight the urgency for innovative financial sector development strategies that foster competition and innovation within Africa's financial sectors, crucial for supporting digitisation efforts. Similarly, Collier (2014) underscores the acute need for substantial foreign private finance in Africa's infrastructure, particularly water utilities, to surmount the hurdles posed by inadequate transport and power infrastructure.

Harvey (2007) further elaborates on the necessity for sustainable financing strategies that account for the true costs associated with providing sustained water services, advocating for a systematic approach to develop practicable long-term financing mechanisms. Ncube (2010) discusses various financing models under public-private partnership arrangements, stressing the importance of leveraging private sector investment for infrastructure development in Africa. Collectively, these studies indicate a critical need for a reimagined approach to financing water utility digitisation in Africa, involving a mix of innovative financial instruments, sustainable financing strategies and the engagement of both public and private sectors to bridge the investment gap.

2.7.4. Cybersecurity

Cybersecurity represents a significant barrier to digitisation, notably because the increasing reliance on digital infrastructure introduces vulnerabilities that must be managed. The cybersecurity landscape in Africa is marked by a rapid increase in cybercrime activities, making the continent both a target and a source of cyber threats, including attacks on critical water infrastructure (Kshetri, 2019).

Moreover, the legislative and policy environment across various African countries, such as South Africa, has begun to address these threats by developing national cybersecurity strategies (Malatji, Marnewick, & Solms, 2020). However, the implementation of these strategies often reveals gaps and challenges, such as the complex interplay between government action and the cybersecurity strategy, and the need for sector-specific governance frameworks and resilience strategies to protect critical assets like water and wastewater infrastructure (Malatji, Marnewick, & Solms, 2020).

2.8. Conclusion

The literature review conducted a detailed analysis of the NRW problem in African water utilities with their relevant measures currently undertaken for management as compared to other parts of the world. The chapter made it possible by firstly diving into the keywords used with their meaning as used in the context and then further analysing the water balance which is widely used for water audits. It further delved into the different digital solutions available for NRW management with their enablers and in turn their complexities. In the last part, the literature review was an exhaustive analysis of the NRW management in the selected water utilities: ONEA, LWB and SODECI to further asset the need for the digital approach for NRW management.

CHAPTER 3: MATERIALS AND METHODS

3.0. Introduction

This chapter presents briefly the socio-economic profile, environment, administration and population of serviced study areas with the research design and methodology for the entire project. This research was conducted in three water utilities: ONEA, Lilongwe Water Board and Wolaita Sodo water. Secondary data from the selected water utilities was collected, tabulated and analysed to assess the solutions in place for NRW management. The research methodology has been derived as per a recommendation by Umutangampundu (2020), who conducted a comparative study of NRW management between ONEA and SODECI. She came up with a conceptual model for NRW management of which the Main Operational Activities section sparked interest for the research project

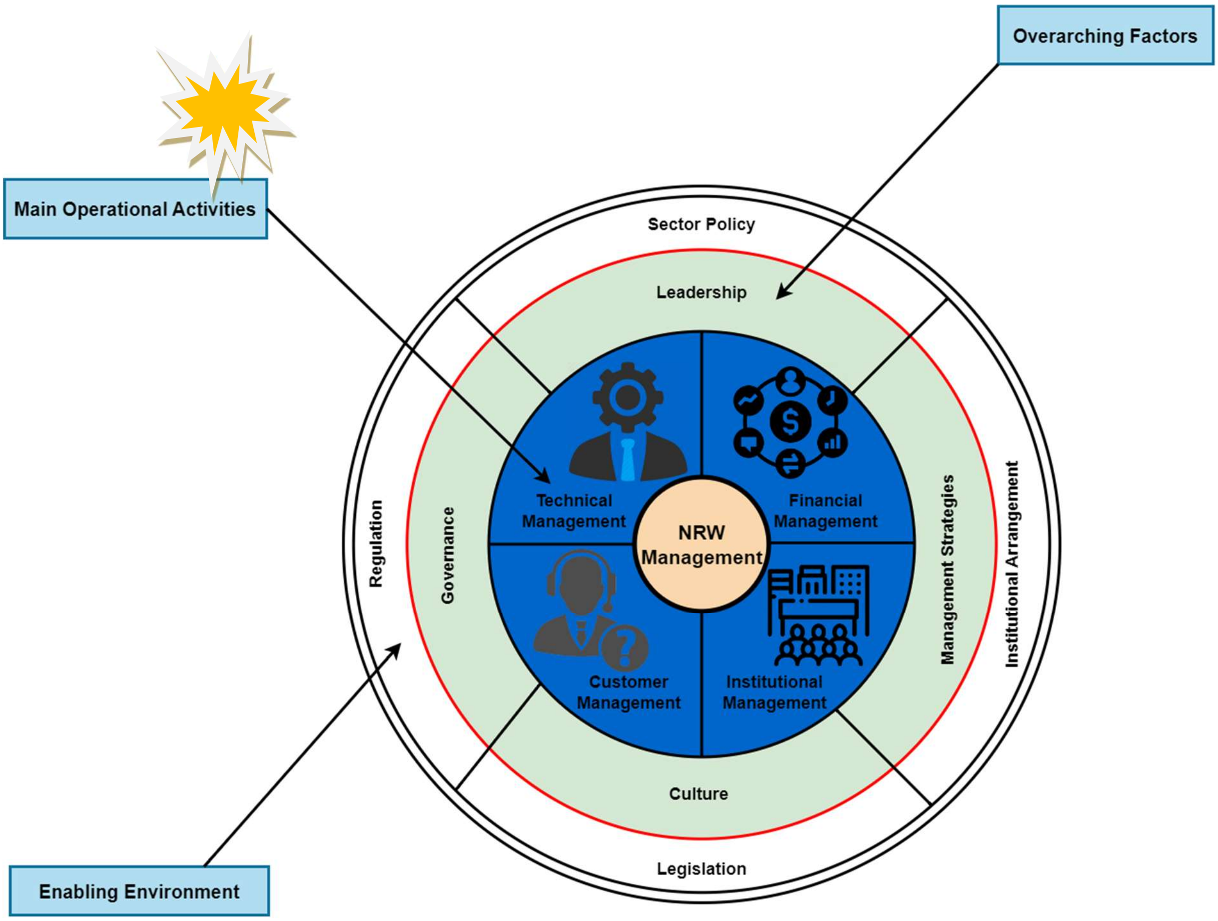

Figure 3.0: *A proposed Conceptual model for effective NRW management (source: Umutangampundu, 2020)*

3.1. Study Areas

This part will give a detailed overview of the location and climatology of Ethiopia, Malawi and Burkina Faso. It will also give insight on the ONEA, Wolaita Sodo and Lilongwe Water Boards background information and functions.

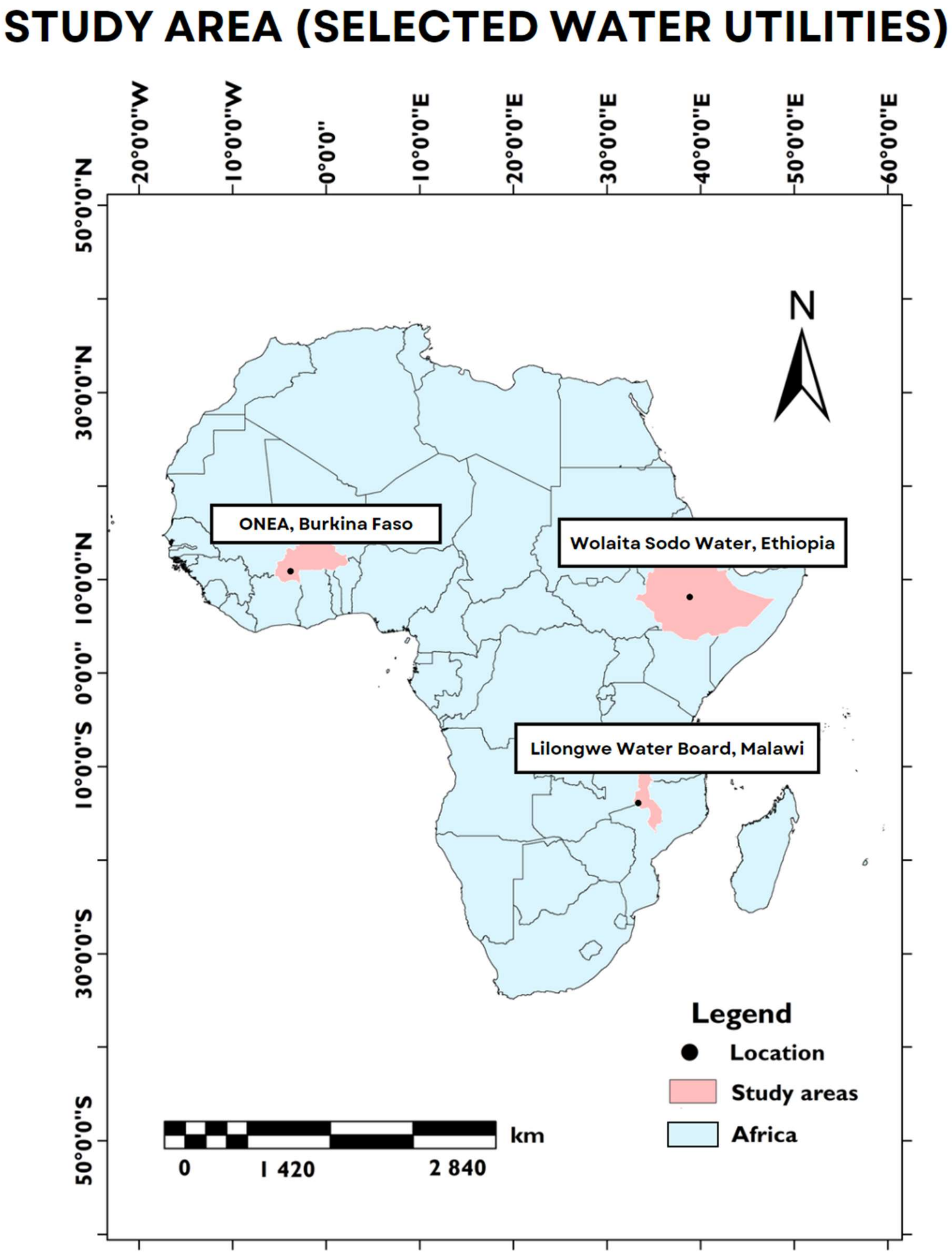

Figure 3.1: *Location of the selected water utilities*

3.1.1. Ethiopia

Ethiopia is a landlocked country on the Horn of Africa with a population estimate of 109,900,000, projected to reach 139.6 million by 2030 and 190.8 million by 2050. It has a land mass of 1,104,300 km^2 and located between approximately E 32°58’00” to E 48°00’00” and 3°25’00” N to 14°55’00” N. The capital is Addis Ababa, located almost at the centre of the country. The country’s president is Sahle-Work Zewde and the head of government is the Prime Minister, Abiy Ahmed. The form of government is a federal republic with two legislative houses namely: the house of the federation and the house of peoples’ representatives. Ethiopia is a mosaic of about 100 languages that can be classified into four groups. The vast majority of languages belong to the Semitic, Cushitic, or Omotic groups, all part of the Afro-Asiatic language family. A small number of languages belong to a fourth group, Nilotic, which is part of the Nilo-Saharan language family. Amharic is one of the country’s principal languages and is native to the central and northwestern areas.

Relief and Drainage

Ethiopia is bounded by Eritrea, Djibouti, Somalia, Kenya, South Sudan and Sudan. Its topography is built on four geologic formations. Five topographic features are distinct in the country. These are the Western Highlands, the Western Lowlands, the Eastern Highlands, the Eastern Lowlands and the Rift Valley. Ethiopia has three principal drainage systems. The first and largest is the western drainage system, which includes the watersheds of the Blue Nile (known as the Abay in Ethiopia), the Tekeze and the Baro rivers. All three rivers flow west to the White Nile in South Sudan and Sudan. The second is the Rift Valley internal drainage system, composed of the Awash River, the Lakes Region and the Omo River. The Lakes Region is a self-contained drainage basin and the Omo flows south into Lake Turkana (Rudolf), on the border with Kenya. The third system is that of the Shebele and Genale rivers. Both of these rivers originate in the Eastern Highlands and flow southeast toward Somalia and the Indian Ocean.

Climate

The country has a diverse climate and landscape, ranging from equatorial rainforest with high rainfall and humidity to desert-like conditions in the north-east, east and south-east lowlands. Overall, Ethiopia is considered largely arid, but exhibits a high variability of precipitation Ethiopia’s climate is generally divided into three zones:

1. the alpine vegetated cool zones (Dega) with areas over 2,600 meters above sea level, where temperatures range from near freezing to 16°C;
2. the temperate Woina Dega zones, where much of the country's population is concentrated, in areas between 1,500 and 2,500 meters above sea level where temperatures range between 16°C and 30°C; and
3. the hot Qola zone, which encompasses both tropical and arid regions and has temperatures ranging from 27°C to 50°C.

The areas of lower elevation in Ethiopia experience climatic conditions typical of tropical savanna or desert whilst higher elevated areas experience weather typical of temperate zones. There are three seasons in Ethiopia. From September to February is the long dry season known as the bega; followed by a short rainy season, the belg, in March and April. May is a hot and dry month preceding the long rainy season (kremt) in June, July and August. The coldest temperatures generally occur in December or January (bega) and the hottest in March, April, or May (belg).

Ethiopia is divided into four rainfall regimes. Rain falls year-round in the southern portions of the Western Highlands, where annual precipitation may reach 2,000 mm. Summer rainfall is received by the Eastern Highlands and by the northern portion of the Western Highlands; annual precipitation there may amount to 1,400 mm. The Eastern Lowlands get rain twice a year, in April to May and October to November, with two dry periods in between. Total annual precipitation varies from 500 to 1,000 mm. The driest of all regions is the Denakil Plain, which receives less than 500 mm and sometimes none at all. Climate change adaptation and resilience priorities in the country are focused on increased adaptation for key sectors including Agriculture, Forestry, Transport, Electric Power, Industry (including mining) and Buildings.

Vegetation

Ethiopia's natural vegetation is influenced by four biomes. The first is the savanna, the second biome is mountain vegetation, the third biome is tropical thickets and wooded steppe and the fourth biome is desert steppe vegetation.

Livelihood

Ethiopia's most prominent livelihood activity is Agriculture. Soil erosion, overgrazing and deforestation have seriously damaged the plateaus, making nearly half the land inarable. Ethiopia is among the richest countries in Africa in livestock, including cattle. This gives the country great internal as well as export markets. Agriculture contributes almost half of Ethiopia's GDP (World Bank, 2019).

3.1.1.1. Wolaita Sodo City Water Supply and Sewerage Services Enterprise

Wolaita Sodo City Water Supply and Sewerage Services Enterprise (WSCSSE) in Ethiopia plays a crucial role in providing essential water supply and sanitation services to the residents of Wolaita Sodo. Wolaita Sodo is a city located in the Southern Nations, Nationalities and Peoples' Region of Ethiopia. This enterprise is tasked with the development, maintenance, and expansion of water supply and sewerage infrastructure to meet the growing needs of the city, which is an important administrative, commercial and educational centre in the region. The NRW for Wolaita Sodo water is 35.4% for the year 2024. Given below is the location of the company in Ethiopia.

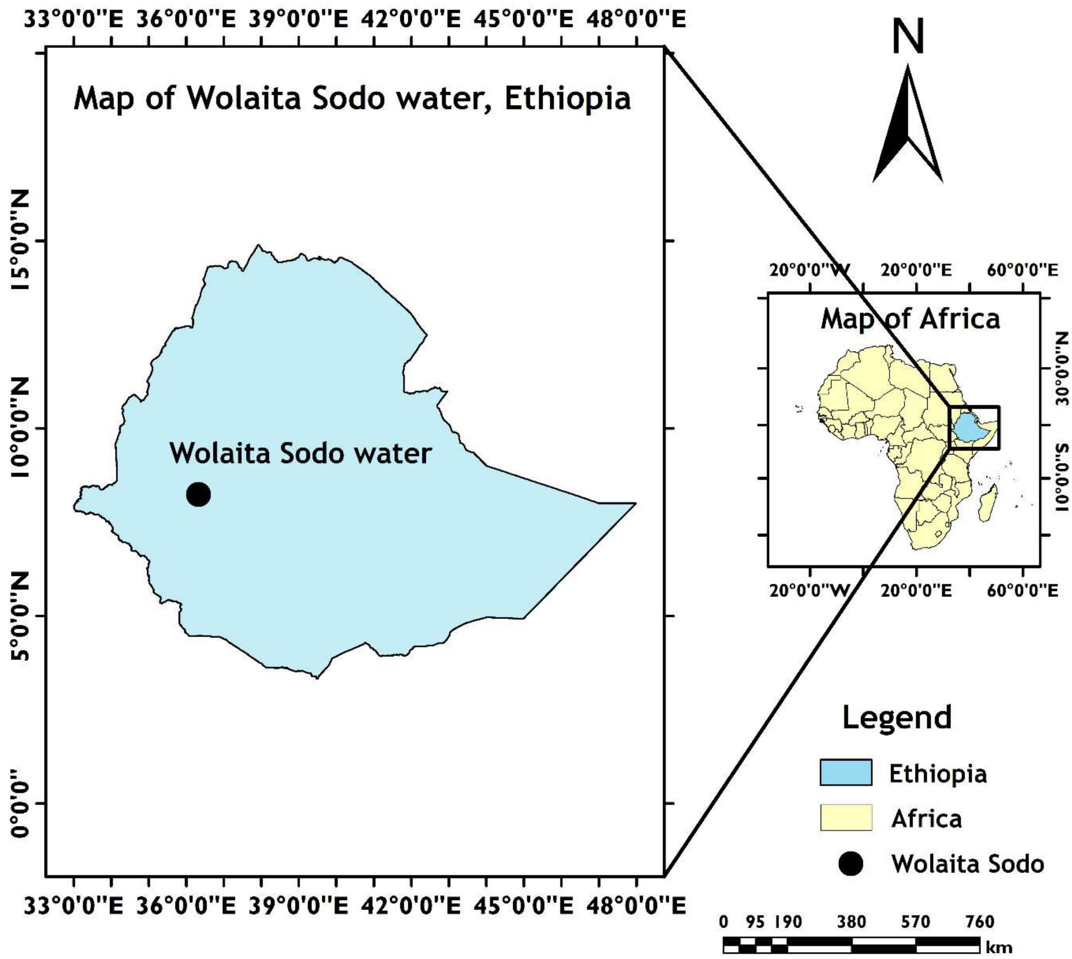

__Figure 3.1.1__: Map showing the location of Wolaita Sodo water in Ethiopia

The detailed role of WSCSSE is the planning and implementation of projects aimed at expanding the water distribution network, improving water quality and constructing wastewater treatment facilities. The enterprise is also responsible for the management of water resources, including the sourcing, treatment, and distribution of potable water, as well as the collection, treatment and disposal of sewage and wastewater (Ministry of Water, Irrigation and Energy, Ethiopia, 2018).

WSCSSE faces challenges that include limited financial resources, aging infrastructure and the increasing demand for water and sanitation services due to rapid urbanisation. To address these challenges, the enterprise has embarked on various initiatives, such as seeking partnerships with international donors and implementing water conservation measures. Additionally, there is an emphasis on community engagement and awareness programs to promote water conservation and sanitation practices among the city's residents (World Bank, 2019)

WSCSSE has made significant strides in improving water supply including the successful completion of water supply expansion projects, which increased the availability and reliability of water services. The enterprise also introduced innovations in wastewater management, including the construction of new sewage treatment plants, which have significantly improved the environmental and public health conditions in the city (United Nations Development Programme, 2020).

WSCSSE aims to continue its efforts in expanding and upgrading water supply and sewerage services to meet the needs of Wolaita Sodo's growing population. Such efforts include adopting sustainable water management practices, enhancing the efficiency of water use and expanding access to sanitation services. The enterprise is also exploring the use of renewable energy sources to power its operations, thereby reducing its environmental footprint and ensuring the sustainability of its services (African Development Bank Group, 2021).

3.1.2. Burkina Faso

Burkina Faso is a rural, landlocked country covering area of 274,000 km² located in West Africa sharing borders with Mali, Niger, Benin, Togo, Ghana and Côte d'Ivoire. Its capital city is Ouagadougou, situated in the heart of the country. The country has 13 districts with relatively flat terrain. The low slope of the relief hinders the flow of water from the three rivers: Mouhoun, Nazinon and Nakambé which drain the country. The average altitude of the plateaus is 450 m with the highest point, the Tenakourou rising up to 747 m in the western part of the country.

The climate is tropical with mild, dry winters and hot, rainy summers. There are two types of natural environment: the Sahel (North) and the Savannah (South). Burkina Faso has few natural resources with a few deposits of natural minerals (Manganese, Gold, Phosphate, etc). and is an arid country. The vast majority of the population is agricultural and cultivates sorghum and millet, groundnuts, sesame, etc. for personal consumption. Cotton is one of the country's main export products.

3.1.2.1. ONEA

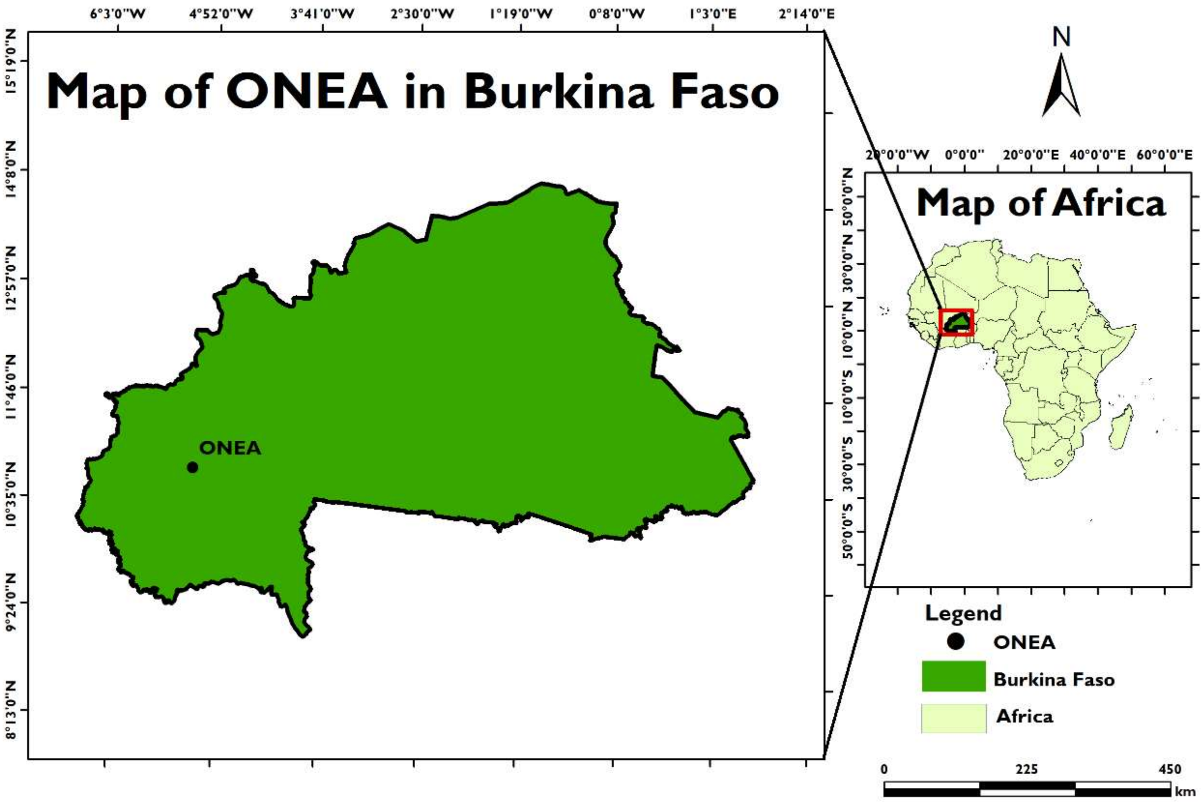

Figure 3.1.2: *Map showing the location of ONEA, Burkina Faso*

Office National de l'Eau et de l'Assainissement (ONEA) translates to the National Water and Sanitation Office of Burkina Faso in English. ONEA is a state company created by decree 1985-387/CNR/PRES. It has a capital of 3,080 million CFA Francs entirely detained by the State and its functions are the provision of clean water, sewerage services and capacity building and cooperation. A three-year contract plan and specifications govern relations between the State and ONEA, establishing the conditions for the establishment, operation and protection of ONEA-managed water and sanitation infrastructure. The two main missions of ONEA are to create, manage and protect installations for the collection, supply, treatment and distribution of drinking water for urban and industrial needs. In addition, ONEA develops, advances, and oversees the management of group, individual or autonomous sanitation facilities for the removal of excreta and wastewater in urban and semi-urban regions.

ONEA manages 56 centres in Burkina Faso. Being a public utility, ONEA's technical operation is supervised by the Ministry of Water and Sanitation (MEA), while its management is supervised by the Ministry of Industry, Trade and Handicrafts, and finally the Ministry of Economy and Finance. Burkina Faso has become a benchmarking point for African water utilities due to its good performance in water management (AfWA/USAID, 2015). ONEA also obtains funding from AfWASA and is valuable in water quality monitoring. It further is a regional supplier of water to several West African countries namely: Sierra Leone, Ghana, Nigeria, Togo, Côte d'Ivoire and Niger.

The water distributed by ONEA to its subscribers comes from surface water and groundwater. The surface water comprises of 9 reservoirs for the cities of Ouagadougou (Loumbila, Ouaga 3 and Ziga), Koudougou (Salbisgo), Pouytenga (Itengué), Kompienga, Ouahigouya, Dori (Yakouta), Fada N'Gourma (Tandjari) and Kaya (Dem) 2 river intakes for the cities of Banfora and Koudougou (Mouhoun). The groundwater resources are one 1 artesian spring for the city of Bobo-Dioulasso, 219 boreholes and 18 wells.

3.1.3. Malawi

Malawi is a landlocked country in Southern Africa that borders Tanzania, Zambia and Mozambique. In 2022, there were 20.41 million people living in the nation, growing at a 2.6% yearly pace. According to the World Bank Group (2023), Malawi has made substantial structural and economic reforms to support economic growth, amidst being among the poorest. With over 80% of the workforce employed in agriculture, the economy is highly reliant on this sector and is susceptible to outside shocks, especially climate change.

In 2021, the government launched the Malawi 2063 Vision that, with an emphasis on agriculture commercialization, industry and urbanisation, seeks to make Malawi a prosperous, independent, industrialised upper-middle-income nation. The president is Dr Lazarus Chakwera with a five-year period spanning from 2020 to 2025. Malawi's economy continues to be significantly weakened by frequent exogenous shocks coupled with macro-fiscal imbalances. The African Development Bank expects Malawi's real GDP growth of 2.0% in 2023 and 3.5% in 2024.

3.1.3.2. Lilongwe Water Board (LWB)

Established in 1947, LWB is a Public Corporation that was reorganised by the 1995 Parliament Water Works Act No. 17. It supplies Lilongwe city and neighbouring areas. Water is provided by the Lilongwe Water Board to 45,000. Domestic, institutional, commercial and industrial users are LWB's main customers. The board's duties include overseeing the raw water source, extracting and treating water in accordance with regulations set forth by the World Health Organization (WHO) and the Malawi Bureau of Standards (MBS).

The Dzalanyama Ranges provide the Lilongwe River, from which the Board obtains its raw water. Along the river, are two constructed dams: Kamuzu Dam I and II. About 1,870 km^2 make up the catchment area. Built in 1966, Kamuzu Dam I can hold 4.5 MCM of water. Kamuzu Dam II, built in 1989 has a storage capacity of 19.8 MCM. Water enters Kamuzu Dam II, which acts as an equilibrium reservoir, and then conveys the water by gravity roughly 20 km downstream to the extraction point. There are two treatment plants that have a combinedly produce about 125,000 m^3/day. The board presently serves 996,000 in Lilongwe which constitutes 83% of the total population. In the city, there are roughly 83,000 clients with meters with an estimated WDN length of 1,758 km and over 1,000 water kiosks (community water selling points).

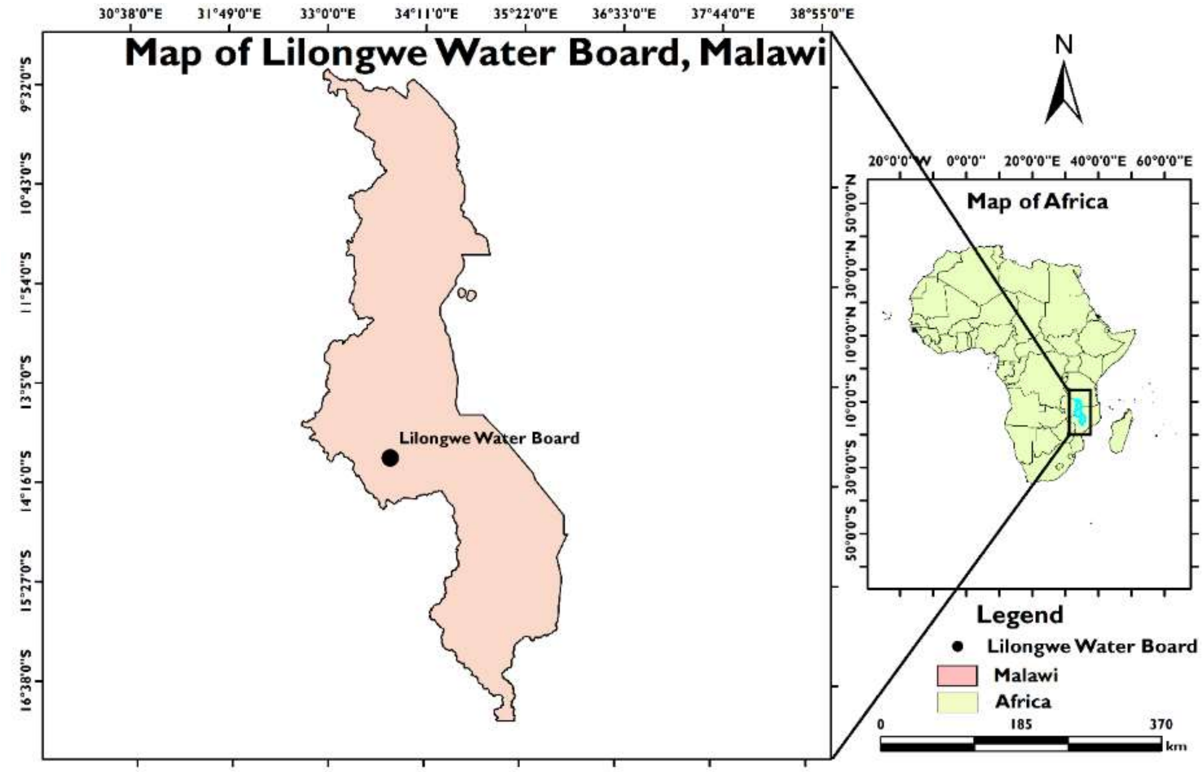

Figure 3.1.3: *Map showing location of Lilongwe Water Board in Malawi*

3.2. Research Design

Research was designed in the following phases:

- Literature review to obtain the overall problem of NRW in African water utilities and justify the need for digital approach,
- Questionnaire design and formulation. Purposive sampling to obtain questionnaire respondents. Questionnaires sent out for responses,
- Comparative analysis of results from both literature and questionnaires and
- Conclusion and recommendations.

3.3. Data Collection

For this study, both primary and secondary data types were used. The purposive sampling method was used to select the respondents of the developed questionnaires (water utility directors).

3.3.1. Primary data

Questionnaires were designed on google forms and sent out to the selected water utilities as a primary data collection mechanism to the three selected utilities; Wolaita Sodo, ONEA and LWB. Leveraging the working relationship and membership of the utilities with AfWASA, sourcing the required data was less complex and was facilitated easier. Attached are the survey participation request letters and questionnaires used for the study as appendices 1,2,3,4,5 and 6.

3.3.2. Secondary data

Secondary data was obtained from relevant and trusted sources from the internet such as google scholar, research gate and R discovery to obtain the most relevant journals. Trusted publications, blogs, conference proceedings, IBNET data and utility annual reports were also used also to source out the most accurate literature to get the relevant data.

3.4. Research Methodology

The study used the following chronological approach:

i. A review of relevant literature from African water utilities performance using NRW levels as a reference basis and the digital solutions employed for the NRW management. The literature review also included the comparison of water utilities from different parts of the world other than Africa, their NRW levels and their digital solutions employed for NRW management.
ii. Questionnaires were sent out to the water utilities (Lilongwe Water Board, Wolaita Sodo water and ONEA) to assess them on their main operational activities (Technical,

Institutional, Financial and Customer/ Commercial performance). The questionnaire was a checklist of all the specific operational activities that attribute to NRW levels in the utilities.

iii. Data analysis for the different water utilities from the questionnaires were represented through graphical illustration for all the water utilities used in the study indicating their shortcomings on the specific operational activities.

Below is a simplified figure of the methodology used in this project.

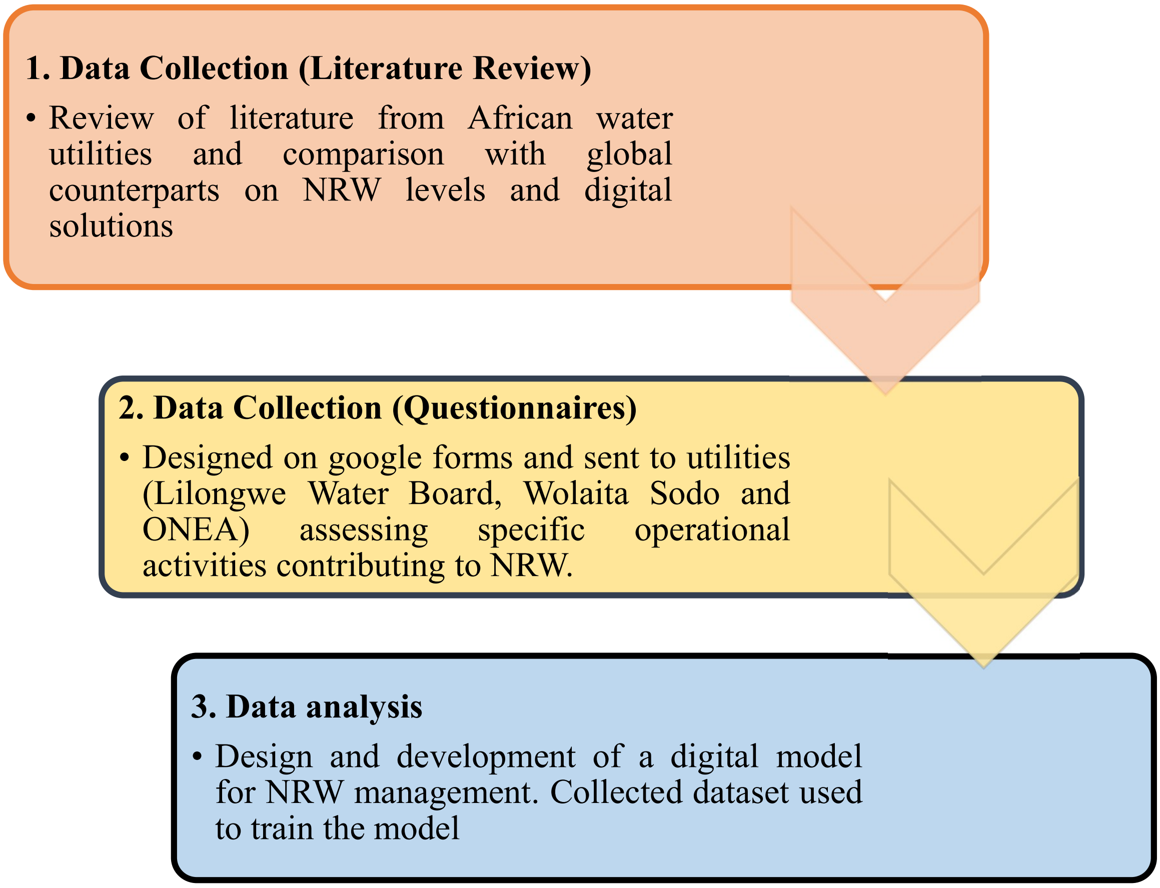

Figure 3.4: *Methodology used in the project*

3.5. Data Presentation and Analysis

The data from literature review was presented in the form of graphs and tabulated for easier comprehension. Data from the questionnaires was tabulated, graphed and explained in detail finding implications of the specific operational activities on the NRW management in the utilities. The digital solutions were also compared to find the best use from the different utilities and which could be adopted by African water utilities in the context.

3.6. Ethical considerations

Ethical consideration was taken in account in this project duration. Information from questionnaires was handled with confidentiality and discretion and as such was not passed on. Consent and a clear outline of the project deliverables was clearly communicated to the interviewees.

3.7. Conclusion

The material and methods chapter defined clearly the study areas (countries) and in detail the water utilities used. It further detailed on the research work entailing its design overview, the data collection methods, tools and data sources. The research builds on previous comparative studies, notably the work by Umutangampundu (2020), which investigated NRW management between ONEA and SODECI. This study's conceptual model for NRW management, especially its main operational activities, sparked the research interest, suggesting a continuity and an opportunity to expand the knowledge base by incorporating additional water utilities into the comparative framework. The chapter further on entailed the precise methodology utilised in the project in its chronological format and later followed by the modes of data presentation and the analysis methods. The chapter also gave light on the ethical considerations in undertaking the project and hence interactions with the relevant utilities.

CHAPTER 4: RESULTS AND DISCUSSION

4.0. Introduction

This chapter presents and discusses the findings of this study. The research used an explorative means from identifying the operational activities influencing non-revenue water management, to quantifying the impact of any specific operation on the total Non-Revenue Water levels and finally the creation of a digital model for non-revenue water management. The research questions and hypothesis also formed a strong frame for the methodology employed. The utilities used namely; ONEA in Burkina Faso, Wolaita Sodo water in Ethiopia and LWB in Malawi formed a good base firstly because of their location, available water resources and their resounding management abilities. The aforementioned results obtained from literature review and questionnaires are outlined below.

4.1. Analysis and Discussion of Results

The study collected the data for analysis in different stages with the corresponding research questions and objectives. The study firstly investigated the first objective of identifying the operational activities influencing non-revenue water management ONEA, Wolaita Sodo water and LWB water utilities. The study identified such activities through a comprehensive literature review and a questionnaire developed as a checklist of all the relating specific operational factors to NRW management.

4.1.1. Questionnaire Respondents distribution

The three questionnaires sent to ONEA, Wolaita Sodo water and LWB were all responded to. Below is a table to summarise the respondents; their affiliation, institution and country.

Table 4.1: Summary for questionnaire respondents

No.	Institution, Country	Position	No. of Respondents
1	ONEA, Burkina Faso	Director for Water Works Training Centre	1
2	Wolaita Sodo, Ethiopia	Projects Coordinator	1
3	LWB, Malawi	Director of Production and Distribution	1
		Total	3

4.1.2. Question 1: What are the operational activities that increase Non-Revenue Water in utilities?

The specific operational activities identified from literature are grouped into four main groups: Technical management, customer management, financial management and institutional management as identified by Umutangampundu (2020) detailed in a conceptual model for NRW management. These main operational activities were verified from various literature sources on the utilities used for the study. For further assessment and more detailed analysis, 9 specific operational activities were derived from the main, namely: Corporate management, maintenance of production and distribution bulk meters, conducting water balance, physical water loss reduction, commercial loss reduction, pressure management, staff training and knowledge transfer, customer education program implementation and financial management. The specific operational activities used for the detailed analysis have been adopted from the NRW reduction strategy by Lilongwe Water Board and AfWA in their assessment forms generated in the NRW program synthesis report (AfWA/ USAID, 2015; Lilongwe Water Board, 2021). These factors all contribute significantly to the NRW levels with the technical management verified with much specific operational activities which has been concisely grouped in the table below.

Table 4.1.2: Grouping of the checklist specific activities to main operational activities

Technical management	**Customer management**	**Financial management**	**Institutional management**
Pressure management	Customer education	Financial management	Staff training and knowledge transfer
Maintenance of bulk meters	Commercial loss reduction		Corporate management
Conducting water balance calculations			
Physical water loss reduction			

4.1.3. Question 2: What is the value of impacts of the specific operations on the total NRW levels?

The specific operational activities were sub-grouped into the four groups and a checklist questionnaire developed to get an overview of the activities employed to manage NRW. The 9 specific activities were grouped as the above table 7.

4.1.3.1. Contribution of digital solutions to NRW levels in Africa and rest of the world

To further quantify the impact of digital solutions with the NRW levels, a comparison of the levels with their respective digital solutions was conducted from different literature sources for Africa against the rest of the world.

Table 4.1.3: Comparison of NRW levels and technologies for selected water utilities

Digital solutions in Africa	Digital solutions for other parts of the world
(LWB) Malawi (NRW= 37.2% in 2019, 39.2% in 2020 and 42% in 2021). Technologies: • Prepaid water metering systems • Remote water monitoring and water management system (SCADA) • DMA management • Data loggers for flow and pressure data collection and management • Leak detection technology • Water meter management programs • Water balance calculations conducted regularly	Denmark (NRW= 7.33% in 2020, 7.22% in 2021, 7% in 2023): Sample from a benchmarking exercise with 76 water companies evaluated. Due to strict legislation. Heavy fines/ payments for any utility with NRW levels exceeding 10%. Technologies: • Flow & Pressure management in sections • Online remote metering and reading • Leak detection technology (listening method). Acoustic leakage detector coupled with correlators. Done proactively with repairs. • Hydraulic modelling • Water balance (water audits) • Segmenting pipe network
(ONEA) Burkina Faso (NRW= 19.3% in 2016, 19.3% in 2017 and 19.3% in 2018). Technologies: • Water balance calculations conducted regularly • Pressure reducing valves • Maintenance manuals developed	USA (NRW= 16% in 2016). Technologies: • Advanced Metering Infrastructure (AMI) • Acoustic Leak Detection • Pressure Management • Data Analytics • Geographic Information Systems (GIS)

LWB, 2021; Water in figures, Denmark, 2022; Umutangampundu, 2020

The above table compares the NRW levels in the water utilities selected for the study (ONEA and LWB) to Denmark and USA with their digital solutions used for NRW management derived from table 1. For a comparative analysis, Denmark and USA digital solutions were compiled to derive better practices in difference to the selected water utilities because of their low NRW levels. Found to be exclusive to USA and Denmark, proactive leak detection and repairs, advanced metering infrastructure (AMI), data analytics and hydraulic modelling are those noted to have a significant impact in lowering the NRW levels for the water utilities.

Table 4.1.3.1: Specific operational activities, challenges and potential digital solutions in Africa and other parts of the world

1. Technical management

Pressure management	**Challenges**	**Digital solutions**	**Potential digital solutions available in Africa**	**Potential Digital solutions available from Europe, US, Asia.**
ONEA	No data loggers installed, No developed and installed pressure monitoring program, No team for pressure management	Pressure reducing valves	Data loggers for flow and pressure data collection and management	Network management Flow & Pressure management in sections Hydraulic modelling Pressure management (booster pumps)
Wolaita Sodo Water	No data loggers installed, No pressure reducing valves installed, No developed and installed pressure monitoring program, No team for pressure management			
Lilongwe Water Board	No developed and installed pressure monitoring program	Data loggers Pressure reducing valves		

Maintenance of production and distribution bulk meters	**Challenges**	**Digital solutions**	**Potential digital solutions available in Africa**	**Potential Digital solutions available from Europe, US, Asia.**
ONEA	No maintenance team			Water meter management programs

Wolaita Sodo Water	No maintenance team		Water meter management programs	
Lilongwe Water Board				

Conducting water balance	**Challenges**	**Digital solutions**	**Potential digital solutions available in Africa**	**Potential Digital solutions available from Europe, US, Asia.**
ONEA	No frequent DMA management and demarcation	Water balance	DMA management Water balance calculations conducted regularly	Water balance (water audits) Segmenting pipe network Reconfiguration of water network
Wolaita Sodo Water	No frequent DMA management and demarcation No customer data integration No water balance calculations			
Lilongwe Water Board		DMA management Water balance		

Physical water loss reduction	**Challenges**	**Digital solutions (for those that have them)**	**Potential digital solutions available in Africa**	**Potential Digital solutions available from Europe, US, Asia.**
ONEA	No leak detection methods and equipment, No quality control inspection checklist, No SCADA system		Remote operation and real-time systems (Telemetry, Automatic Meter Reading) SCADA	Proactive leak detection and repair
Wolaita Sodo Water	No SCADA system, No synchronization and fault management system	Leak detection methods and equipment		
Lilongwe Water Board		Leak detection methods and equipment Synchronization and fault management system SCADA system		

2. Customer Management

Commercial loss reduction	Challenges	Digital solutions	Potential digital solutions available in Africa	Potential Digital solutions available from Europe, US, Asia.
ONEA	No revisits on uprooted systems, No policing unit for illegal connections, No corporate lawyer, No tip off anonymous program, No uprooting long disconnected accounts, No permanent staff hired for water connections, disconnections and meter replacement, No team for commercial loss management		Prepaid water meters Smart meters Water meter testing	Advanced Metering Infrastructure (AMI) Online remote metering and reading Water meter testing
Wolaita Sodo Water	No policing unit for illegal connections, No meter replacement programs, No consumption trend monitoring, No fire hydrant consumption monitoring, No team for commercial loss management	Tip off anonymous reporting program		
Lilongwe Water Board	No consumption trend monitoring	Water meter testing Tip off anonymous reporting program		

Customer education program implementation	Challenges	Digital solutions	Potential digital solutions available in Africa	Potential Digital solutions available from Europe, US, Asia.
ONEA	No customer awareness programs, No online platform for customers, No team for customer education		Customer Relationship Management System (for leak reporting, billing, database)	Active reporting platforms
Wolaita Sodo Water	No customer awareness programs, No online platform for customers, No team for customer education			
Lilongwe Water Board	No online platform for customers, No team for customer education			

3. Financial Management

Financial management	Challenges	Digital solutions	Potential digital solutions available in Africa	Potential Digital solutions available from Europe, US, Asia
ONEA	Customer database not regularly updated, No cybersecure systems for online billing		Customer Relationship Management System (for billing)	Advanced Metering Infrastructure (AMI)
Wolaita Sodo Water	No cybersecure systems for online billing			
Lilongwe Water Board		Cybersecure systems for online billing		

4. Institutional Management

Staff training and knowledge transfer	Challenges	Digital solutions	Potential digital solutions available in Africa	Potential Digital solutions available from Europe, US, Asia.

ONEA	No technical capacity building programs for staff, No maintenance manuals developed			
Wolaita Sodo Water	No technical capacity building programs for staff, No maintenance manuals developed			
Lilongwe Water Board	No technical capacity building programs for staff, No maintenance manuals developed			

Corporate management	**Challenges**	**Digital solutions**	**Potential digital solutions available in Africa**	**Potential Digital solutions available from Europe, US, Asia.**
ONEA				Data management and analytics Hydraulic modelling
Wolaita Sodo Water	No policies in place, No approval plans, No management team			
Lilongwe Water Board				

From the above tables, it is evident that Wolaita Sodo Water shows significant gaps across all categories, with particular emphasis on Physical Water Loss Reduction, indicating a broad area for improvement in managing physical losses and implementing relevant technologies and practices. ONEA on the other hand, has challenges distributed across the board but shows a slightly better situation in maintenance of production and distribution bulk meters and conducting water balance calculations which is also highlighted in thesis work by Umuntangampundu. (2020). In commonality with the other utilities, it faces issues in physical water loss reduction and commercial losses reduction. Lilongwe Water Board shows strength in technical management and financial management. It has some few setbacks in customer management particularly customer education program implementation, an online platform and a team for customer education and on institutional management as identified also in their NRW reduction strategy (Lilongwe Water Board, 2021).

In the above tables, across all three utilities (ONEA, Wolaita Sodo and Lilongwe Water Board), the need for digital transformation is clearly outlined. The solutions range from data management and customer engagement tools to advanced metering and cybersecurity measures matching the aforementioned challenges stated. The constant challenge is on the technical capacity building for staff with potential digital solutions of development of digital training modules and online resource centres.

Attached below is a table with the digital solutions proposed for adoption in Africa with their brief attenuated impacts as evident in the assessed water utilities where they have been employed.

Table 4.1.3.2: Potential digital solutions for adoption in Africa and their attenuated impacts

Potential Solutions for Adoption in Africa	Attenuated impacts
Proactive leak detection and repair	Adopting advanced acoustic leak detection technologies and correlators for proactive leak detection and repair, similar to practices in Denmark and the USA. It ensures less water is lost from leaks hence lowering NRW levels.
Data management and analytics	Enhance data analytics capabilities for predictive maintenance, leak prediction and efficient resource management, as used by the USA could improve NRW management for African utilities.
Network management	Introduce network reconfiguration and demarcation strategies to improve water distribution efficiency, exemplified by the Manila Water in Philippines. African utilities can adopt such.
Advanced Metering Infrastructure (AMI)	As used in USA, AMI improves a utility's ability to collect water usage data to improve billing, leak detection and water resource management that can improve NRW management.

The solutions as listed above could leverage maximum benefit if adopted by African water utilities. This is evident from the briefly explained attenuations and the examples of where such solutions have been deployed with their relative NRW levels. The countries in which the potential digital solutions have been applied, reflect very low NRW levels and thus the correlation therefore supports the potential for the digital solutions likewise for African utilities.

4.1.4 Question 3: What would a digital model for NRW management in water utilities look like?

The model is for a later stage upon a compiling a database with NRW percentage performance upon implementing certain operational activities for a number of water utilities. For the target variables (% NRW contribution from the utility main operational activities), it is the complete database that is required to load in the programming language (Python) as a training set and then later predict the NRW relating to implemented operational activities.

4.2. Conclusion

The results and discussion chapter systematic approach used a combination of literature review and a questionnaire for sound data presentation and analysis. The study identified specific operational challenges and gaps contributing to NRW. The findings highlighted four main categories of operational activities impacting NRW: technical, customer, financial and institutional management. These were further divided into nine specific activities including corporate management, maintenance of production and distribution bulk meters, water balance, physical and commercial loss reduction, pressure management, staff training, customer education and financial management. The data analysis revealed significant differences and similarities among the utilities in addressing NRW management challenges and such were benchmarked against other parts of the world with quantified NRW percentages.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.0. Introduction

This chapter gives the conclusion of the study with derived recommendations and future research work that can be conducted in regards to the subject matter. The chapter tries to identify if the set research objectives were met and the research questions answered holistically. From the response on objectives and research questions, the chapter then links relevant recommendations and what future research could entail.

5.1. Conclusion

The study objectives for the project were met. The conclusion drawn is that while there are common challenges among the utilities utilised for the research. From the data analysis for the water utilities; ONEA, Wolaita Sodo water and Lilongwe water board, significant challenges across all the operational activities (technical, customer, financial and institutional management) were observed. Comparatively, it was found that utilities in other parts of the world, employing proactive leak detection, advanced metering infrastructure (AMI), data analytics and network management, reported lower NRW levels such as Denmark with 7% NRW in 2023 and the USA with 16% NRW in 2016. This highlights a considerable prospect for African utilities to integrate similar digital solutions to mitigate NRW effectively. Strict legislation proves to resulting in low NRW levels in Denmark, thus highlighting the role of regulatory frameworks in effective water management. The research thus emphasises the critical role of coupling digitalisation and regulatory measures in enhancing NRW management. It points towards a strategic direction for African water utilities to adopt digital solutions for NRW management whilst ensuring stringent legislation on NRW management.

5.2. Recommendations

From the project findings, the author proposes the following:

- African water utilities should adopt the solutions including proactive leak detection and repairs, data management and analytics, network management and advanced metering infrastructure (AMI) as they could leverage maximum benefit if adopted successfully as evident in other regions.
- A digital model must be formulated for water utilities to conduct their own benchmarking and thus conduct necessary repairs, maintenance or make tactical decisions instantly to lower NRW in utilities.

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APPENDICES

APPENDIX 1: SURVEY PARTICIPATION REQUEST LETTER FOR LILONGWE WATER BOARD, MALAWI

Dear Mr. G. Chikasema

Director of Production & Distribution, Lilongwe Water Board, Malawi

AfWASA, with its partners (United Nations University and the Pan African University Institute for Water and Energy Sciences), is conducting a project titled **"Analysing the Adoption of a Digital Approach for Non-Revenue Water Management in African Water Utilities"** with the main aim of **creating a digital model for Non-Revenue Water management**.

We kindly request you to spare some 10 minutes of your time to fill out the survey in the link below, your utility performance based on your experience:

https://forms.gle/jcBowPCrj8HaGoGU9.

We apologise for this short notice. We will be grateful to have your response by **07 March 2024.**

We are looking forward to hearing from you.

Kind regards,

Dr. Simeon Kenfack

Director of Programs, African Water and Sanitation Association (AfWASA)

APPENDIX 2: QUESTIONNAIRE FOR LILONGWE WATER BOARD, MALAWI

Please take part in the following 10-minute survey and respond based on your experience in your utility. Thank you in advance for your participation.

SECTION 1: REFERENCES OF SURVEY RESPONDENT

* **Indicates required question**

1. Name/ Surname:

…………………………………………………………………………………………………

2. Utility name (please select one) *

- ○ ONEA
- ○ SODECI
- ○ Lilongwe Water Board

3. Utility Country (please select one) *

- ○ Malawi
- ○ Burkina Faso
- ○ Côte d'Ivoire

4. Gender*

- ○ Male
- ○ Female
- ○ Other:

5. Position*

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

6. Department

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

7. Years in Company*

- ○ 1-3 years
- ○ 3-5 years
- ○ 5-10 years
- ○ > 10 years

7. Education*

- ○ PhD
- ○ Masters
- ○ Bachelor/ Diploma
- ○ High School

○ Other

8. Telephone:

……………………………………………………………………………………………………..

9. email:

……………………………………………………………………………………………………..

SECTION 2: CONTRIBUTION OF SPECIFIC OPERATIONAL ACTIVITIES ON NON-REVENUE WATER LEVELS.

For this section, please indicate whether or not your utility has the following in place for NRW management by ticking the corresponding box.

Main Activity	Specific activities	Yes	No
1. Corporate Management	Do you have policies in place for NRW management?		
	Do you have approval plans for NRW management?		
	Is there fund sourcing for NRW management?		
	Do you have a team for NRW management?		
2. Maintenance of Production and Distribution Bulk Meters	Do you make replacements, installations and accuracy testing for production and distribution meters?		
	Is there a team in place that focuses on the maintenance of production and distribution bulk meters?		
3. Conducting Water Balance	Do you conduct frequent DMA management and re-demarcation?		
	Do you integrate customer data between GIS and billing systems?		
	Do you frequently conduct water balance calculations?		
4. Physical Water Loss Reduction	Do you have any leak detection methods and equipment in place?		
	Do you have a functional quality control inspection checklist?		
	Do you have a SCADA system in place?		
	Do you have a synchronization and fault management system for reported faults?		
	Do you have a responsive emergency to attend to bursts and leaks?		
	Do you rehabilitate aged/ frequently bursting pipes?		
	Is there a team in place for physical water loss management?		

5. Commercial Losses Reduction	Do you conduct investigations on illegal connections and uproot them?		
	Do you make revisits on all previously uprooted illegal connections?		
	Do you have an established policing unit for illegal connections?		
	Do you have a corporate lawyer for unpaid illegal connections?		
	Do you have a tip off anonymous program (hotline/ toll free) for reporting illegal connections?		
	Do you uproot all long-disconnected accounts (over 6 months)?		
	Do you implement meter replacement programs?		
	Do you have permanent staff hired for new water connections, disconnections and meter replacement?		
	Do you conduct consumption trend monitoring?		
	Do you conduct consumption monitoring for fire hydrants?		
	Do you have a team for commercial losses management?		
6. Pressure Management	Do you have data loggers installed for flow and pressure data collection?		
	Do you have pressure reducing valves installed?		
	Do you have a developed and installed pressure monitoring program?		
	Is there a team in place for pressure management in your water distribution system?		
7. Staff Training and Knowledge Transfer	Are your meter readers and billing staff trained on good data handling?		
	Do you have technical capacity building programs for staff on NRW?		
	Do you conduct routine monitoring of staff on NRW?		
	Do you have maintenance manuals developed?		
	Do you have a team for staff training and knowledge transfer?		
8. Customer Education	Do your customers have awareness on NRW		

Program Implementation	management?		
	Do you have an online platform to raise awareness on NRW to customers?		
	Is there a team responsible for implementing customer education programs?		
9. Financial Management	Do you have accurate systems/ technologies for tracking billing records for customers?		
	Do you update your customer database regularly?		
	Do you have cybersecure systems for online billing?		
	Do you have a team responsible for financial management in the utility?		

Thank you for your participation.

APPENDIX 3: SURVEY PARTICIPATION REQUEST LETTER FOR WOLAITA SODO WATER, ETHIOPIA

Dear Mr. Fanta

Projects Coordinator, Wolaita Sodo water

AfWASA, with its partners (United Nations University and the Pan African University Institute for Water and Energy Sciences), is conducting a project titled **"Analysing the Adoption of a Digital Approach for Non-Revenue Water Management in African Water Utilities"** with the main aim of **creating a digital model for Non-Revenue Water management**.

We kindly request you to spare some 10 minutes of your time to fill out the survey in the link below, your utility performance based on your experience:

https://forms.gle/jcBowPCrj8HaGoGU9.

We apologise for this short notice. We will be grateful to have your response by **07 March 2024.**

We are looking forward to hearing from you.

Kind regards,

Dr. Simeon Kenfack

Director of Programs, African Water and Sanitation Association (AfWASA)

APPENDIX 4: QUESTIONNAIRE FOR WOLAITA SODO WATER, ETHIOPIA

Please take part in the following 10-minute survey and respond based on your experience in your utility. Thank you in advance for your participation.

SECTION 1: REFERENCES OF SURVEY RESPONDENT

* **Indicates required question**

1. Name/ Surname:

……………………………………………………………………………………………

2. Utility name (please select one) *

- O ONEA
- O Wolaita Soda
- O Lilongwe Water Board

3. Utility Country (please select one) *

- O Malawi
- O Burkina Faso
- O Ethiopia

4. Gender*

- O Male
- O Female
- O Other:

5. Position*

……………………………………………………………………………………………

6. Department

……………………………………………………………………………………………

7. Years in Company*

- O 1-3 years
- O 3-5 years
- O 5-10 years
- O > 10 years

7. Education*

- O PhD
- O Masters
- O Bachelor/ Diploma

- ○ High School
- ○ Other

8. Telephone:

…………………………………………………………………………………………………..

9. email:

…………………………………………………………………………………………………..

SECTION 2: CONTRIBUTION OF SPECIFIC OPERATIONAL ACTIVITIES ON NON-REVENUE WATER LEVELS.

For this section, please indicate whether or not your utility has the following in place for NRW management by ticking the corresponding box.

Main Activity	Specific activities	Yes	No
1. Corporate Management	Do you have policies in place for NRW management?		
	Do you have approval plans for NRW management?		
	Is there fund sourcing for NRW management?		
	Do you have a team for NRW management?		
2. Maintenance of Production and Distribution Bulk Meters	Do you make replacements, installations and accuracy testing for production and distribution meters?		
	Is there a team in place that focuses on the maintenance of production and distribution bulk meters?		
3. Conducting Water Balance	Do you conduct frequent DMA management and re-demarcation?		
	Do you integrate customer data between GIS and billing systems?		
	Do you frequently conduct water balance calculations?		
4. Physical Water Loss Reduction	Do you have any leak detection methods and equipment in place?		
	Do you have a functional quality control inspection checklist?		
	Do you have a SCADA system in place?		
	Do you have a synchronization and fault management system for reported faults?		
	Do you have a responsive emergency to attend to bursts and leaks?		
	Do you rehabilitate aged/ frequently bursting pipes?		
	Is there a team in place for physical water loss		

	management?		
5. Commercial Losses Reduction	Do you conduct investigations on illegal connections and uproot them?		
	Do you make revisits on all previously uprooted illegal connections?		
	Do you have an established policing unit for illegal connections?		
	Do you have a corporate lawyer for unpaid illegal connections?		
	Do you have a tip off anonymous program (hotline/ toll free) for reporting illegal connections?		
	Do you uproot all long-disconnected accounts (over 6 months)?		
	Do you implement meter replacement programs?		
	Do you have permanent staff hired for new water connections, disconnections and meter replacement?		
	Do you conduct consumption trend monitoring?		
	Do you conduct consumption monitoring for fire hydrants?		
	Do you have a team for commercial losses management?		
6. Pressure Management	Do you have data loggers installed for flow and pressure data collection?		
	Do you have pressure reducing valves installed?		
	Do you have a developed and installed pressure monitoring program?		
	Is there a team in place for pressure management in your water distribution system?		
7. Staff Training and Knowledge Transfer	Are your meter readers and billing staff trained on good data handling?		
	Do you have technical capacity building programs for staff on NRW?		
	Do you conduct routine monitoring of staff on NRW?		
	Do you have maintenance manuals developed?		
	Do you have a team for staff training and knowledge transfer?		

8. Customer Education Program Implementation	Do your customers have awareness on NRW management?		
	Do you have an online platform to raise awareness on NRW to customers?		
	Is there a team responsible for implementing customer education programs?		
9. Financial Management	Do you have accurate systems/ technologies for tracking billing records for customers?		
	Do you update your customer database regularly?		
	Do you have cybersecure systems for online billing?		
	Do you have a team responsible for financial management in the utility?		

Thank you for your participation.

APPENDIX 5 : LETTRE DE DEMANDE DE PARTICIPATION À L'ENQUÊTE POUR ONEA, BURKINA FASO

Chère Madame SANFO,

Directrice du CEMEAU (Centre des Métiers de l'Eau), ONEA, Burkina Faso

L'AfWASA, avec ses partenaires (Université des Nations Unies et Institut universitaire panafricain des sciences de l'eau et de l'énergie), mène un projet intitulé « **Analyse de l'adoption d'une approche numérique pour la gestion de l'eau non génératrice de revenus dans les services d'eau africains** » dans le but principal de **créer un modèle numérique pour la gestion de l'eau non génératrice de revenus**.

Nous vous demandons de bien vouloir consacrer environ 10 minutes de votre temps pour répondre au sondage dans le lien ci-dessous, votre performance des services publics en fonction de votre expérience :

https://forms.gle/uknhXGo75XVhrfJn7.

Nous nous excusons pour ce court préavis. Nous vous serions reconnaissants de recevoir votre questionnaire d'enquête avant le **07 Mars 2024.**

Nous sommes impatients d'avoir de vos nouvelles.

Cordialement

Dr. Siméon KENFACK

Directeur des programmes, Association africaine de l'eau et de l'assainissement (AfWASA)

APPENDIX 6 : QUESTIONNAIRE POUR ONEA, BURKINA FASO

Veuillez participer au sondage de 10 minutes suivant et répondre en fonction de votre expérience dans votre service public. Merci d'avance pour votre participation.

SECTION 1 : RÉFÉRENCES DES RÉPONDANTS À L'ENQUÊTE

*** Indique la question requise**

1. Nom/Prénom :

....

2. Nom de l'utilitaire (veuillez en sélectionner un) *

- ○ L'ONEA
- ○ Wolaita Sodo
- ○ Office des eaux de Lilongwe

3. Pays de l'utilitaire (veuillez en sélectionner un) *

- ○ Malawi
- ○ Burkina Faso
- ○ Ethiopie

4. Sexe*

- ○ Mâle
- ○ Femelle
- ○ Autre

5. Position*

....

6. Département

....

7. Années dans l'entreprise*

- ○ 1-3 ans
- ○ 3-5 ans
- ○ 5-10 ans
- ○ > 10 ans

7. Éducation*

- ○ Doctorat
- ○ Masters
- ○ Baccalauréat/ Diplôme
- ○ Lycée
- ○ Autre

8. Téléphone :

....

9. Courriel :

....

SECTION 2 : CONTRIBUTION D'ACTIVITÉS OPÉRATIONNELLES SPÉCIFIQUES SUR LES NIVEAUX D'EAU NON FACTURÉE.

Pour cette section, veuillez indiquer si votre service public a mis en place les éléments suivants pour la gestion des Eau Non Facturée en cochant la case correspondante.

Point fort	Activités spécifiques	Oui	Non
1. Gestion d'entreprise	Avez-vous mis en place des politiques pour la gestion de la Eau Non Facturée ?		
	Avez-vous des plans d'approbation pour la gestion de la Eau Non Facturée ?		
	Existe-t-il des sources de financement pour la gestion de la Eau Non Facturée ?		
	Disposez-vous d'une équipe pour la gestion de la Eau Non Facturée ?		
2. Maintenance des compteurs de vrac de production et de distribution	Effectuez-vous des remplacements, des installations et des tests de précision pour les compteurs de production et de distribution ?		
	Y a-t-il une équipe en place qui se concentre sur l'entretien des compteurs de vrac de production et de distribution ?		
3. Conduite de l'équilibre hydrique	Effectuez-vous fréquemment la gestion et la redémarcation des DMA ?		
	Intégrez-vous les données clients entre le SIG et les systèmes de facturation ?		
	Effectuez-vous fréquemment des calculs de bilan hydrique ?		
4. Réduction de la perte d'eau physique	Avez-vous mis en place des méthodes de détection des fuites ?		
	Disposez-vous d'une liste de contrôle de l'inspection du contrôle de la qualité fonctionnelle ?		
	Avez-vous mis en place un système SCADA ?		
	Disposez-vous d'un système de synchronisation et de gestion des pannes pour les pannes signalées ?		
	Disposez-vous d'une urgence réactive pour intervenir en cas		

	d'éclatement et de fuite ?		
	Réhabilitez-vous des tuyaux vieillissants ou qui éclatent fréquemment ?		
	Y a-t-il une équipe en place pour la gestion des pertes d'eau physiques ?		
5. Réduction des pertes commerciales	Menez-vous des enquêtes sur les connexions illégales et les déracinez-vous ?		
	Faites-vous des revisites sur toutes les connexions illégales précédemment déracinées ?		
	Disposez-vous d'une unité de police établie pour les connexions illégales ?		
	Avez-vous un avocat d'entreprise pour les connexions illégales non rémunérées ?		
	Disposez-vous d'un programme de dénonciation anonyme (ligne d'assistance téléphonique / sans frais) pour signaler les connexions illégales ?		
	Déracinez-vous tous les comptes déconnectés depuis longtemps (plus de 6 mois) ?		
	Mettez-vous en œuvre des programmes de remplacement des compteurs ?		
	Avez-vous embauché du personnel permanent pour les nouveaux raccordements d'eau, les débranchements et le remplacement des compteurs ?		
	Effectuez-vous une surveillance des tendances de consommation ?		
	Effectuez-vous un suivi de la consommation des bornes-fontaines ?		
	Disposez-vous d'une équipe pour la gestion des pertes commerciales ?		
6. Gestion de la pression	Avez-vous installé des enregistreurs de données pour la collecte de données de débit et de pression ?		
	Avez-vous installé des réducteurs de pression ?		
	Avez-vous développé et installé un programme de surveillance de la pression ?		
	Y a-t-il une équipe en place pour la gestion de la pression dans votre système de distribution d'eau ?		

7. Formation du personnel et transfert de connaissances	Vos releveurs de compteurs et votre personnel de facturation sont-ils formés à une bonne gestion des données ?		
	Avez-vous des programmes de renforcement des capacités techniques pour le personnel de Eau Non Facturée ?		
	Effectuez-vous un suivi régulier du personnel en Eau Non Facturée ?		
	Avez-vous développé des manuels d'entretien ?		
	Avez-vous établi un stockage des rapports de formation ?		
	Disposez-vous d'une équipe pour la formation du personnel et le transfert de connaissances ?		
8. Mise en œuvre d'un programme de formation des clients	Vos clients sont-ils sensibilisés à la gestion des Eau Non Facturée ?		
	Disposez-vous d'une plateforme en ligne pour sensibiliser les clients à l'Eau Non Facturée ?		
	Existe-t-il une équipe responsable de la mise en œuvre des programmes de formation des clients ?		
9. Gestion financière	Disposez-vous de systèmes/technologies digitales précis pour le suivi des dossiers de facturation des clients ?		
	Mettez-vous régulièrement à jour votre base de données clients ?		
	Disposez-vous de systèmes cybersécurisés pour la facturation en ligne ?		
	Disposez-vous d'une équipe responsable de la gestion financière au sein du service public ?		

Merci de votre participation.

APPENDIX 7 : THESIS WORK PLAN

TASKS/ ACTIVITIES	TIMELINE (December 2023 to April 2024)																			
	December 2023 (weeks)				January 2024 (weeks)				February 2024 (weeks)				March 2024 (weeks)				April 2024 (weeks)			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1. Writing Introduction	■	■	■	■																
Background information	■	■	■	■																
Objectives	■	■	■																	
Research questions	■	■	■																	
Hypothesis	■	■	■																	
Significance of research	■	■	■																	
2. Wring Literature review	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
3. Writing the methodology				■	■	■	■	■												
Study area				■	■	■	■	■												
Research design				■	■	■	■	■												
Research methodology				■	■	■	■	■												
4. Write and Submit mid-term thesis report				■	■	■	■	■												
5. Write and Submit internship report						■	■	■	■											
6. Write Results and Discussion									■	■	■	■	■	■	■					
7. Write Conclusion and Recommendations															■	■	■	■		
8. Write and Submit draft thesis													■	■	■					
9. Thesis revision and corrections															■	■	■			
10. Submit final thesis																	■	■	■	
11. Monthly meeting with supervisor, UNU					■				■				■				■			

APPENDIX 8: PROJECT SYNOPTIC TABLE

SYNOPTIC TABLE

THEME: ANALYSING THE ADOPTION OF A DIGITAL APPROACH FOR NON-REVENUE WATER MANAGEMENT IN AFRICAN WATER UTILITIES: A CASE STUDY FOR BURKINA FASO, MALAWI AND ETHIOPIA WATER UTILITIES

Main Research Question: How can a digital approach be effectively adopted and utilized to improve non-revenue water (NRW) management in African water utilities?

General Objective: The general objective of the study was to analyse the adoption of a digital approach for non-revenue water management in African water utilities.

General Hypothesis: The main hypothesis states that the adoption and utilization of digital approach can significantly support the improvement of NRW management in African water utilities.

RESEARCH QUESTIONS	SPECIFIC OBJECTIVES	HYPOTHESIS	CHAPTER/ PARTS	EXPECTED OUTCOMES	SUMMARIES
Question 1: What are the operational activities that increase Non-Revenue Water (NRW) in utilities?	**S.O 1:** To identify operational activities influencing Non-Revenue Water (NRW) management in utilities.	**Hypothesis 1** Operational activities have significant impact on total NRW level of a water utility.	Chapter 2 Part 2.2 Chapter 3 Part 3.0	A detailed understanding of the operational subfactors that significantly increase NRW in utilities under the main operational activities: Technical management, Customer/ commercial management, financial management and Institutional management.	The specific operational activities were identified and verified as recurring from various literature sources as relating in the African context.
Question 2: What is the value of impacts of the specific operations on the total NRW levels?	**S.O 2:** To quantify the impact of any specific operation on the total NRW levels of the utility.	**Hypothesis 2** The design and implementation of a digital model on operational activities can significantly enhance NRW	Chapter 2 Part 2.2 Chapter 4 Part 4.1.3	A quantified understanding of how specific operational activities impact total NRW levels. This can include indicators such as the technologies in place, teams	The specific operational activities were correlated for the utilities with the NRW levels in the utilities assessed. The

		management in a water utility.		responsible for NRW management, metering and billing and the efficiency of data handling processes.	technologies impacted the NRW levels directly.
Question 3: 3. What would a digital model for NRW management in water utilities look like?	**S.O 3:** To create a digital model for NRW management in water utilities.		Chapter 2 Part 2.3 Part 2.4 Part 2.5 Part 2.6 Chapter 4 Part 4.1.4	The creation of a digital model for NRW management in water utilities incorporating various factors and indicators related to NRW, such as specific operational activities, key operational indicators and other relevant data. The digital model should ideally provide a comprehensive, real-time overview of NRW levels and their contributing factors, enabling utilities to make informed decisions and implement effective strategies for NRW management.	

APPENDIX 9: MANAGEMENT STRUCTURE OF ONEA, BURKINA FASO (ORGANIGRAMME ONEA, 2018)