AN ASSESSMENT OF THE EFFECTIVENESS OF STRATEGIES USED BY BLANTYRE WATER BOARD TO REDUCE NON-REVENUE WATER

MSc. (WATER RESOURCES AND SUPPLY MANAGEMENT) THESIS

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UNIVERSITY OF MALAWI

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A thesis submitted to the Department of Physics and Biochemical Sciences, Faculty of Applied Sciences in partial fulfilment of the requirements of Master of Science Degree in Water Resources and Supply Management

University of Malawi

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May, 2018

DECLARATION

I, **Bright Mziliwanda**, hereby declare that this research is my own work. It is being submitted for the first time for the Master of Science Degree in Water Resources and Supply Management at the University of Malawi, the Polytechnic. It has not been submitted before for examination of any degree in any university.

Date:……………………………………………………….

Signature:………………………………………………….

CERTIFICATE OF APPROVAL

We the undersigned certify that we have read and hereby recommend for acceptance by the University of Malawi, a thesis entitled "An assessment of the effectiveness of strategies used by Blantyre Water Board to reduce non-revenue water."

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DEDICATION

To Christ Jesus be all the Glory!

To my dear wife Doneth, my son Christian and my daughter Joy for enduring my absence.

To my mother Lucy and all for your prayers and encouragement.

THANK YOU.

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First and foremost, I would like to thank the Almighty God for the love and mercies he has shown me since the time I was brought forth to this world. Every good and perfect gift comes from the Lord and I thank God for this work.

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I would like to thank the executive management of Blantyre Water Board for sponsoring my academic needs to carry out this study. Thanks should also go to my colleagues at Blantyre Water Board for their words of encouragement, and indeed as the Bible says that "better is a neighbour nearby than a brother far away", I feel your love.

ABSTRACT

Blantyre Water Board has been experiencing a high level of Non-Revenue Water (NRW) which stands at 52%. Reduction of NRW is one of the major challenge facing BWB. Blantyre Water Board is a parastatal organization which was established and reconstituted under the Malawi Waterworks Act No. 17 of 1995. To reduce NRW and improve operational performance, BWB has developed strategies based on the engineering studies conducted in the recent past. BWB is failing to improve in areas of operational efficiency, capital investments, customer care and coverage for water supply due to high NRW. Ineffective implementation of NRW reduction strategies is the major cause for the rise in the physical and apparent water losses. This study sought to assess the effectiveness of the strategies that BWB uses to reduce NRW in the water distribution network.

The research employed the descriptive survey methodology with both quantitative and qualitative research designs. The study purposely sampled 120 participants from a population of 249 employees that are directly involved in day to day activities of reducing NRW at BWB. Primary data, provided information that was specifically for the purpose of this research and was obtained through questionnaires and field measurements while secondary data was acquired from BWB Financial Management reports, Quantum Geographical Information System (QGIS), Departmental reports, Fault Management System (FMS) and the Hydraulic Model.

The study showed that the Board was not able to effectively implement strategies that it used to reduce NRW. The study identified that there was a positive, partial correlation between understanding of PPS and compliance to PPS, ($r = 0.545$, $p < 0.05$, $n = 109$). The positive correlation indicated that the more employees understand the PPS the better they comply with PPS when carrying out their duties. With the financial constraints of the Board, investment in the fight against NRW has not been adequate as BWB fails to comply with the budget by 27.3%. To reduce NRW, the study recommends that BWB should train its staff, use materials which are compliant with the design specifications, increase and improve resource investment in NRW reduction-activities.

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LIST OF ABBREVIATIONS AND ACRONYMS

AC	Asbestos Cement
AWWA	American Water Works Association
BWB	Blantyre Water Board
CARL	Current Annual Real Loss
DAI	Development Alternative Incorporated
DI	Ductile Iron
EPANET	Environmental Protection Agency Water Supply Model
FMS	Fault Management System
GDP	Gross Domestic product
HDPE	High-density Polyethylene
IBNET	International Benchmarking Network for Water and Sanitation Utilities
IETC	International Education Technology Conference
ILI	Infrastructure Leakage Index
ISO	International Organisation for Standardisation
IWA	International Water Association
IWRM	Integrated Water Resources Management
NRW	Non-Revenue Water
O&M	Operation and Management
PI	Performance Indicators
PPIAF	Public Private Infrastructure Advisory Facility
PPS	Policy and Procedure Statement
PVC	Polyvinyl Chloride

QGIS	Quantum Geographical Information System
SDGs	Sustainable Development Goals
SP	Steel Pipe
STS	Standard Transfer Specification
UARL	Unavoidable Annual Real Loss
UNEP	United Nations Environmental Protection
USEPA	United States Environmental Protection Agency
WDS	Water Distribution Systems

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CHAPTER ONE

1.0 Introduction and Background.

Blantyre Water Board (BWB) is a parastatal organization established and reconstituted under the Malawi Waterworks Act No. 17 of 1995. It is mandated to abstract water under Water Resources Act, treat and distribute potable water to the City of Blantyre and its surrounding areas such as Bvumbwe, Nguludi and Chiradzulu. The total population served by BWB is about 894,696 with a population growth rate of 2.8%, an estimate based on 2008 population and housing census by National Statistics Office (NSO, 2008).

One of the challenges facing water utilities in the developing world is the considerable difference between the amount of water put into the distribution system and the amount of water billed to consumers (Simbeye, 2010). This loss is commonly known as Non-Revenue Water (NRW). The problem of high NRW seriously affects the financial viability of water utilities through lost revenues and increased operational costs.

1.1 Background to the Study

Public water utilities in developing countries face enormous challenges in meeting water needs for their growing urban populations. Many of these challenges are as a result of inappropriate utility management practices (Israel, 2009). However, there are several strategies which public water utilities employ to successfully meet their operational requirements. Strategic planning, strategy implementation and control are major dimensions that are used to ensure that their challenges are minimized. Strategic planning concerns the organisation's mission and vision, its objectives and targets as well as strategies for achieving the objectives and targets. Strategic implementation and control is about translating strategic decisions into actions necessary to achieve the desired levels of performance, (Mugabi, Kayaga, & Njiru, 2007).

To achieve efficacy with the growing urban populations, water utilities in developing countries must quickly reduce the growing service gap, by reducing non-revenue water (NRW), increase revenues to cover operation cost and expand services to the urban poor. In addition, utilities must also adapt to the changing institutional and policy environment in which they operate, (Mugabi et al., 2007).

BWB experiences 52% of Non-Revenue Water within its distribution network. Therefore, a problem solving approach, with practical implementation of strategies which are effective for reducing non-revenue water is required. However, experts in developing countries invariably face; financial constraints, less developed infrastructure and lower levels of skills and technology to effectively develop and implement NRW reduction strategies, (Farley, 2003). BWB faces these challenges as 57% of its operation costs is used for energy consumption (electricity bills), the rest is shared amongst; water treatment, salaries, maintenace materials and vehicle maintenance. The distribution infrastructure is very old dating back to 1929 and most of the Board's operations do not use modern technology, (Zizwe, 2016).

1.1.1 Components of NRW

NRW has three components: Physical (Real) losses which comprise leakage from all parts of the distribution system and overflows from the storage tanks. The losses occur as a result of poor operations and maintenance, the lack of leakage control mechanisms and poor quality of underground assets. Real losses are any leakage downstream of a production source and upstream of the consumer meter; Commercial (Apparent) losses are caused by customer meter under-registration, meter reading errors, data handling errors, and theft of water in various forms; and Unbilled Authorised Consumption which include water used by the utility for operational purposes, water used for firefighting, and water provided for free to certain consumer groups, (IWA, 2013). The various components are shown in Table 1.1.

Table 1.1 Components of NRW

System Input Volume	Authorised Consumption	Billed Authorized Consumption	Billed Metered Consumption	**Revenue Water**
			Billed Non-metered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	**Non-Revenue Water**
			Unbilled Non-metered Consumption	
	Water Losses	Apparent Losses	Un authorized Consumption	
			Metering Inaccuracies	
		Real Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to Customers' meters	

1.2 Statement of the Problem

High levels of NRW affect financial viability of water service providers through lost revenue, increased operational and capital costs, all of which impact on the quality of services provision, (Christodoulou & Deligianni, 2010). NRW includes physical losses, commercial losses and free authorised water for which payment has not been collected. The physical losses are as a result of pipe leakages and pipe bursts while the commercial losses are due to illegal consumption, data handling errors and inaccurate meter reading, (Roux & Hennie, 2002).

Regardless of NRW challenge, BWB has been implementing a number of strategies to ensure that NRW is reduced to an acceptable level of 23%. With the level of NRW hovering at 52%, BWB losses about MK 575 Million of revenue per month estimated at 23% NRW, (Zizwe, 2016). BKS Global Consultants and Vitens Evides International carried out engineering studies and recommended the following strategies for BWB to implement with an objective of reducing NRW (Roux & Hennie, 2002).

The following are the strategies recommended based on the engineering studies:

1. Active leakage control – regular sounding, night flow measurements and step tests
2. Mains renewal programme (Pipe Replacement)
3. Advanced pressure management.
4. Improving capacity for maintenance of the system.
5. Bulk, large consumer and domestic metering renewal and testing and recalibration.
6. Water meter audits to improve integrity of billing database, detect unauthorised connections, and measure authorised unbilled use by institutional consumers.
7. Repair programmes for reduction of wastage from plumbing installations in households and institutional complexes.

For the past 10 years BWB has been implementing the above strategies (especially strategy number 2, 4, 6 and 7), to reduce NRW but the Board has not been able to achieve the acceptable level of 23%, (Willie & Hennie, 2002). However, in many developed countries the same strategies have been implemented and produced better results (Washali, 2011). For instance, in the city of Ra'anana in Israel, NRW was reduced from 15.7% to 6.8% within a period of 10 years (1997 to 2007); in Jordan, the Water Authority managed to reduce NRW from 46.3% to 43.6% in a period of 5 years, and in South Africa NRW was reduced from 30%

to 16% between 1999 and 2003. Although it is not practical to eliminate all NRW in a water utility, reduction to acceptable level of 23% losses appears a realistic target, (Kingdom, Liemberger, & Marin, 2006).

Effective implementation of the strategies is a prerequisite to achieving acceptable levels of NRW in line with benchmarking frameworks. This study was thus designed to identify gaps that could be narrowed down to decrease the level of NRW for BWB.

1.3 Main Objective of the Study

The main objective of the study was to assess the effectiveness of the strategies that Blantyre Water Board uses to reduce Non-Revenue Water in its distribution network.

1.3.1 Specific Objectives

The study sought to attend to the following specific objectives:

1. To assess the efficiency of fault maintenance on Non-Revenue Water.
2. To determine the level of resource investment on Non-Revenue Water reduction.
3. To examine the extent of illegal connections on Non-Revenue Water.
4. To measure the status of distribution network infrastructure on Non-Revenue Water

The study hypothesized that ineffective implementation of the NRW reduction strategies is a major cause for the increase in NRW.

1.4 Significance of the Study

Rapid population growth, urbanization, and industrialization contribute to inadequate water supply capacity. Blantyre City is a commercial hub of Malawi, with new housing developments and economic growth of activities continue to increase water demands for the entire City and surrounding areas, (Zizwe, 2016). With the diminishing of water resources, it is important that BWB manages the available water resource to ensure that the water demand is met by having minimal losses in its distribution system.

NRW reduction initiatives are therefore very fundamental requirements for improved water demand management and sustained water resources in the City of Blantyre. It is therefore imperative that the BWB identifies and addresses the causes of high non-revenue water within the distribution system. Findings from this research will help BWB improve the efficiency of the strategies that are employed to reduce NRW. Reducing water loss is critical to efficient resource utilization, efficient utility management, enhanced consumer satisfaction, and financial sustainability of the companies. If proper NRW strategies are initiated and sustained, the gains to consumers and BWB alike will be significant. It will be much cheaper to improve efficiency and sustainability through investment in non-revenue water reduction rather than through investments in capital projects to boost water supply capacities, (Kingdom et al., 2006).

1.5 Scope of the Study

This research was conducted at BWB as a case study. The study involved assessment of the strategies that BWB uses to reduce NRW in its distribution network. This research focused mainly on fault maintenance, resource investment, levels of illegal connections and status of the distribution network infrastructure with an aim of reducing water losses as per IWA water balance.

Although there are several indicators for the assessment of the performance of urban water supply services provision according to Farley (2003), the relative performance of BWB has been based on comparing the total volume of water that the utility produces to the total volume of water for which the utility collects revenue, (Farley, 2003). The level of NRW provides an approximate indication of the overall position of a utility which assisted to making an overall conclusion on effectiveness of the strategies that are used to reduce NRW.

1.6 Limitations of the Study

In conducting this study, a number of challenges were encountered. Like many water utilities in the developing countries, BWB does not conduct water balance to demarcate components of water losses as such there was limited non-revenue water data. High possibility of inaccurate data as some of the data may be erroneous or incomplete and lack credibility where the respondents may not have provided right data. Due to lack of water balance at BWB, there is no clear definition of water loss components to define the magnitude of NRW elements. Frameworks that have been used to benchmark performances of water utilities do not address all the challenges and are not acceptable by other researchers. However, these limitations were overcome by using data for a period of over 20 years to arrive at credible averages. Meanings of terms were carefully scrutinized to ensure they were not contradicting and conform to International Water Association (IWA) for water balance.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of work carried out by other scholars and researchers relevant to the problem of the study. It focuses on the relevant information from previous studies which have focused on components of NRW, the influencing factors and strategies that are used to minimize water losses in the distribution system to acceptable levels.

With the growing urban population in the cities, water utilities in the developing countries must adapt quickly to reduce the growing service gap, by reducing NRW, increasing revenues to cover operation costs and expanding services to the urban poor, (Mugabi et al., 2007). The key in developing strategies for management of NRW is to gain a better understanding of the factors which influence its components. Thereafter techniques and procedures can be developed and tailored to the specific characteristics of the distribution network, (Farley, 2003).

2.2 Global Perspective of Non-Revenue Water

Water loss is considered as a global issue in water resources management that requires a solid and effective management strategy, (Masheka, 2013). This can only be achieved through a better understanding of the causes of water loss and factors that influence it, (Liemberger, 2010). Leakages from water distribution network have been receiving attention worldwide because water loss leads to economical loss, contamination risk and excessive environmental load in terms of water resources and operational energy consumption, (Wyatt, 2010).

Due to structural deterioration of the pipe network, water losses exist in any water distribution network. The problem is more pronounced in developing than developed countries, (Kingdom et al., 2006). This is due to lack of financial resources to maintain water distribution systems, limited availability of required technologies for detecting and locating leaks, and lack of qualified and trained staff (Masheka, 2013). Furthermore, low level of public awareness and corruption also contribute to the rising levels of NRW, (Kingdom et al., 2006).

Each year more than 32 billion m^3 of treated water are lost through leakage from distribution networks, (Paola, 2012). An additional 16 billion m^3 per year are delivered to customers but not invoiced because of theft, poor metering, or corruption. According to Wyatt (2010), conservative estimate of the total annual cost to water utilities worldwide is US$14 billion.

Based on the global water and sanitation assessment carried out by World Health Organization (WHO) and UNICEF in 2000, on average in large cities in North America, NRW was estimated at 15%, in Africa NRW was estimated at 39% while in Asia, Latin America and Caribbean was at 42%, (Makaya, 2015). Water utilities in Netherlands have NRW estimated at 4% and in United Kingdom NRW is averaged at 16% according to Kamani, et al (2012), as shown in Figure 2.1.

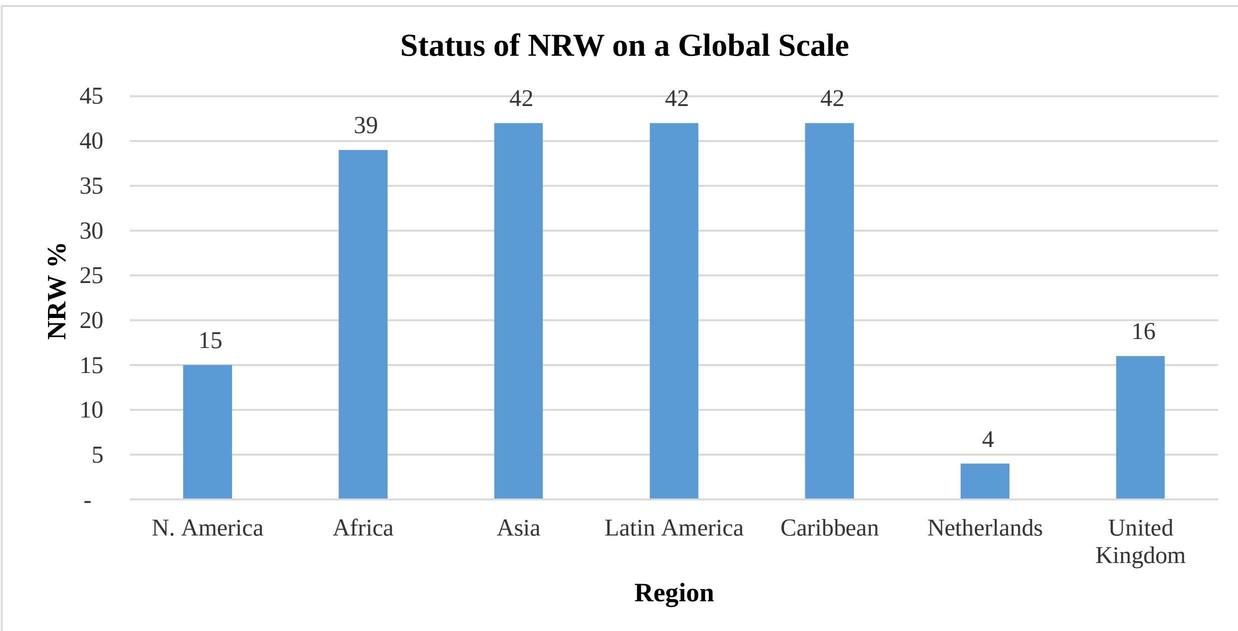

Figure 2.1: Status of NRW on a Global Scale (Source: Makaya, 2015)

Globally NRW is still a major challenge but the problems are more evident in developing countries. Most water utilities in Africa report a crude figure on NRW hence there is no proper reduction strategies planned for NRW (Kingdom et al., 2006). High levels of water losses in the distribution networks have remained one of the major challenge facing water utilities in Malawi, (Zizwe, 2016). Most water utilities in Malawi do not have proper data on water losses in their water distribution networks upon which planning and corrective measures can be based, (Willie & Hennie, 2002). Reduction of NRW can only be achieved once quantification and partition of NRW into various components is carried out, (Masheka, 2013).

2.2.1 Global differences in Water Distribution Losses

2.2.1.1 Water Losses in Some Developed Countries

The level of NRW scenarios in developed countries differ from those in developing countries in various ways. The main difference is in the response strategies and response sensitivity of the water utilities and governments of these countries, (Kamani, Malakootian, Hoseini, & Jaafari, 2012). Utilities in developed countries have managed to reduce their water losses to acceptable and manageable ranges. NRW in Larissa, Greece, has been estimated at 34%, that is according to Kamani, et al (2012), while in Italy NRW has been estimated between 15 to 60%, (Edwards, Koval, Lendt, & Ginther, n.d.). Furthermore, Portugal loses between 20 to 50% in NRW, (Christodoulou & Deligianni, 2010). The Netherlands has reported water losses of 3 to 7% of the water distribution input, (Jung, Boulos, & Wood, 2007). The United States of America (USA) has an average NRW of 15% ranging from 7.5 to 20%, (Paola, 2012), as shown in Table 2.1. In the United Kingdom (UK), about 20 to 23% of water entering the distribution system is lost before it reaches consumers, (Makaya, 2015).

Table 2.1: NRW Ranges in the Developing Countries

Country	NRW Range (%)
Greece	13 - 34
Italy	15 - 60
Portugal	20 - 50
Netherlands	3 - 7
United States of America (USA)	7.5 - 20
United Kingdom (UK)	20 - 23

Much as the developed countries have made significant efforts in reducing NRW, however there still remains room for improvements. The wide variations in water losses in one country imply inconsistency in the way NRW reduction strategies are managed, (Makaya, 2015).

2.2.1.2 Water Losses in Developing Countries

Many water distribution systems in developing countries are operated under erratic conditions which leads to compromised water supply efficiency, (Haider, Sadiq, & Tesfamariam, 2014). Besides the challenges of intermittent water supply conditions, water losses in the developing nations have skyrocketed to alarming levels in excess of 60%, (Makaya, 2015). The slow progress in the water loss reduction in the developing countries is characterized by political interference and institutional resistance to change, (Sanusi, 2005). Furthermore, one of the major causes of slow progress is that water utilities have not been doing enough to invest in pipe network renewal. Most of the revenue generated by water operators is diverted to other uses instead of maintaining and upgrading water the distribution system, (Kingdom et al., 2006).

In Africa NRW figures ranging from 5% in some South African cities to 70% in Liberia have been reported, (Matinichi, 2014). Zimbabwe has recorded NRW of up to 60%, (Mugabi et al., 2007). The upper limit in the developing countries indicated the severity of the water loss problem. It remains of importance for water utilities to have lower levels of NRW as a way of managing the diminishing water resource at local and global levels, (Ncube, 2011).

2.3 Non-Revenue Water

Water losses occur in all distribution networks, substantially it is the amount of water losses which varies and this has a bearing on levels of asset maintenance for the water utility company, (Mutikanga, Sharma, & Vairavamoorthy, 2012). NRW can be defined as the water supplied by the water utility to the consumers but not billed which can be estimated by subtracting the volume of the billed authorized consumption from the system input volume according to Farley (2003). This loss includes physical and commercial losses (Ruhana, Mahamud, Shahbani, Bakar, & Teknikal, 2007).

2.3.1 Assessment of NRW using IWA Water Balance

According to Mukundi (2010), the first step in assessing NRW is to make water balance within the distribution system in order to determine the percentage that is lost through apparent losses and physical losses. Water balances are widely used by the water utilities but the diversity of formats and assessments of losses prevented international comparisons between water utilities (Lambert et al., 2003). Research done by Washali (2008) indicated that the most widely accepted framework for describing NRW is the International Water Association (IWA) Water balance which is provided in Table 1.1. The NRW definition offered by IWA (2003) is as follow:

NRW = System Input Volume – Billed Authorised Consumption.

This water balance is generally accepted to define the apparent and physical water loss in the distribution system. However, Makaya (2015) argues that the water balance by IWA (2003) is more applicable in the developed world since most of the revenue billing for water is collected. Contrary, in the developing world a substantial amount of billing is never collected and therefore may be considered as losses. Mukundi (2010), points out in line with IWA (2003) that there is need to have an adjusted water balance to show the true picture in the developing nations and suggested the following:

NRW = System Input Volume – Paid for Billed Authorised Consumption.

In most cases, NRW is expressed as a percentage of the system input volume, (Mukundi, 2010). Though many utilities use this percentage for measuring performance, Masheka (2013) points out that it may be misleading when used to show the actual trends and performance of the water utility overtime. He points out that the percentage can only be used when water consumption remains constant which is usually not the case. Changes in water tariff structures affect consumption and water usage behaviour of customers. Mukundi (2010) relates that when there is drop in consumption, the water utility will likely increase system input volume and if such a drop occurs with constant water losses in absolute terms, then the NRW in percentage terms becomes greater.

2.3.2 Physical Losses

Physical losses (Real losses) are losses which occur as a result of storage overflows, pipe bursts and leaks, (Farley, 2003). According to Masheka (2013), around 90% of water that is physically lost from leaks cannot be seen on the surface but in the long run the leaks might eventually become visible after many years, but until then, large volumes of water could have been lost. A water utility that does not practice a policy of efficient and intensive active leakage control will always have a high level of leakages, except in a situation when the infrastructure is new or is in excellent condition in terms of pipe works and were done with high level of workmanship, (Masheka, 2013).

The three main components of physical losses include leakage from transmission and distribution mains, leakage and overflows from utility's reservoirs and storage tanks and service connections, (Kingdom et al., 2006). Leakages from transmission and distribution mains are the major physical losses which normally occur in most of distribution networks. Leakages and overflows from reservoirs and storage tanks are easily quantified but most of the overflow normally occurs at night because of less industrial and domestic usage of water hence proper monitoring system should be put in place to avoid such occurrences (Kingdom et al., 2006).

Leakages from tanks are calculated using a drop test where the utility closes all inflow and outflow valves, measures the rate of water level drop, and then compute the volume of water lost (Kingdom et al., 2006). The volume of water lost from an individual pipe burst does not only depend on the flow rate of the event, but is also a function of run time which is often overlooked, (Farley, 2003). In addition to the above, age and pipe material are parameters that influence leakage magnitudes in most of the cases, (Lambert et al., 2000). This comes as a result of a combination of corrosion of pipes and high water pressures which increase breakages, and result in more leakage, (Masheka, 2013).

2.3.2.1 Analysis tool for physical water loss

EPANET is a public-domain, water distribution system modelling free software package developed by the United States Environmental Protection Agency (USEPA), Water Supply and Water Resources Division. It performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. EPANET is a commonly used tool by many water utilities because apart from being a free software, it is capable of providing information on flows in pipes, pressures at pipe junctions, propagation of a contaminant, water age (time taken for water to travel from a source to consumers), and even alternative scenario analysis. This helps to compute pumping energy and cost and then model various types of valves and check pressure and control flows, (Jung et al., 2007).

2.3.2.1.1 Usage and application of modelling software (EPANET)

In order to evaluate the hydraulic performance of the distribution system, EPANET can be used to simulate leakage in the water networks,(Tabesh & Asadiani, 2005). EPANET is one of the computer based hydraulic models developed by USEPA to perform hydraulic simulations within a pressurized pipe network (Seago, Mckenzie, & Liemberger, 2005). It uses a relationship between flow and pressure to determining the leakage level of the distribution system.

Hydraulic calibration is a process of comparison between the models results to the results obtained from the field. The purpose of calibration is to increase the confidence in the results obtained from the hydraulic simulation, (Washali et al., 2013). When calibrating EPANET hydraulic simulation model, parameters that may be adjusted may include water demand patterns, water demand, pressure, friction factors and pump discharges, (Lambert et al., 2000). Predictive ability of the model depends on the calibration. The availability of calibrated model is of fundamental importance for water utility company as it can be used as a decision support tool, (Washali et al., 2013).

2.3.3 Apparent losses

Apparent losses (commercial losses) are losses which occur due to illegal connections, meter inaccuracies and billing errors, (Kingdom et al., 2006). These losses result due to measurement errors, illegal connections and unaccounted for uses like cleaning of reservoirs and firefighting. Apparent losses are caused by under registration of customer meters, inaccurate meters, meters not working, vandalized meters, bypassed meters, bribery and corruption of meter readers. Lack of proper customer metering policy, poor levels of education and inefficient regulatory and legislative policies contribute more to commercial losses, (Farley, 2003). These losses are also referred to some nominal percentage of the system input volume which are assumed based on the figures from other utilities, (Paola, 2012).

2.3.4 Various Components and Definitions of NRW

Various literature was identified in order to get a better understanding of a number of components of water losses and their definitions as they relate to this study. With the increasing international trend towards sustainability, economic efficiency and protection of the environment, the problem of losses from water supply systems is of major interest worldwide. Both the technical and financial aspects are receiving increasing attention, especially during water shortages and periods of rapid development (ADM, 2010). However, particular problems and unnecessary misunderstandings arise because of differences in the definitions used by individual countries for describing and calculating losses. Also, traditional performance indicators give conflicting impressions of true performance in controlling water losses, (Kingdom et al., 2006).

NRW is a good indicator for water utility performance and high levels of NRW typically indicate a poorly managed water utility, (Wyatt, 2010). However, NRW as a performance indicator should be taken with caution when used to benchmark water utilities because of the factors that contribute to NRW.

Most recently many scholars and researchers have made references to International Water Association (IWA) Water Task Force for concepts and methodologies for quantifying and definitions of the NRW components. According to IWA Task Force on Water Loss, (Lambert et al., 2014), NRW, is the difference between System Input Volume and Billed Consumption. Based on the definition by the Task Force, system input is the annual input to the defined as part of the supply system and billed consumption is the billed metered consumption including water exported and billed unmetered consumption.

The World Bank Group (Berg, 2013) and its affiliate partners (Water and Sanitation Sector Board and Public Private Infrastructure Advisory Facility - the PPIAF) while discussing the issue of NRW in developing countries, defined NRW and its components as the difference between the volume of water put into the water distribution system and the volume that is billed to consumers. NRW has three components:

- **Physical/Real losses**; this comprise leakage from all parts and overflows at the utility's storage tanks. These occur as a result of poor operations and maintenance, lack of active leakage control, and poor quality of underground assets. It is any leakage of downstream of a production source and upstream of consumer revenue water meter, (UNEP/IETC, 1999).
- **Commercial/Apparent Losses**; these are caused by customer meter under registration, data handling errors and theft of water in various forms;
- **Unbilled Authorised Consumption**; these include water used by the utility for operational purposes, water used for firefighting, and water provided for free to certain consumer groups.

The first two of these components constitute Water Loss, (IWA, 2013). Usually it is the water loss indicators that reflect the level of efficiency of management of the water supply system. For effective reduction in water loss, technical, operational, institutional, planning, financial and administrative issues need to be coherently addressed (Yeboah & Kayaga, 2008).

2.4 Non-Revenue Water Reduction Efforts

Most funding organisations, including the World Bank, Africa Development Bank and the European Union, have made efforts to reduce NRW in their respective projects. The projects have included the following: prioritizing water loss reduction, inclusion of NRW reduction components and setting targets for reduced NRW as a condition for funding, (Bwire, Onchiri, & Mburu, 2015).

Nevertheless, many projects have not been as effective despite the above measures. Some of the reasons for failure in reducing NRW include:

- Little understanding of the nature of water loss by the people tasked with the responsibility.
- Little or no appreciation of the impact of water loss.
- Poor project design.
- Grossly underestimated costs of water loss reduction resulting in this task being abandoned.
- "Lip service" to obtain international funding; "NRW reduction" used as a politically correct term that is included in project proposals when sourcing for international financing.
- Failure to realize that NRW reduction is not just an isolated technical problem, tied to overall asset management and operation and, not a once-off activity, but one requiring long term commitment.

2.5 Impacts of NRW: The Vicious and Virtuous Circles

The terms vicious circle and virtuous circle refer to the complex chains of events which reinforce themselves through feedback loop. A vicious circle figure 2.2 has detrimental results, while a virtuous circle figure 2.3 has favourable results. Both circles are complexes of events with no tendency towards equilibrium, (Washali et al., 2013). The two systems of events have feedback loops in which each iteration of the circle reinforces the previous one and will continue in the direction of their momentum until an external factor intervenes and breaks the circle, (Farley, 2003).

A virtuous circle (Figure 2.3) is one where a good event feeds on itself to improve business further. It is a positive feedback loop. A virtuous circle sometimes can be small operating over days or it can drive a whole company's strategy for decades. The same positive feedback loop can also run in reverse however, to create a vicious circle (Figure 2.2), when a bad situation feeds on itself to make it even worse. A feedback loop exists that reinforces the poor results. A vicious circle is also known as a downward spiral and slippery slope, (Farley, 2003).

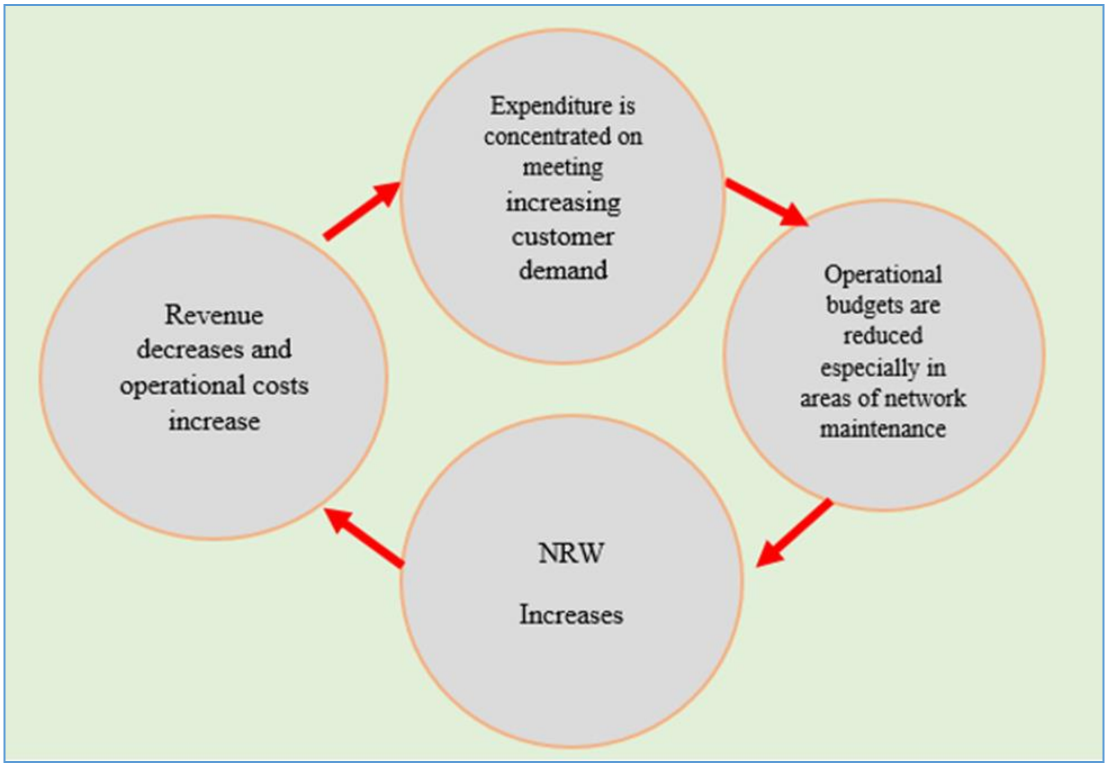

Figure 2.2: The Vicious Circle of NRW

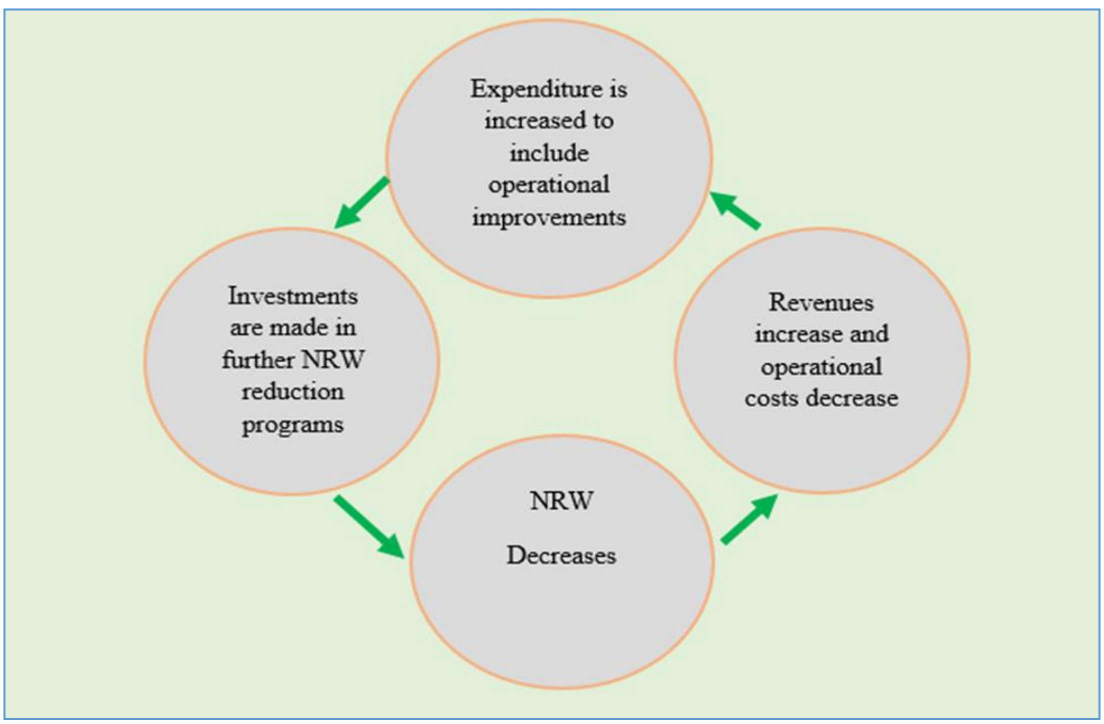

Figure 2.3: The Virtuous Circle of NRW

The Vicious Circle of NRW in Figure 2.2 explains key reasons for poor water utility performance and results in both physical and commercial losses. Physical losses divert precious water from reaching customers and increase operating costs. They also result in larger investments than necessary to augment network capacity. Commercial losses, caused by customer meter inaccuracies, poor data handling and illegal connections, reduce income and thereby financial resource generation, (Patience, 2014).

The challenge for water utilities in the developing nations is to transform the Vicious Circle to Virtuous Circle, (Farley, 2003). In effect, reducing NRW releases new sources of both water and finances. Reducing excessive physical losses results in a greater amount of water available for consumption and postpones the need for investing in new sources. It also lowers operating costs. Similarly, reducing commercial losses generates more revenues, (Washali et al., 2013). Transforming from the vicious to virtuous circle requires water utilities to have efficient and effective strategies that can be used to bring such a change, (Makaya, 2015).

One of the major yardsticks in measuring performance of a water utility is the level of non-revenue water. The lowest level of non-revenue water is desirable and is as a result of various inputs. This desired level is a product of an elaborate policy and procedures which bring together strategies to control and reduce leakages and bursts, eliminate accounting errors and water theft, infrastructure rehabilitation and necessary resources. When all these input factors are brought together, their interaction would bring about a desirable end product of low non-revenue water and higher income for the water utility, (Schwartz, 2005).

2.6 Steps in Developing NRW Reduction Strategy

The first step in developing the strategy is to ask some questions as shown in Table 2.2 about the network characteristics and the operating practices, and then use the available tools and mechanisms to provide appropriate solutions, which can be useful in formulating the strategy, (Kingdom et al., 2006). Typical questions are;

1. How much water is being lost?
2. Where is it being lost?
3. Why is it being lost?
4. What strategies can be introduced to reduce losses and improve performance?
5. How can we maintain the strategy and sustain the achievements gained?

Table 2.2: Tasks and Tools for Developing NRW Strategy

QUESTION	TASK
1. How much water is being lost? - Measure components	Water Balance - Improved estimation/measurement techniques - Meter calibration policy - Meter checks - Identify improvements to recording procedures
2. Where is it being lost from? - Quantify leakage - Quantify apparent losses	Network Audit - Leakage studies (reservoirs, transmission mains, distribution network) - Operational/customer investigations
3. Why is it being lost? - Conduct network and operational audit	Investigate: - historical reasons and poor practices - quality management procedures and poor materials/infrastructure - local/political influences and cultural/social/financial factors
4. How to improve performance? - Design a strategy and action plans	Upgrading and Strategy Development - Update records systems - Introduce zoning and Introduce leakage monitoring - Address causes of apparent losses and Initiate leak detection/repair policy - design short/medium/long term action plans
5. How to maintain the strategy?	Policy Change, Training and O&M Training: - improve awareness and increase motivation - transfer skills and introduce best practice/technology O&M: - Community involvement - Water conservation and demand management programmes - Action plan recommendations, O&M procedures

Source: Washali (2013)

There is a growing optimism that public water utilities in the developing countries can improve their own performance by applying commercial management principles, (Sharma, 2006). One of such principle that utilities can adapt is strategic planning. This principle is traditionally viewed as setting a long-term direction based on sound predictions, analysis of options, and key decisions about the future of an organisation. However, water utilities dominated by engineering profession, often lack the necessary tools and capabilities to carry out strategic planning.

2.7 Water Audit

To understand and quantify water lost from the water distribution systems, water utilities need to undertake water audit where the total water supplied is compared to amount of water billed (Kamani et al., 2012). Water auditing assesses the distribution metering, and accounting operations of the water utility using accounting principles to determine water amounts being lost, (Tabesh & Asadiani Yekta, 2005). The American Water Works Association (AWWA, 2017) recommends that an annual water audit be compiled by the water utility as a standard business process.

The strategies that are developed to reduce NRW should be based on the components of NRW. Components that contribute to the rise of NRW should be given high priority to ensure that there are quick wins, (Berg, 2013). It is therefore important for any water utility to fully understand the components in Table 1.1 and the solutions to questions in the Table 2.2.

2.8 Benefits of Reducing NRW

NRW reduction initiatives are fundamental requirement for improved water demand management and sustained water resources (Patience, 2014). It is therefore imperative to identify the causes of high non-revenue water within the distribution system in order to develop proper strategies and realize the benefits of water losses reduction.

Water utilities can make several gains if they would operate at low NRW ranges, (Berg, 2013). Water utilities with low NRW are financially sound and have the advantage of delaying costly capacity expansion for additional water sources. Coverage of supply is increased hence assisting nations in meeting the Sustainable Development Goals (SDGs). With increased efforts to control NRW, utilities build resilience and increase knowledge about water distribution network thus increasing infrastructure life span. Energy cost is reduced for systems that are largely dependent on pumping and more stabilized water pressure throughout the system and with lower levels of NRW, water utilities have increased firefighting capability due to increased pressure and reduced risk of water contamination.

2.9 Frameworks for NRW reduction

Various agencies and organizations have developed detailed performance evaluation frameworks including several indicators that comprehensively cover all the aspects (e.g., physical asset, staffing, operational, customer satisfaction, economical) of the Water Distribution Systems (WDSs). Most of these frameworks and indicators have been developed for large-sized WDSs, (Haider et al., 2014). Not much has been done for small sized water utilities or rural water supply systems as they are not commercially sustainable and are government dependent with an aim of improving livelihood of low income earners in rural areas. However, most small sized water utilities use similar practices for NRW reduction initiatives, (Matinichi, 2014).

2.9.1 Benchmarking frameworks for the water sector

Frameworks consist of concepts with definitions and their respective references to relevant existing literature that is used for a particular study. As such, frameworks have to demonstrate an understanding of theories and concepts that are relevant to the topic of study, (Matinichi, 2014). Selection of the framework must depend on its appropriateness, ease of application and explanatory power, (Shamsaei, Jaafar, Ezlin, & Basri, 2013). The framework used in this study helped to limit the scope of the relevant data by focusing on specific variables and defining the specific viewpoint in analyzing and interpreting data.

Over the past years, there has been a number of efforts to develop and standardize the approach to benchmarking in the water sector. Among them some notable efforts have been made by the American Water Works Association (AWWA), the International Water Association (IWA) and the International Benchmarking Network for Water and Sanitation Utilities (IBNET) of the World Bank. IWA provides a framework within a utility perspective and a comprehensive set of indicators for water supply and waste water. Both IBNET and AWWA provide ready-to-use frameworks and a platform for data collection, analysis, quality check and dissemination of results, (Sharma, 2006). Both IBNET and IWA highlight the importance of reliability of information and suggest methods for assessing the reliability of indicators and related level of confidence. The IWA, AWWA, IBNET and ISO frameworks are similar as they make emphasis on standardizing definitions of terms and feature a set of rational performance indicators that evaluate utilities on system specific attributes such as average pressures in the distribution system and total length of mains. The IWA framework has been evaluated instead of AWWA, IBNET and ISO as it encompasses most of the indicators in these frameworks according to (Berg, 2013).

There are two main frameworks that have been used for a longtime to assess the performance of water utilities in the world (Berg, 2013). The two frameworks are the International Water

Association (IWA) and the Tynan and Kingdom Frameworks. These two frameworks are used for performance assessments and benchmarking among water utilities. According to Cabrera et al. (2011), benchmarking has become a key tool in the water industry to promote and achieve targets for water utilities. During the past decades, the use of these frameworks have expanded globally to assess performance improvement of water utilities.

2.9.2 IWA Framework

The IWA framework has been developed based on an extensive field test of performance indicators system that relied on contributions from over 70 volunteer undertakings. The participants included bulk and direct water suppliers, water utilities and multi utilities, holding companies and regulators. Participants from developed and developing countries serving populations ranging from 10,000 to more than 20 million took part in the exercise to finalize the framework. The IWA Framework provides a baseline framework and guidelines for operators and associations that want to undertake benchmarking and has been used in many European countries, (Berg, 2013). This framework has been used in many European countries for many years since its inception.

The International Water Association (IWA) has developed an extensive performance measurement system with sub-components of data elements, variables, performance indicators (PI) and context information. Under the IWA system, Performance Indicators are classified into five groups: water resources, personnel, physical, operational, quality of service and economic and financial. This framework has been used in many European countries, (Washali, 2013).

Before the indicators are developed, the IWA Framework emphasizes on the understanding of the terms in the Table 1.1. The objective is to provide a long overdue standardized international approach to the calculation of NRW, its components, and performance. However, adoption of the approach in European countries has been rather mixed. In 2013 European Commission’s Water Blueprint’s proposed tool box approach which allows each country to choose its own performance measures for improved water loss management, (Lambert et al., 2000).

2.9.3 IWA Methodology and Performance Indicators

The IWA methodology for determining and comparing leakage in water distribution systems is now generally accepted as the world's best practice. There has been a debate regarding the use of various performance indicators and this is expected to continue for many years to come. South Africa has been one of the leading proponents of the use of the Infrastructure Leakage Index (ILI) according to Seago et al. (2005) and ILI has been used as main indicator for comparing levels of leakage amongst Water Utilities for the last ten years.

IWA uses bands to assess ILI, (Makaya, 2015). Table 2.3 shows the bands of Infrastructure leakage index.

Table 2.3: Details of IWA Water Balance

Developing Countries	**Developed Countries**	**BAND**	**General description of real loss performance management categories**
ILI Range	**ILI Range**		
<4	<2	A	Further loss reduction may be uneconomic unless there are shortages, careful analysis is needed to identify cost effective improvement
4 to <8	2 to <4	B	Potential for marked improvements; consider pressure management, better active leakage control practices and better network maintenance
8 to <16	4 to <8	C	Poor leakage control record, tolerable only if water is plenty and cheap; even then analyse level and nature of leakage and intensify leakage reduction efforts
16 or more	8 to more	D	Very inefficient use of resources; leakage reduction programs imperative and high priority

To determine ILI, there is need to compute the Unavoidable Annual Real Losses (UARL) and Current Annual Volume Real Losses (CARL). The UARL is a reference value that represents the theoretical low level of leakage that would exist in a distribution system if all the best leakage management techniques were successfully employed, as specified by, (Makaya & Hensel, 2014). Calculation of UARL and CARL heavily depends on acquisition of accurate data as such the usefulness of ILI in the developing countries is a challenge amidst inadequate resources.

2.9.4 Strength of IWA Framework

Water Loss Audit is a detailed and accurate assessment of the water loss status of a utility. An audit is comprised of a detailed data review and analysis, combined with actual measurements and investigations to determine the level of real and apparent losses and its components (Ncube, 2011). The water audit forms an excellent basis for the development of a NRW management strategy as it shows the percentage of losses of each component.

The IWA Framework promotes compilation of data to make analyses with high level of competencies. Many developed countries use this framework as they have adequate financial and human resources, coupled with less political interference. Application of this framework is easier in developed countries because most developed nations have solid infrastructure and established operational practices for managing and controlling NRW, (Ruhana et al., 2007). The framework recommends using 95% confidence limits to water calculations and this gives reliable results that can help determine areas that would need investments to improve the utility performance in both long and short terms, (Mosha, 2007).

2.9.5 Weakness of IWA Framework

The ILI is criticized for being too simplistic and not incorporating some of the key factors which influence leakage from a water distribution system, (Seago et al., 2005). Regardless of the simplicity of the ILI, calculation of the same requires a lot of data which is a major challenge for water utilities in developing nations. The five areas that make the use of this framework (indicator ILI) difficult to be employed especially in the developing world are as follows:

- ILI values of less than 1.0 should not occur since this implies that the actual leakage is less than the theoretical minimum level of leakage.

- The Unavoidable Annual Real Loss (UARL) equation is too simplistic as it is based only on the length of mains, number of service connections, length of underground pipe from the mains to the point of metering and the average system pressure.
- The use of the ILI in cases where a Water Utility operates under either abnormally high or unusually low pressures
- The use of ILI for systems with less than 2000 connections.
- Updating of the ILI parameters as more reliable information becomes available.

The ILI approach is less useful in developing countries than in developed countries, as it ignores commercial losses, the annualized cost of water supply capacity expansion, and situations in which production capacity does not meet demand (Wyatt, 2010).

Most developed countries have adequate water distribution infrastructure, established operational practices for managing and controlling NRW with proper systems of keeping records. This is not the case with developing countries where many are struggling to ensure that customers receive a reasonable supply of safe drinking water, (Ruhana et al., 2007). Water utilities in the developing countries are characterized with pipe network that is inadequate, poor record systems and a low level of technical skills and technology, (DAI, 2010). Tariff systems and revenue collection policies often do not reflect the true value of water supplied, which limits the utility's cost recovery and encourages customers to undervalue the service.

2.9.6 Tynan and Kingdom Framework

Data from 246 water utilities in 51 developed and developing countries were used to highlight wide variation in performance on key indicators: NRW, labour costs, working ratio, service coverage, water price and connection costs and continuity of supply. On the basis of the top 25 percent of developing utilities (Tynan & Kingdom, 2002) proposed the best practice targets for developing countries.

Water Services Management (Schwartz, 2005), provides the framework for analyzing the performance of water utilities by Tynan and Kingdom. This framework was originally developed as a tool for benchmarking between different utilities. The framework distinguishes the following dimensions: operational efficiency, cost recovery, commercial performance, coverage and access, asset maintenance, service quality, price and affordability, (Schwartz, 2005).

2.9.6.1 Operational Efficiency

This refers to the lowest cost use of labour, energy, water and materials in the day to day operation of a utility. The most efficient combination partly dependent on local input prices and prior capital investment decision, (Tynan & Kingdom, 2002). The framework suggests two possible indicators to measure operational efficiency. These are: number of staff per 1000 connections and number of staff per 1000 people served. For well performing utilities they propose a target of 5 staff per 1000 connections.

2.9.6.2 Cost Recovery

For a utility to provide water services of adequate quality and quantity, utilities need adequate funding to pay for its capital investments and day to day operational costs. Failure to meet operational obligations leads to a decline in the level of service delivery. This framework uses working ratio as an indicator to gauge performance. A working ratio of less than 1 means that the utility is able to cover all its operating costs from annual revenue. The target proposed by Tynan and Kingdom is 0.68 and this means that a utility has sufficient funds for operational costs and is able to meet part of the investment costs.

2.9.6.3 Commercial Performance

In order to collect sufficient revenue from consumers, the utility must bill consumers for what they consume, and must collect payment for these bills in a timely manner. The indicator used for measuring commercial performance is the collection period which refers to the ratio of accounts receivable to annual revenues. The Tynan and Kingdom Framework proposes that the collection period be 30days utmost.

2.9.6.4 Coverage and Access

In developed countries water coverage and accessibility are in vicinity of 99% and in the developing world coverage level vary from 100% to 18%, (Schwartz, 2005). The Tynan and kingdom Framework proposes a coverage level of 100% with appropriate levels of service.

2.9.6.5 Asset Maintenance

The indicator of NRW is used as an indicator for state of the service provision network. The principle is that the state of NRW is lower when the state of service network is better. The target level of NRW as proposed by Tynan and Kingdom framework is less than 23%. This means that a utility would perform well when they manage to lose less than 23% of the water they produce.

2.9.6.6 Service Quality

Tynan and Kingdom uses continuity of service as the main indicator with which to measure the level of service quality. The continuity of service is expressed in the number of hours per day that services are provided to consumers. The framework proposes a target of 24 hours per day, (Tynan & Kingdom, 2002). In the developing countries 50% of the utilities in the low and middle income are already achieving this target.

2.9.6.7 Price and Affordability

The framework measures this indicator by calculating affordability of service provision as a price of 20 litres per day as a percentage of per capita GDP. The target for this indicator in most low and middle income countries is 0.2% of per capita GDP for 20 litres of water.

2.10 Strengths of the Tynan and Kingdom Framework

The indicators and proposed targets capture a broad range of performance measures for utilities and these pointers are comprehensive as they are dependent on a wide range of studies. This framework is applicable to both developed and developing nations, (Schwartz, 2005). The framework analyses performance in a variety of dimensions and allows for cross-case comparisons and can also be used as a yardstick for performance for individual water utilities, see Appendix 1.

Most developing countries do not have solid infrastructure and established operational practices for managing and controlling non-revenue water (NRW). Many developing nations struggle to ensure that customers receive reasonable supply of safe drinking water, via pipe networks that are inadequate, with poor record systems and a low level of technical skills and technology. These challenges make the application of other frameworks difficult as they require effective operational practices, high level of technical skills and technology with excellent record systems. This therefore, makes Tynan and Kingdom framework suitable for developing countries.

2.11 Weaknesses of the Tynan and Kingdom Framework

The first limitation of this framework is the inability to catch a particular dimension in a few indicators, for example NRW covers other practices apart from asset maintenance. In analyzing some indicators, the framework seems not to be comprehensive, for example on operational efficiency, it refers to lowest cost use of labour, energy, water and materials and yet the dimension is only measured by labour. Another weakness is the applicability of some dimensions in other countries, like Netherlands few consumers are concerned with operational efficiency but are concerned with reliability and trustworthiness of service provision, (Schwartz, 2005).

2.12 Framework selection and justification

Based on the merits and demerits of the two frameworks, Tynan and Kingdom Framework was preferred to IWA Framework as a basis for assessing the effectiveness of the strategies used by BWB to reduce NRW. The framework was selected based on the fact that most countries in the developing countries prefer using this framework for measuring their performance because of lack of solid infrastructure and established operational practices for managing and controlling non-revenue water (NRW) in the distribution system. BWB does not have comprehensive data system that could permit the researcher use the other framework.

2.13 Challenges in NRW reduction activities

Although reduction of NRW should be given a priority for many water companies, the majority of water utilities struggle to reduce water losses to acceptable levels within their respective water distribution system, (Farley, 2003). The reasons for failure in NRW reduction ranges from inability to understanding the gravity of the problem to inadequate financial and human resource capacities. In addition, many water utility professionals do not pay enough attention to NRW because of weak internal policies and procedures which contribute to increase in NRW, (Washali et al., 2008).

NRW reduction programmes are not supposed to be a one-off activity but requires a long-term commitment and involvement of all departments in a water utility organisation, (Schwartz, 2005). Majority of water companies do not have right information of the entire network which would enable the utility to fully understand the complexity of water losses and its impact on the operations of water distributions, (Davydoff & Gabaut, 2011). Underestimating the complexity of water losses, potential benefits of reducing NRW lead to failure of reduction programmes. For NRW to be minimized successfully it requires prudence in asset management, operations, customer support, financial allocations, management support and proper record keeping, (Washali et al., 2008).

In many African nations, poor governance affects NRW reduction initiatives. Utility companies often lack autonomy, accountability, technical and managerial skills that are necessary for provision of reliable service (Ioris, 2008). Utilities fail to tackle organisational challenges such as policy barriers, inadequate technical capacity and aging infrastructure (Ncube, 2011). However recent trends show that understanding of the institutional dimension of NRW is growing in many developing nations. For instance, new methodologies that quantify physical and commercial losses more accurately have been developed. More effective technical approaches to manage leakage and reduce system pressure and new instruments for engaging the private sector such as performance-based contracts have been established according to Haider et al. (2014).

2.14 Empirical literature

According to Farley (2003), the problem of NRW has received substantial concern in the recent past and various studies have been conducted to come up with ways to tackle the challenge. Leakage reduction, both real and apparent losses have been the subject of studies and reports since 1980's and IWA (2003) produced reports to help water operators understand their water losses and develop strategies to reduce NRW (Mukundi, 2010). Substantial improvements have been made in developing both technical (pressure management and flow monitoring) and operational management to reduce physical losses however, the developing nations face more challenges to cope with their losses. Kingdom et al. (2006) quote poor infrastructure and equipment that have stayed for long time without being maintained and high level of unbilled water consumption through fraud and illegal connections have negated performance of many water utilities in the developing countries.

Yeboah (2011) investigated NRW levels in the water service delivery in Accra and to assess the management practices being adopted to manage NRW and then to come up with recommendations that would help improve the strategies that were adopted. The study focused on the infrastructure management of the distribution networks, identification of the main pipes that needed replacements and areas that had high frequency of bursts and leakages. The researcher adopted; field work, document review and interviews as a methodology for his research. The study found out that there was poor management of the infrastructure, identified 15 District Metering Areas (DMAs) that needed urgent pipe replacement and the need to improve workmanship in pipe work construction. Through this research the following were recommended to improve service delivery; appoint the NRW manager to coordinate all activities that were aimed at reducing NRW in the Distribution Department and other Sections that were related to the same. The water utility should increase the resources that are used to fight against NRW, there should be more proactive measures to monitor the work of meter readers in order to avoid corruption and that management should embark on educational programmes to sensitize the general public and staff on NRW.

A study by Dominic (2013) focused on the effects of water pipe bursts on water quality and NRW in Arusha City, Tanzania. The researcher adopted the methodology of document review, observation, questionnaires and interviews to determine the effects of water losses and found out that to reduce NRW utilities needed to raise NRW awareness knowledge of the staff. The utility needed to improve response to customer fault reports and speed bursts isolation and rectification. The study concluded that poor management of the utility had a very serious effect on the level of NRW and recommended that strategies should be revisited to improve performance of the water utility. Washali et al (2008), claims that poor performance of water utilities in the developing countries is as a result of insufficient financial capacity and old infrastructure.

Masheka (2013) carried out a study themed optimization of NRW management for Livingstone Town in Zambia a case study of Lizuma Ward with an objective of investigating suitability of using EPANET in estimating leakages and opportunities for optimizing NRW management. Through the methodology of pressure and flow logging, response time to faults and meter accuracy tests he found out that the level of NRW keep on increasing due to delayed response time to faults, no clear demarcation between real and apparent losses to guide the utility to invest in critical areas and difficult to measure the Infrastructure Leakage Index (ILI) due to poor record keeping systems. The study concluded that there was no distinctive trend observed for the period under review and that NRW was as high as 65% and that EPANET could successfully be used to estimate real loss.

Makaya (2015) experienced difficulties to evaluate the water balance for water supply system in Harare Zimbabwe because of nonfunctional bulk meters and absence of bulk meters in some sections of the distribution network. The study revealed that political limitations have an influence on the prioritization of the objectives, selection of project and attribution of budget. The researcher denounced the choice to commence a significant and expensive engineering project to increase water supply capacity before assessing the gain of the reduction of water losses within the distribution system. This case illustrated the importance of external pressure from politicians and funders and underlines the complexity of water projects and the need for a strong leadership.

Contrary to the findings of Makaya (2015), Kennedy (2016) revealed positive role of the Iranian government by devoting a part of the budget to combat NRW by pressing the water and wastewater companies to allocate a part of their budget to this task. Because of the foregoing reason they are improving their water losses management through better operational practices (leakage detection and quicker response to detection, replacements and implementation of new monitoring equipments, following national standards whilst installing new branches and conducting pilot projects).

Zuleta et al (2005) stressed the significance of evaluating the reliability of the measurement made and used in the calculation of NRW, for a careful interpretation and a good use, particularly because the evaluation of essential volume of losses for the water balance can be limited to a simple appreciation. The evaluation of real losses can be more precise due to night flow analysis, but this method is quite expensive and not always applicable. IWA (2017) raised the issue of poor equipment and technologies in developing countries with the example of Maputo. Lack of flow meters or their non-accuracy prevent a good knowledge of the networks and make difficult the establishment of a precise water balance and therefore action plans (Mukundi, 2010). The authors emphasize the fact that in their attempt to assess the water losses in Bogota Colombia most of the values were uncertain or based on estimated data that prevented them from making any reliable conclusion on volumes lost or recommendation to tackle the loss. Furthermore, they also missed data on the network installation conditions and number of connections (particularly illegal connections). In such a situation, the only recommendation they could strongly argue for is the installation of monitoring equipments and the conduct of surveys on physical and commercial data.

Mons (2010) conducted a study on strategies for NRW management in developing countries; a case study of Kampala, Uganda. The objectives of the study were to evaluate the water loss situation in the distribution network of Kampala, to identify the existing strategies employed globally for combating NRW, to evaluate existing strategies for tackling NRW and assess the possibility of implementing new strategies. The methodology used was a case study on the water supply in Kampala. In his research Mons (2010) concluded that most of the water utilities in the developing nations have high NRW due to dilapidated infrastructures, conflicting interests, lack of strategies and culture.

The research study by Yeboah (2008) on management of NRW a case study of the water supply in Accra, Ghana and the research objectives were to analyse the existing NRW situation in Accra and the management strategies that the utility uses to address NRW, to determine the extent that NRW has on overall performance of the water utility and recommend how the existing NRW control can be improved. The methodology used was a case study approach. The research identified the following as determinants of NRW levels; network pressures, lack of leakage control, meter reading inaccuracies, billing inaccuracies, meter under-registration and unbilled authorized consumption. The study recommended holistic approach to NRW management starting with analysis of the NRW components and prioritization of activities in NRW reduction.

2.15 Summary and Research Gap

Many water utility companies in developing countries have managed to identify determinants of NRW and developed strategies to address the challenge. However, the effectiveness of the strategies need assessment to ensure that water utilities in developing nations do not register high NRW of above 23%. This study recognized the existence of the strategies that BWB use to reduce NRW and was thus designed to assess the effectiveness the strategies that are being employed by BWB. The study hypothesized that ineffective implementation of strategies for water loss reduction was the cause for high NRW. The available records indicated that the level of NRW for BWB was 52% above the 23% which is recommended in the Tynan and kingdom Framework. This study was then designed to assess the effectiveness of the strategies that are used by BWB to reduce NRW.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses methods that were applied in the process of conducting this research study. The study looked specifically at the methods under the following sections: research design, location of the study, target population, sampling techniques, data collection and processing and analysis techniques.

3.2 Research Design

The study mainly employed quantitative approach which mainly focused on quantifiable data in terms of numbers and measures that could be analysed statistically. The research study made an interpretation of data by developing a description of outcome of results from SPSS, Reports, Hydraulic Model and QGIS, (Tabesh & Asadiani Yekta, 2005). For the purposes of this study, the main focus was to assess the strategies that Blantyre Water Board have been using to reduce the level of NRW to acceptable level of 23% as recommended by Tynan and Kingdom Framework. Conclusions from the results were deduced by comparing outcomes from data analysis tools to the accepted standards from the frameworks that are used to benchmark water utilities.

3.3 Description and location of the Study

The study was carried out at Blantyre Water Board which is in Blantyre City, Malawi. Blantyre is the chief commercial and industrial centre of Malawi. Blantyre Water Board is a parastatal organization reconstituted under the Malawi Water Works Act no. 17 of 1995 to supply water for commercial, industrial, institutional and domestic use in the water supply area of Blantyre City and surrounding environs. BWB abstracts raw water from Shire River (an outlet of Lake Malawi) at Walker's Ferry about 40 kilometres away from Blantyre City. The elevation difference between the abstraction point and receiving reservoirs at Nyambadwe Tanks is 800 metres. BWB provides water to 85% of the 1.4 million population through a daily production of 96, 000, 000 litres of treated water. BWB also extracts surface water from Mudi Dam which provides 8, 000, 000 litres of water daily through Mudi Treatment Works. Walker's Ferry and Mudi Dam are the major two sources of surface water, with Walker's

Ferry providing 95% and Mudi Dam 4%. The Board also has three sources of underground water at Nguludi, Bvumbwe and Lunzu which provides the remaining 1% of the total daily production.

The supply network as shown in figure 3.1 is located at an average of 1039m above sea level and between -15.786111, 35.0005833. The total area is 228km^2 with a population density of 4,700 people per square kilometer, (www.bccmw.com, 2017).

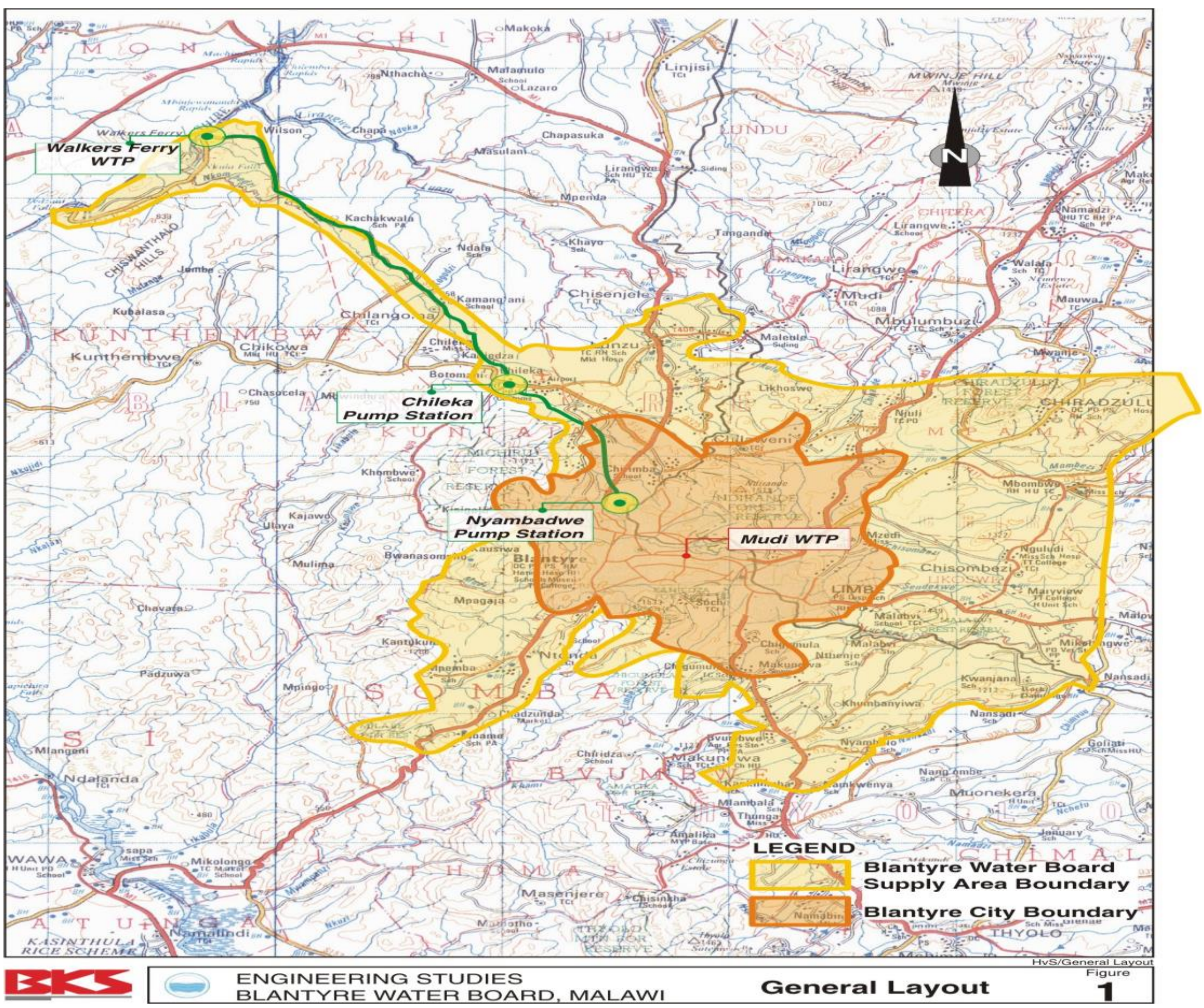

Figure 3.1: Map of BWB Water Supply Area (Source: BKS 2002)

3.4 Target Population

The population that was selected to take part in this research study at BWB was those that are directly involved in the activities that relate to NRW at various levels of operations.

Questionnaires were designed and administered to the employees in the following sections and units:

- Distribution Section; the staff in this section are directly involved in maintenance of faults and are directly responsible for planning and controlling physical losses within the distribution system.
- Revenue Section; this section is responsible for reduction of apparent losses through meter reading, bill distribution, reporting of faulty meters and illegal connections.
- Network Unit; this unit is responsible for network improvements through the use of QGIS and Hydraulic Modelling. The unit is also responsible for system calibration through measurements of water flows, pressures and maintenance of water meters. It also takes the duty of ensuring that the distribution network is capable of conveying water with minimal interruptions and adequate pressure.
- Production Section; this section is responsible for water production and measuring the input volume into the distribution network.
- Water Supply Unit; this unit is responsible for water transmission into the water reservoirs (tanks) and coordinating faults that are reported mainly at night.
- Projects Section is responsible for projects design and implementation. Most of the water distribution network is designed and implemented by this section.
- Finance Section is responsible for budgeting and control of finances for day to day operations of the Board.

BWB has 520 employees and 249 are in the sections and units that are directly responsible for reduction of NRW. The sections are headed by managers while units are headed by officers. Various points within the distribution were selected purposively for pressure measurements.

3.5 Sampling Techniques and Sample Size

3.5.1 Sampling Techniques

To achieve the objectives of this study a purposive and non-probability sampling techniques were used. Purposive sampling is most effective when one needs to study a certain cultural domain with knowledgeable experts within (Bryman & Cramer, 2005). This technique is also known as judgmental, selective or subjective sampling and can be used with both qualitative and quantitative research techniques. This method enables researchers to use their own judgment when choosing members of the population, (Bluman, 2004).

There are some broad advantages and disadvantages in using purposive sampling techniques. One of the major benefits of this method is the wide range of sampling techniques that can be used across research designs. The technique also provides researchers with the justification to make generalizations from the sample that is being studied, whether such generalizations are theoretical, analytic and/or logical in nature according to Creswell (2008). Irrespective of the advantages of this technique, it is highly prone to researcher bias and sometimes it becomes difficult to defend representativeness of the sample (Creswell, 2008).

To ensure the integrity and validity of research findings and interpretation of the results, the researcher used a variety of tools to prepare, analyze and interpret data before making descriptive and inferences into population (Kamani et al., 2012). Several important concepts from literature were analysed before interpreting and drawing inferences from research findings.

3.5.2 Sample Size

The sample size is an important feature in any empirical study in which the goal is to make inferences about a population from a sample (Ciochetto & Haley, 1995). The issue of sampling was considered important and is discussed at this stage because it is rarely the case that researchers have sufficient time and resources to conduct research on all of the entire population that could potentially be included in a study (Bryman & Cramer, 2005). Sampling refers to computing a subset from the population. The main purpose of sampling is to produce a representative sample that has characteristics similar to the population (Raddon, 2015).

For the purpose of this study, considering the population size and available resources, the calculation of the sample size was adopted with ±8% desired level of precision, 95% confidence level and 0.5 degree of variability (Ncube, 2011). The equation below was thus used to compute the sample size (Creswell, 2008) which formed the representative of the population of the targeted employees.

$$n = \frac{N}{1 + N(e)^2}$$

Where N = population size, n = sample size, e =desired level of precision

Based on the population (N) of 249 and ±8% level of precision and computing from the above formula, 96 questionnaires were determined to be administered to respondents. However, the sample was increased by 25% to account for contingencies such as non-response samples (Ncube, 2011). Therefore 120 questionnaires were decided to be distributed to respondents to enhance the representative of the population. Questionnaires were then distributed to random samples to ensure that all the population had an equal chance of selections.

3.6 Research Instruments

Research instruments are fact finding strategies and data collection tools. They include questionnaires, interviews, observations and literature review. To meet the objectives of this study, questionnaires, reports and observations through measurements were undertaken to collect data. The researcher ensured that instruments were valid and reliable. Essentially the validity and reliability of any research project depends to a large extent on the appropriateness of the instruments (Festinger, 2005).

The large part of information was gathered through a structured questionnaire with close ended questions. The purpose of this instrument was to collect comprehensive, systematic and in-depth information in order to allow the researcher analyse the strategies that are employed by BWB to reduce NRW. The closed ended questions permitted the researcher to avoid collecting too much data and work within the available time resource.

3.7 Data Collection Techniques

A structured questionnaire (Appendix 2) with close ended questions was used to collect empirical primary data, this was augmented with field measurements to ensure that the fundamental principle of mixed research methods which provides complementary strengths and avoids non-overlapping weaknesses (Bluman, 2009). Official documents and reports were used to obtain secondary data. Official documents and reports are basically written or recorded for public or private organisations.

3.7.1 Questionnaires

The most widely used method to scaling responses approach in survey research is the Likert-Type Scale. A Likert Scale is a psychological measurement device that is used to gauge attitudes, values and opinions. This scale functions by having a person complete a questionnaire that requires them indicate the extent to which they agree or disagree with the series of statements (Ciochetto & Haley, 1995). The scale is named after its inventor and psychologist Rensis Likert.

As Brown (2010) recommends that respondents should be offered a choice of five or more pre-coded responses with neutral point being neither agree nor disagree based on the Likert Scale (Ciochetto & Haley, 1995). The statement opinion questions should be softened and treated as opinions as they help respondents asked in softer format about their opinion on a particular theme. For the purposes of this study a five-point Likert scale was applied to enhance the measuring of agreement and disagreement level. According to Washali (2011) the typical five-point scale is the best known rating scale and most widely used research approach within the opinion research due to its simplicity and reliability.

3.7.2 Reports

Documents from BWB provided the secondary data and were reviewed during this study. The study used monthly reports from the water distribution section of BWB, fault management system reports and annual financial reports. Data collected from these reports were; number of illegal connections, number of personnel working in the units and sections that are directly involved in the NRW reduction activities, number of faults and financial investments toward reduction of NRW.

3.7.3 Field Measurements

Field measurements were conducted to check the pressure variations using data loggers. Pressure logging was carried out using a Vermor type of data loggers. The devices are manufactured by Vernon Morris Solutions in the United Kingdom. They are portable data loggers which can be installed at strategic locations within the distribution system and they have accuracy of ±1% and operate between temperatures from 5^{o}C to 50^{o}C (Masheka, 2013).

Pressure loggers were installed at three different points of the distribution mains for a minimum of four days with an aim of measuring pressures in the pipelines. Pressure measurement throughout the entire day was conducted at different zones in the distribution system. At location where pressure gauges were installed, flows were also taken. Critical times were noted while pressure were automatically recorded. The critical time for high pressure was mid night and early morning (0:00-4:00), (Lambert, 2003).

There are three distribution pipelines that supply water from Chileka Pumping Station to Nyambadwe Tank, Ndirande Tank and South Lunzu Tank. Most areas in the distribution system in Walkers Ferry, Chileka, Chatha, Lunzu and Kameza receive water supply direct from the pumping mains. The hydraulic modelling software (EPANET) was used to analyse water pressure in the distribution mains. The EPANET was preferred as it is cheap and a freeware.

3.8 Data Processing and Analysis

The quantitative data collected through the survey questionnaires were analysed using the Statistical Package for the Social Sciences (SPSS Version 20.0). The numerical coding scheme based on the range of responses obtained was developed and codes were assigned to each subject then the numerical response was analysed (Festinger, 2005). Data was explored specifically for distribution trends and frequency responses. Most of the outputs from SPSS v20.0 were presented in form of graphs (Pie-Charts and Bar Graphs).

For the purposes of decoding the responses from the questionnaires, Table 3.1 was used to supply different rates of agreement and disagreement choices in the questionnaire (Washali, 2011). Statistical tests performed on the study data using SPSS v20 software generated answers' means which were placed in the appropriate range as provided in Table 3.1 to guide the researcher to obtain descriptive analysis of results. The process of producing descriptive statistics from the SPSS v20 generated means which were used vis-à-vis the interpretation on the Likert scale. From Table 3.1, if the mean from the frequency tables range within 1.00 to 3.39, the respondents would be rated as not aware and 3.40 to 5.00 would be rated as aware.

Table 3.1: Awareness Measuring Table based on rating of Five-Likert Scale. Source Washali, 2011

	Mean	Responses Average	Response Decoding
1	From 1.00 – 1.79	Strongly Disagree	
2	From 1.80 - 2.59	Disagree	Not Aware
3	From 2.60 – 3.39	Neutral/Average	
4	From 3.40 – 4.19	Agree	
5	From 4.25 – 5.00	Strongly Agree	Aware

3.9 Correlation of Variables

Correlation analysis was used to describe the strength and direction of the relationship between variables, (Festinger, 2005). SPSS v 20.0 provided a table of correlation coefficients as an output between each pair of variables listed, the significance level and the number of cases.

This analysis dealt with inferential statistics which was concerned with how well the sample data represented the parameters of the population, supported the null hypothesis and enabled the researcher to reject it in favour of the alternative hypothesis (Creswell, 2008).

The purpose of making correlation was to explore the relationships among variables. Correlational techniques are often used by researchers engaged in non-experimental research designs (Fox & Hunn, 2009). Correlation coefficients (**r**) provide a numerical summary of the direction and the strength of the linear relationship between two variables. The correlation coefficients range from -1 to +1. The sign in front indicates whether there is a positive correlation (as one variable increases, so too does the other) or a negative correlation (as one variable increases, the other decreases), (Pallant, 2007).

Correlation is significant at the 0.01 level (2-tailed). For the purposes of this study the strength of relationships is determined using the correlation coefficients in three categories according to (Pallant, 2007) as in table 3.2. For the purposes of this study relationship was considered strong at r greater than 0.49 correlation coefficient.

Table 3.2: Determination of strength of relationship using correlation coefficient

Strength of Correlation	Correlation Coefficient (*r*)
Small	0.1 – 0.29
Medium	0.3 – 0.49
Large	0.5 – 1.0

3.10 Ethical Consideration

Due to sensitivity of some information collected for this research, sources of information and respondents were assured of confidentiality of the information that was provided. All the participants that took part in this research were provided with information which enabled them to make informed decision about their participation. The following information was provided:

- The purpose and objectives of the study with the description of the procedures to be followed.
- The length of time the researcher needed to get the feedback from respondents.
- The extent to which results would be confidential.
- The freedom to withdraw from participation in this study.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter provides the research findings and analysis of results. The chapter outlines the findings and analyses based on the research objectives. The general objective of the study was to assess the effectiveness of the strategies that BWB uses to reduce NRW. The study therefore sought to scrutinize factors that inhibit the BWB from implementing the strategies effectively so that NRW is reduced and maintained at an acceptable level based on the Tynan and Kingdom framework, (Kingdom et al., 2006).

Descriptive analyses were frequently used to summarize the study sample prior to inferential analyses. This provided the overall representativeness of the sample while inferential statistics helped the researcher to draw conclusions beyond sample data.

4.2 Questionnaire Return Rate

A total of 120 questionnaires were administered to the respondents and only 112 questionnaires were duly filled and completed representing 93.3% response rate. The response rate of 93.3% conforms to Mugenda & Mugenda, (2003) argument that a response rate of 50% is adequate for analysis and reporting and a response rate of 70% and over is excellent. This shows that the response rate for this study was excellent and enabled the researcher to proceed with the analysis.

4.3 Characteristics of the Sample

4.3.1 Distribution of Respondents by Gender

The first demographic characteristic that the study explored was gender. An analysis of gender distribution of the respondents was carried out and presented as shown in table 4.1. The significance of the gender parameter was to ensure that there is representation of both male and female in this study. According to Zyl (2006), the third principle of the Integrated Water Resources Management (IWRM) advocates the participation of women at all levels of water management. The principle promotes gender and states that women play a central part in the provision, management and safeguarding of water (Zyl, 2006).

Table 4.1: Gender of the Respondents

Gender	Frequency	Percentage (%)
Male	95	86.4
Female	15	13.6
Total	**110**	**100**

Results from the sample revealed that 86.4% respondents were male while 13.6% were female that participated in the study. BWB has 462 male employees and 58 female employees representing 89% and 11% respectively (Zizwe, 2016). The sample also showed that personnel working in the sections and units responsible for NRW reduction were male dominant.

4.3.2 Distribution of Respondents by Job Level

Table 4.2 shows a numerical representation of the distribution of job levels at BWB for staff that is involved in NRW reduction activities.

Table 4.2: Job Level of Respondents

Job Level	Frequency	Percentage (%)
Management	3	2.8
Supervisory	22	20.8
Operational (field work)	55	51.9
Skilled labour	26	24.5
Total	**106**	**100**

Table 4.2 shows that the job level with the highest number of employees is operational with 51.9% followed by skilled labourers with 24.5%. Essentially the skilled labourers are part of the operational staff however they have a lower level of education in the range of primary and secondary education. This makes staff in operations to be 76.4%. This job level structure showed an agreement with many water utility organisations in the developing countries as they have pyramid arrangement in terms of numbers of staff from top to bottom (Ncube, 2011). The number of staff increases from top to bottom which conforms to other water utilities in the developing nations which are labour intensive.

4.3.2.1 Correlation of Job Level and Illegal Connections in the Distribution System

Partial correlation was used to explore the relationship between job level and the level of illegal connections in the distribution system. The results showed that there was a strong, negative, partial correlation between job level and level of illegal connections in the distribution system ($r = -0.493$, $p < 0.05$, $n = 105$). This means that as the job level of employees get better as it is associated with educational qualification of employees, the number of illegal connections in the distribution system decreases. Job level is related to remunerations, employees occupying better and higher positions are reciprocated with better salaries hence are less likely to be involved in installations of illegal connections unlike employees in lower job levels like skilled labourers who get less salaries (Raddon, 2015). Job level has a strong negative relationship with behaviours and attitudes of employees more especially for non-managers (Ng, 2009). This explains that as the job level gets better employees are likely to behave and conduct themselves prudently.

4.3.3 Distribution of Respondents by Years of Experience with BWB

Table 4.3 shows numerical representation of the number of years respondents have been working with BWB in the sections and units that work on non-revenue water reduction.

Table 4.3: Years of Work Experience

Years of Experience (Years)	Frequency	Percentage (%)
0 – 5	55	50
6 – 10	30	27.3
11 – 15	9	8.2
16 – 20	10	9.1
More than 20	6	5.5
Total	**100**	**100**

Table 4.3 shows that 50% of the sample had less than 5 years working experience with BWB followed by 27. 3% in the range of 6 to 10 years. This was found not be a healthy state as experience is key in fight against NRW, most performing water utilities have high retention rate of staff. Work experience opportunities can help water utilities become competitive by having staff with accumulated and appropriate knowledge and skills (Ncube, 2011).

Experienced staff are key to improving performance efficiency of organisations since employees have already built resilience in executing work processes. They are beneficial to organisations since not much time could be wasted in offering trainings to new employees (Israel, 2009).

4.3.4 Distribution of Respondents by Level of Education

Table 4.4 shows the numerical representation of education levels of the sample employees at BWB.

Table 4.4: Education Level of Respondents

Level of Education	Frequency	Percentage (%)
Primary Education	2	1.9
Secondary Education	19	17.6
College/Tertially Education	87	80.6
Total	**108**	**100**

From the table 4.4 above, the sample shows that 80.6% of the respondents has attained a college or tertiary education with 17.5% having attended a secondary education. From these results it was clear that the majority of the BWB employees in the sections and units that are responsible for NRW reduction are well educated.

Well educated and skilled workforce is essential for effective operation of the company business (Ng, 2009). Working environment has become dynamic with the dawning of technologies resulting in the replacement of traditional work methods by new types of jobs and new forms of working which require a different combination of skills. Educated employees have a very high potential of learning and adapting to new technologies (Park, 2006). BWB is implementing a number of projects in its efforts to reduce and control level of NRW. It is therefore required that BWB should have employees with proper levels of education for it to adapt to new technologies, for example the following projects are implemented by BWB; Standard Transfer Specification (STS) pre-paid metering, hydraulic modelling, on spot billing system and digitization of customer meters using QGIS.

4.4 EFFICIENCY OF FAULT MAINTENANCE

4.4.1 Understanding of Policy and Procedure Statements

Figure 4.1 below shows how the employees from the sample understood Policy and Procedures Statements. The PPS is the standardized document that explains all the requirements for maintenance of faults in the water distribution system. It covers guidelines from the time fault is reported, assigned to the technician and what action to be taken after repairs. The policy requires that all employee handling faults should execute their works in compliance with the PPS.

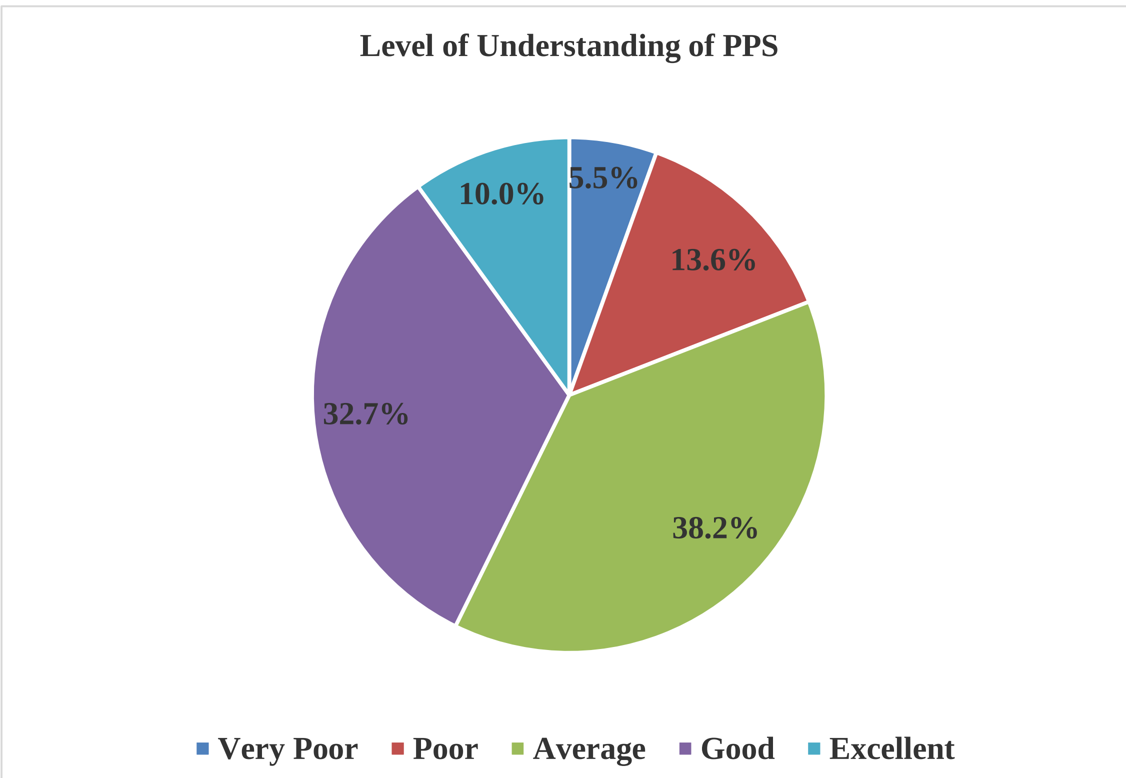

Figure 4.1: Level of Understanding of PPS

Figure 4.1 above indicates that 38.2% of the respondents have an average understanding of the PPS and 32.7% of the respondents had good understanding of the PPS. The mean score for rate of understanding of the PPS is 3.28 as generated from the SPSS v20, referring to Table 3.1 on the Likert Scale, the mean falls within the range of 2.60 to 3.39, this means that the majority of the employees do not understand the PPS that BWB uses to reduce NRW.

To achieve an organizational objective, it is important that employees understand the strategic direction of the company which serve as a platform to nurture the desired behaviors in an organisation. Lack of understanding of the PPS can be used to explain the trends of NRW as shown in Figure 4.1, poor understanding of PPS has a direct relationship with the level of NRW (Washali, 2011). A healthier level of understanding the PPS enable organisations to progress towards a better position that would be fully aligned with the company's vision and mission. Several management methodologies are based on defining specific objectives that are completely in line with the strategies of the organisation.

4.4.2 Compliance to PPS on Fault Maintenance

PPS are important in a workplace as it helps reinforce and clarify the standards expected of employees and help supervisors and managers manage their respective subordinates more effectively. PPS form part of the employment contract. Policies demonstrate that an organisation is being operated in an efficient manner and ensures that there is consistency in the decision making and operational procedures.

Figure 4.2 shows the level of compliance in terms of percentage of the respondents to PPS on fault maintenance at BWB.

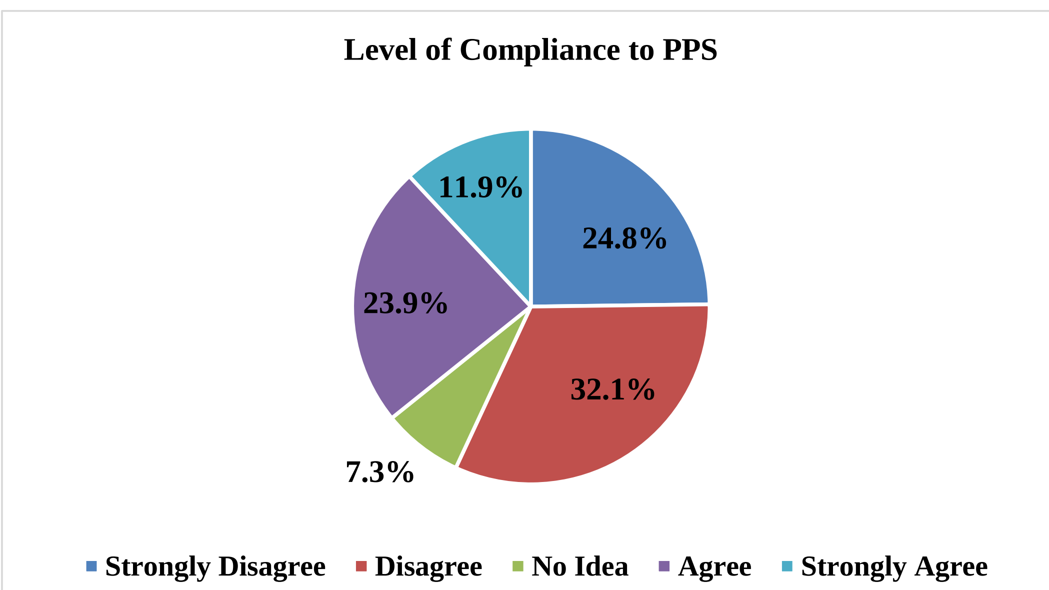

Figure 4.2: Level of Compliance to PPS

Respondents were asked how they rated their level of compliance to the PPS which are used regulate NRW reduction activities and he results from Figure 4.2 show that 64.2% of the respondents believe that there is no compliance in the way faults are being maintained. Only 35.8% of the respondents thought that the employees in the sections and units responsible for NRW reduction comply with PPS in rectifying faults in the distribution system.

The mean computed for compliance to PPS is 2.66 which falls between 2.6 to 3.39. This shows that on average the employees of BWB responsible for NRW reduction do not comply with PPS in carrying out fault maintenance works. Failure to achieve compliance to organizational policy and procedures can lead to underutilization of the water infrastructure, weakened operations and decline level of service to customers (Kingdon et al., 2006). High levels of NRW as described by Tynan and kingdom framework are indication of poor system management and poor commercial practices as well as an indicator of inadequate pipeline maintenance.

4.4.2.1 Correlation of Understanding of PPS and Compliance to PPS

Partial correlation (Appendix 3) was used to explore the relationship between understanding of PPS by employees who deal with NRW reduction activities and compliance to PPS on fault maintenance in the distribution system. The results showed that there was a strong, positive, partial correlation between understanding of PPS and compliance to PPS for the staff that are responsible for NRW reduction, ($r = 0.545$, $p < 0.05$, $n = 109$). This means that with the coefficient of determination (r^2) nearly 30%, level of compliance to PPS on fault maintenance is explained by understanding of PPS. Therefore, if employees understand the PPS that are used to reduce NRW they are likely to comply with the procedures required to maintain faults in the distribution system. Lack of proper understanding of the PPS is the major contributor to noncompliance of procedures in maintenance of faults. The meter validation exercise that BWB carried out showed that faults take time to be repaired in the distribution system and there was high frequency of repeat faults which was attributed as an indicator of poor workmanship. These factors contribute to an increase in the level of NRW for BWB.

4.4.3 Causes of Pipe Bursts

Figure 4.3 provides a graphical representation of the factors that contribute to pipe ruptures in the water distribution system. The percentages in the figure provides an indication of how staff responsible for NRW reduction rate the causes of pipe bursts.

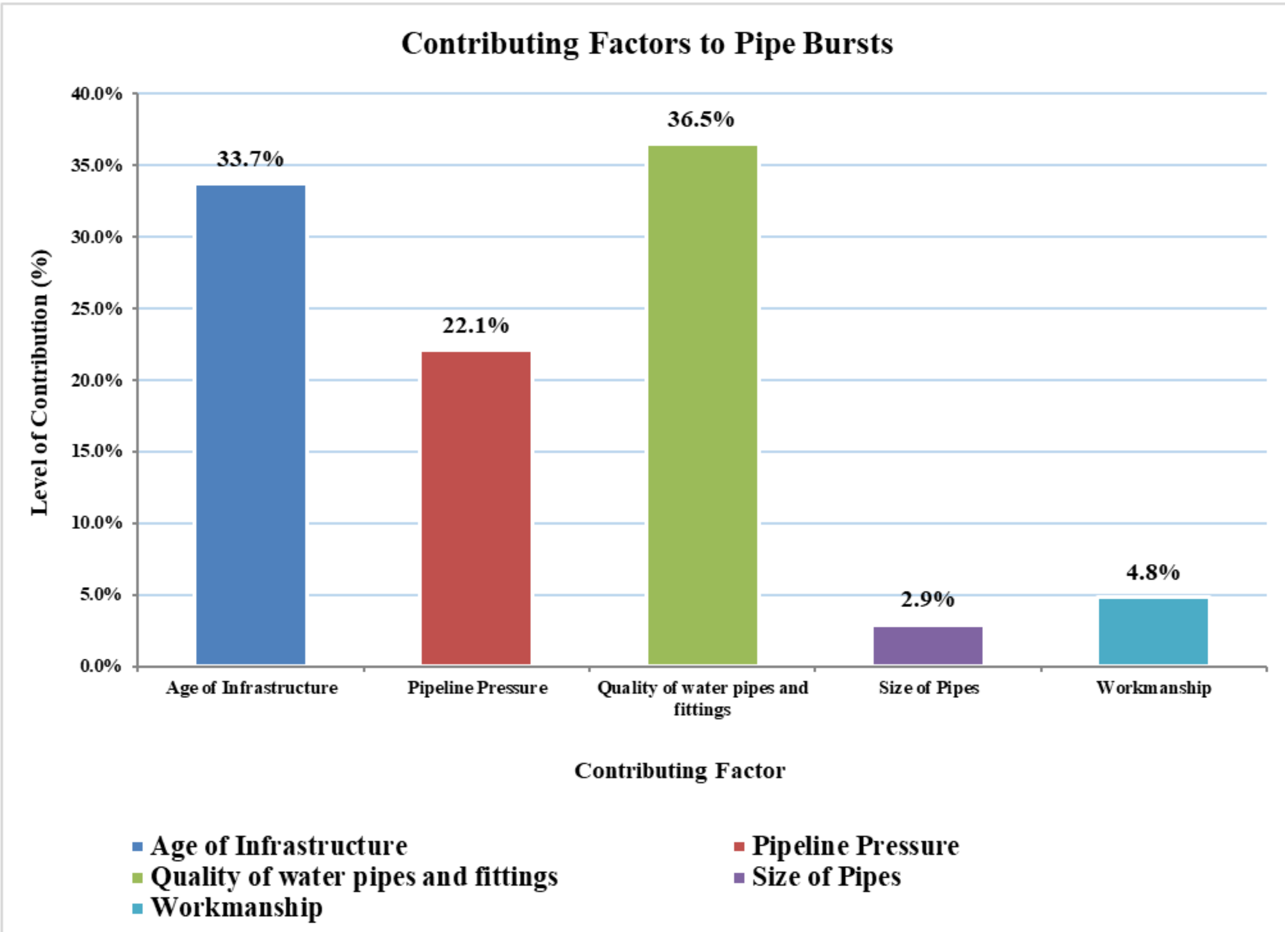

Figure 4.3: Factors Contributing to Pipe Bursts

The highest factor that contributes to pipe bursts is quality of water pipe materials with 36.5% followed by age of infrastructure 33.7% and pipeline pressure 22.1%. Water distribution lines break for a variety of reasons. In case of BWB, substandard pipe materials are the major cause of pipe breakages which leads to more physical water losses. The old infrastructure is another major contributor as some pipelines dates back to 1948 which means they have outlived the design life.

Results from Figure 4.3 shows the number of pipe bursts increase with the usage of substandard materials. The second factor is age of infrastructure; the number of faults increases with the materials age. As age of pipes and fittings increases, the strength and durability of these materials deteriorates due to various kinds of loading both internal and external (Scott & Janikas, 2010). Appendix 7(7A) shows leaking old transmission main which was commissioned in 1963.

Apart from substandard materials and fittings, aged pipes have greater contribution to pipe breakages as 81.6% were laid over 30 years ago. These pipe include ductile iron (DI), Asbestos Cement (AC) and Steel Pipe (SP). All these materials suffer from degradation over time due to operational processes, environmental conditions and general wear and tear result in increased leakage in the distribution system. It is therefore necessary to replace old pipes with an aim of reducing leakages. Appendix 7(7B) shows technician which maintaining a damaged pipeline.

It is believed that pipe burst frequency is proportional to pressure (Ncube, 2011). Kingdon et al, (2006), pointed out that considerable research has shown that burst frequency is very sensitive to maximum system pressure. Similarly, Lambert et al. (2000) concluded that there is unique relationship between maximum pressure and new leak frequency. Evidence also shows that excess pressures in distribution system is due to continuous supply result in higher pipe burst frequencies and higher repair costs.

Therefore, an effective leakage management strategy should take into account the pressure dynamics of a water distribution system. Pressure plays a pivotal role in enhancing the magnitude of water leakage as there is a physical relationship between leakage flow rate and pressure. The frequency of pipe bursts is a function of pressure in most distribution systems according to Ncube (2011). Appendix 7(7C) shows plumbers searching for a broken old pipe due to high pressure.

4.4.3.1 Pressure Logging

The results from the pressure loggers were used to come up with a relationship with the pipe breakages. Pipes and fittings in the distribution network of BWB are designed to operate at a pressure of 16 bars except those in transmission mains from Walkers Ferry to Chileka and from Chileka to Nyambadwe Tank, Ndirande Tank and South Lunzu Tank.

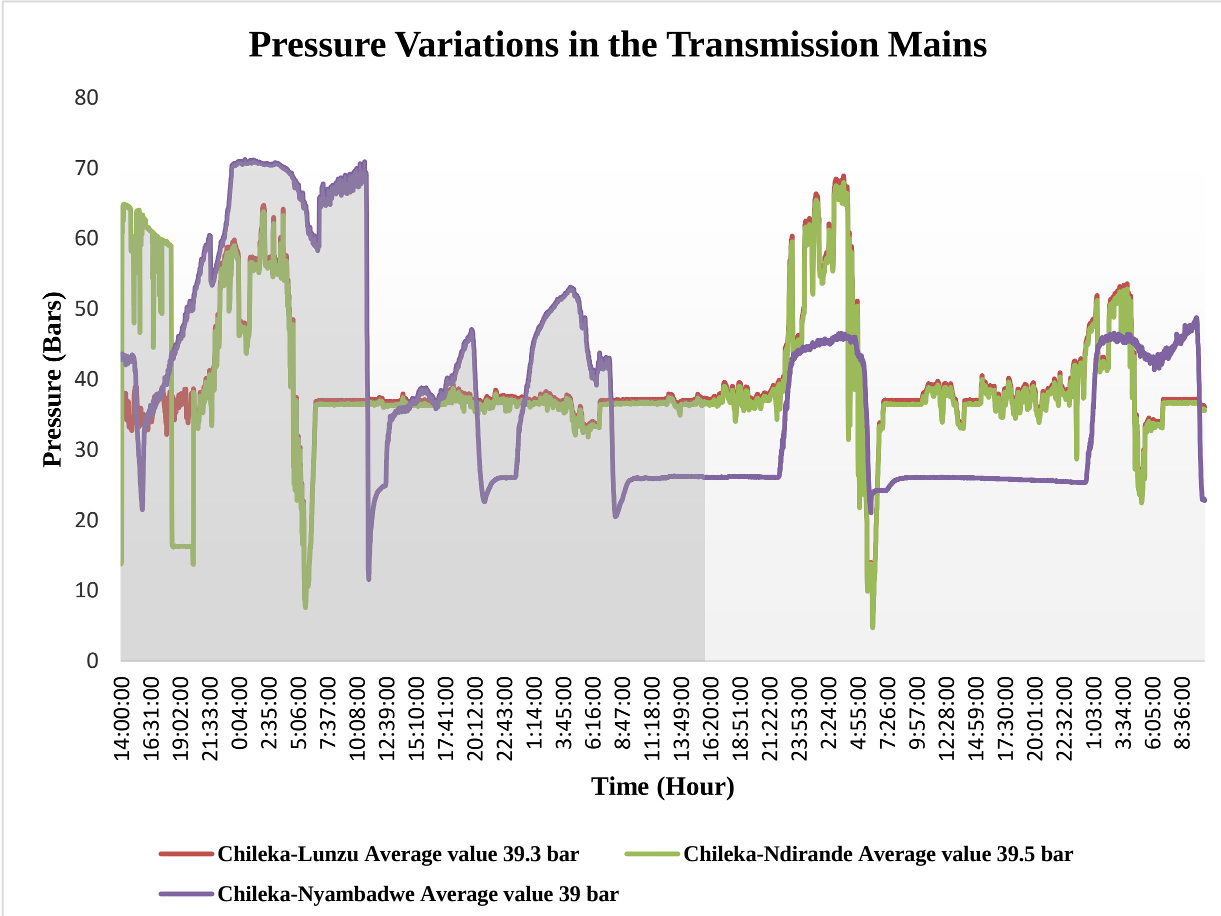

Figure 4.4: Distribution of Main Transmission Pressures

From the figure 4.4, the average pressure in the distribution system for pipelines to Lunzu, Ndirande and Nyambadwe are 39.3 bars, 39.5 bars and 39 bars respectively. Working pressure for most distribution lines is 16 bars and are tested at 1.5 of the working pressure (at 24 bars). This shows that the distribution system conveys water at a very high pressure and this explains the increase in number of burst pipes for BWB distribution network (Appendix 4).

The graph in figure 4.4 also shows that there are rapid changes in pressure with proportional change in water flows, these create pressure surges of excessive magnitude of up to 68.92 bars. These pressures superimposed on the normal static pressure present in the distribution lines and degrade the conditions of the pipes. High pressures are responsible for pipe rupture and separation at bends and joints which results highly in physical water losses, (Jung et al., 2007).

4.4.3.1.1 Main Transmission Pressure Simulation through EPANET

Appendix 5 shows a representation of pressures at various nodes. The nodes represent offtake points where customers are supplied from. From Epanet v2, time series pressure simulation, it shows that customers that are supplied direct from the pumping transmission mains get their supply at pressures greater than 31 bars. This is in agreement with results from field pressure measurement. In addition, average supply pressure fluctuates between 31.0 bars to 37.5 bars, high and fluctuation pressure events have negative effects on durability and strength of pipe lines. If water is supplied to customers, meter performance is affected as water meters for BWB are specified to perform at 16 bars. Failure rate of water meters and leakages increases with high pressure.

Reduction in pressure leads to reduced rate of escape through each leak and may also affect the number of leaks occurring. Pressure reduction is relatively cheap and can be quickly effected, however, lower pressure increases the leak population by making them less detectable. Pressure reduction can be achieved in a number of ways such as reducing pumping heads, installing break pressure tanks and using pressure reducing valves. The control of pressure surges and cycling reduces the numbers of bursts and leaks that occur, especially in plastic pipes. Pressure control then becomes a necessary tool for the technical management of the system. However, apart from pressure, various other factors may play a role and increase the effect of the expanding leak opening. Many leaks are not circular in shape, but in the form of cracks which might expand significantly more due to increases in pressure, (Bwire et al., 2015).

4.4.3.1.2 Distribution Mains Pressure Simulation through Pressure Data Loggers

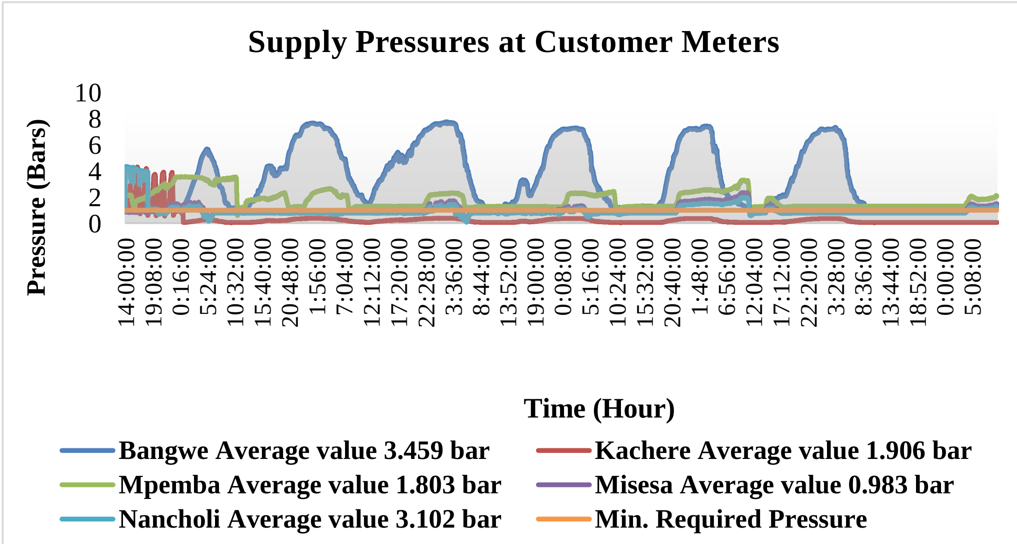

Figure 4.5: Supply Pressure at Customer Meters in the Distribution Network

The graph in figure 4.5 shows water supply pressure at customer meters. The measured areas in this category receive supply from water tanks through gravity. The required minimum pressure at the customer meter is 1 bar (10m) and results show that BWB distribution network is capable of delivering water at acceptable pressure in compliant with the IWA standards (IWA 2003). However, some areas like Bangwe receive water with very high pressure especially at night (between 0:00 to 03:00am). Pressure is normally higher at night when very little water is being taken from the network and most people's taps are turned off at night and figure 4.5 explains pressure variations behaviour of water at customer premises. Appendix 6 shows time series pressure at a node (customer tapping point) within the distribution network.

Pressure standards assist in the design of water distribution systems and the assessment of their performance. Although exact thresholds are sometimes rather vague, unusually high and low pressures are widely understood to increase costs and put systems at risk from events like pipe bursts at the high-pressure end to the risk of contaminant intrusion or poor firefighting conditions at the low-pressure end (Shamsaei et al., 2013).

4.5 RESOURCE INVESTMENT IN NRW REDUCTION ACTIVITIES

Reliable water infrastructure is fundamental for efficient and effective distribution of water to the Board's customers. Meeting investment needs require collaboration across public, private sectors and development partners. Washali et al. (2006) argues that by keeping water infrastructure in a state of good repair, the distribution system becomes reliable and has the confidence of the public. As the water infrastructure ages and capital needs escalate, water utilities need to uphold their commitment to the shareholder by fulfilling their visions and missions.

The level of Non-Revenue Water is an indication of utilities operating efficiency, (AWWA, 2017). There are several gains that BWB can get with better resources investment, for example if materials that meet required design specifications are used in the distribution network then the volume of physical water losses would decrease and in turn reduce the level of NRW, (Mugabi et al., 2007). This section discussed durability and strength of materials, education of employees and the financial investment towards reduction of NRW. The materials that are commonly used in the distribution network of BWB are: Asbestos Cement, Cast Iron, Cast Steel, Galvanized Iron, Polyvinyl Chloride and High Density Polyethylene. Good quality of materials refers to the ability of the materials to meet design specifications.

4.5.1 Durability and Strength of Materials

Figure 4.6 shows how respondents rate their satisfaction on durability and strength of materials. The purpose of capturing this variable was to assess the employee level of satisfaction on the materials that are used in distribution works in terms of ease of use, durability and strength.

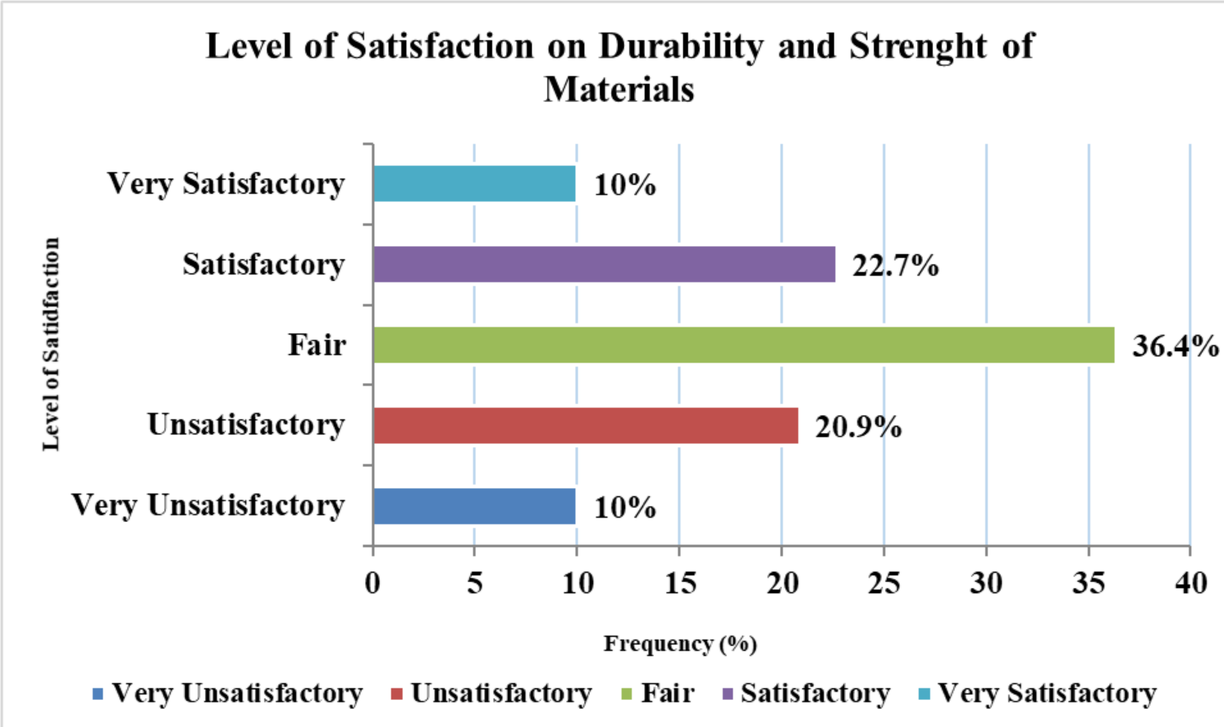

Figure 4.6: Level of Satisfaction on Durability and Strength of Materials

Figure 4.6 shows that 80% (36.4%+22.7%+20.9%) of the respondents believed that pipe materials are not durable and strong enough to effectively prevent breakages which increases the level of NRW. Only 20% of the respondents supported that materials that are used for pipe work in the distribution system are durable and strong. The mean on the level of satisfaction of durability and strength of materials was found to be 3.02 and fell within 2.60 to 3.39. Rating on five-point Likert Scale showed that many respondents are not satisfied with the materials that are used for maintenance in the distribution network for repairs and are of substandard.

Durability and strength of pipe materials has a great effect on capacity reliability which is the material's carrying capacity of water that meets the demand flow (Schneiter, Haimes, Li, & Lambert, 1996). Materials used for maintenance and rehabilitation in the distribution system are required to be durable and strong if they are to withstand water pressure in the distribution system. Substandard materials tend to increase the frequency of burst pipes thus increasing physical water losses.

4.5.3 Financial Investment towards Maintenance of Distribution Network

Figure 4.7 illustrates the financial investment and the level of NRW. Every financial year BWB makes a budget for its operations and administration. Large portion for the budget goes to operation which mainly includes activities for NRW reduction. However, it can be noted that BWB has not been able to allocate adequate financial resources to meet the allocated budget between 2013/14 to 2015/16 unlike the period between 2010/11 to 2012/13.

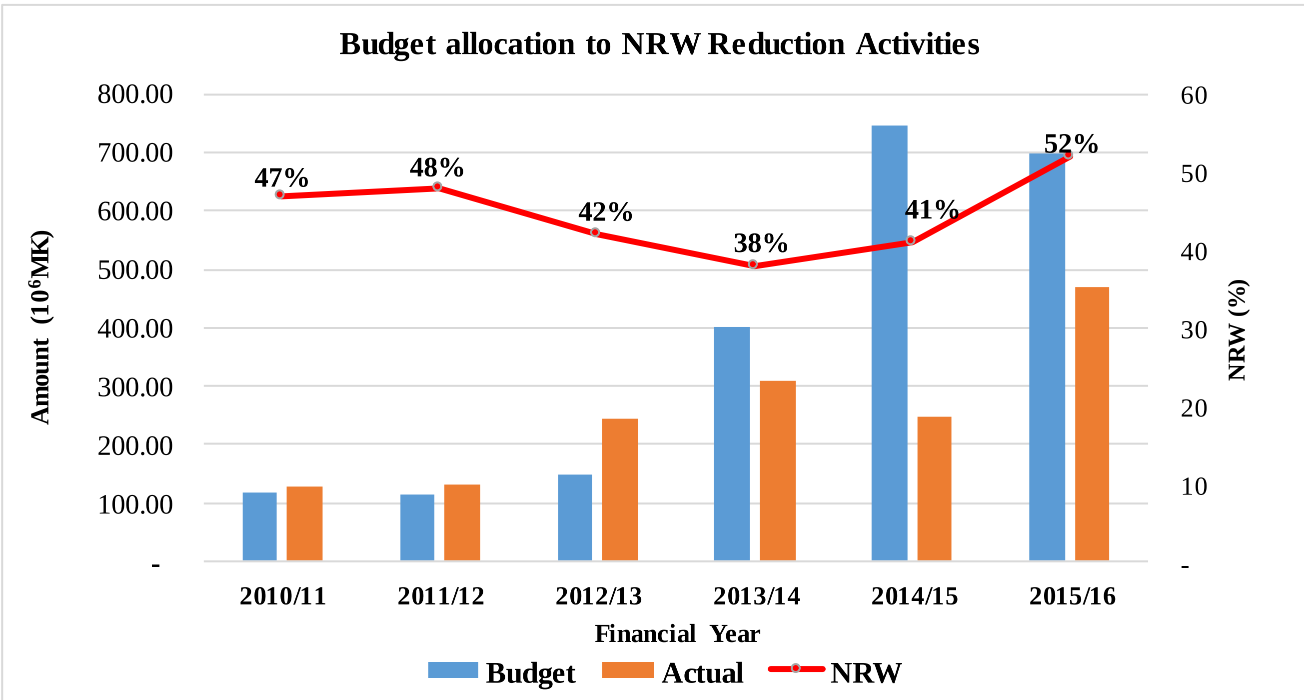

Figure 4.7: Budget allocation to NRW Reduction activities

Figure 4.7 demonstrates that when there is gradual increase in financial investment towards maintenance of the distribution system, the trend of NRW goes down. The graph shows that between 2010/11 and 2013/14 financial years, NRW had decreased from 47% to 38% with an increase in financial investment from 100 Million Kwacha to 400 Million Kwacha. This means that if BWB improves the financial allocation toward pipe replacements and quality of repair materials, the level of NRW would go down as shown by the trend in the graph.

4.6 EXTENT OF ILLEGAL CONNECTIONS

One of the challenges facing water utilities in the developing world is the level of water losses; from physical losses, illegal connections (theft) of water from the distribution system, and improper billing of customers (ADM, 2010). Illegal water connections refer to unauthorised tapping of water which happens when the water that has been used cannot be accounted for. This component is referred to as unbilled unmetered unauthorised consumption (Simbeye, 2010).

4.6.1 Level of Illegal Connections

Figure 4.8 provides a graphical representation of the opinions of respondents regarding the extent of illegal connections within the distribution network of BWB.

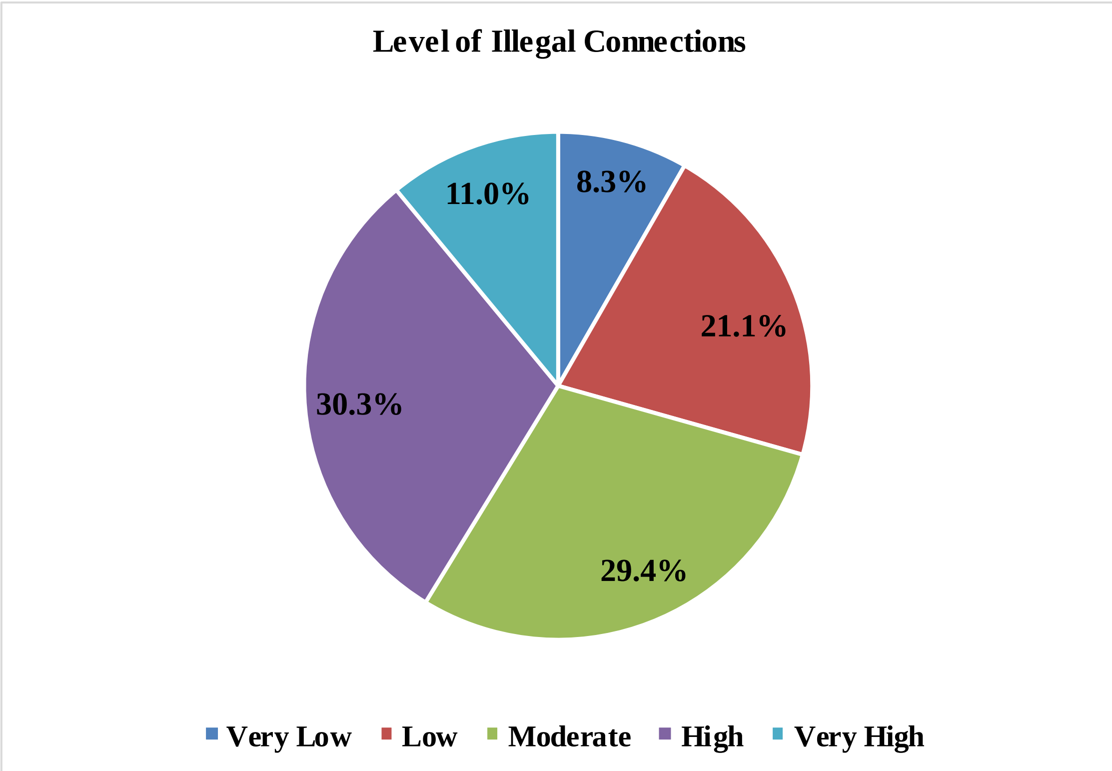

Figure 4.8: Level of Illegal Connections in the Distribution System

Figure 4.8 indicates that 58.8% (29.4%+21.1%+8.3%) of the respondents believed that there is low level of illegal connections while 41.2% believed that the distribution system has high levels of illegal connections. The mean on the level of illegal connections was found to be 3.15 and fell within the range of 2.6 – 3.39, this shows that many employees are not aware of the extent of illegal connections. BWB uprooted 213 illegal water connections in a period of three months (October 106 to December 2017) according to Meter Validation Report 2016. Appendix 7(7D) shows a technician uprooting an illegal water connection in Ndirande Township which was done by bypassing a water meter.

4.6.2 Reasons for Illegal Connections

Figure 4.9 shows a graphical representation of the reasons that make customers get involved in illegal connections in the distribution network of BWB.

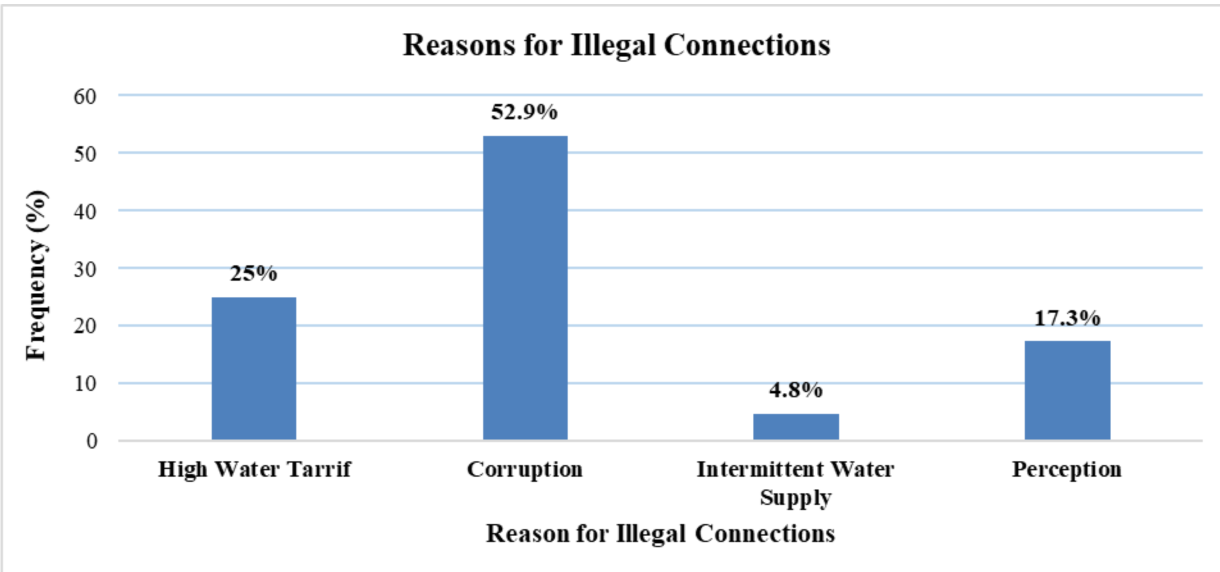

Figure 4.9: Reasons for Illegal Connections

Figure 4.9 shows that the major reason for illegal connections is corruption (52.9%) followed by high water tariff (25.0%). Corruption is a form of dishonest or unethical conduct by a person entrusted with a position of authority, often done to acquire personal benefit. The campaign carried out by BWB in 2016 which was aimed at uprooting of illegal connections has revealed that many cases of illegal water connections involve technical members of staff, (BWB Meter Validation Report, 2016). Tariff plays apart in the prevalence of illegal connections, since over 60% of the water connections are in the low income areas, most customers tend to use water illegally when they have been disconnected due to nonpayment.

Figure 4.10 shows a meter at a commercial consumer, Mapeto David White Head and Sons using a strong magnet to stop the mechanical recorder of the meter from registering water consumption. When this was found, registered water consumption had dropped from 45,000 cubic meters to 5,400 cubic meters in one month. This was charged as an illegal usage of water and one of the manager at Mapeto said that BWB tariff was high and that was the reason they used a magnet to slow down the meter in order to reduce water consumption.

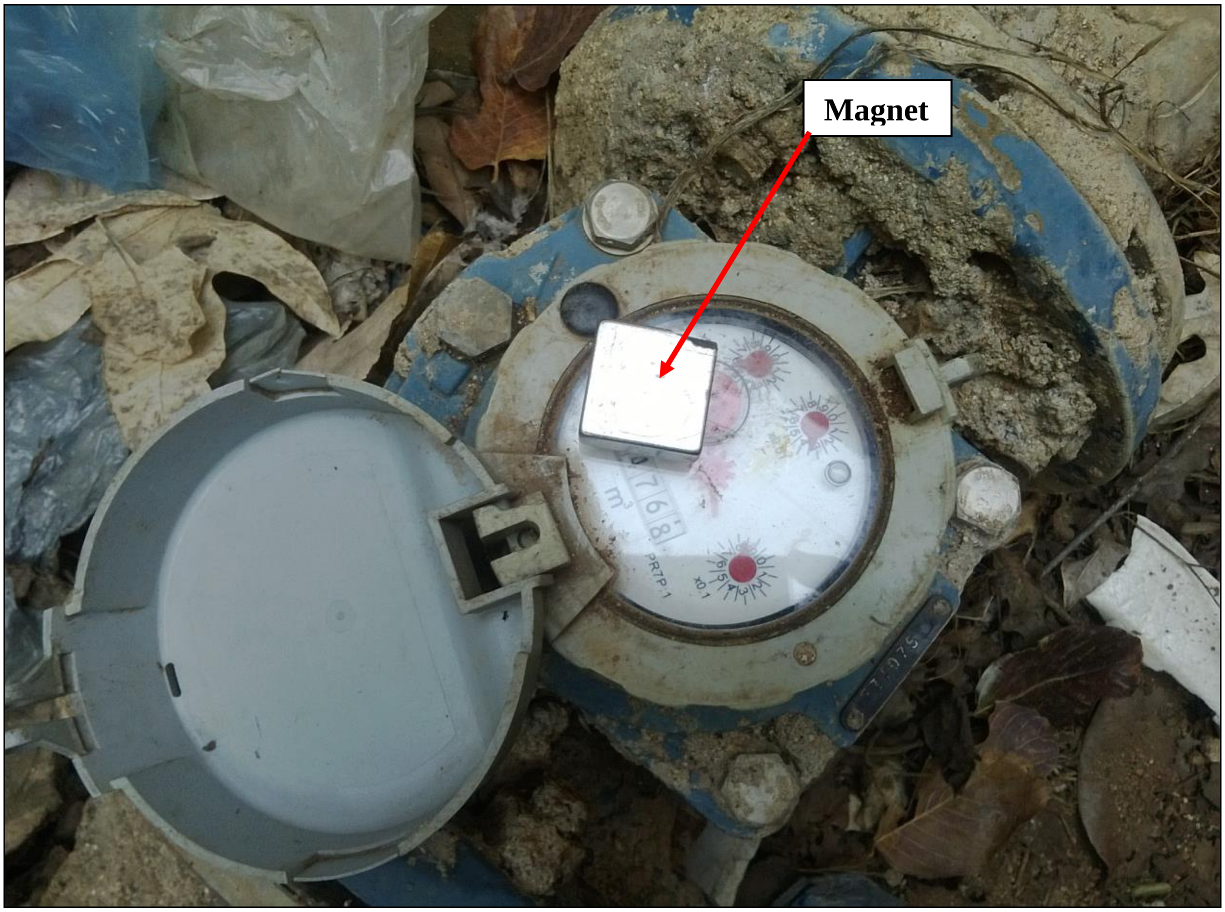

Figure 4.10: A Strong Magnet used to stop Meter from recording at Mapeto in Makata

4.6.3 Distribution of Illegal Connections by Type of Location

Table 4.5 compares the level of illegal connections in the planned and unplanned areas. It shows the frequency and percentage of the distribution of illegal connections in the distribution network of BWB.

Table 4.5: Distribution of Illegal Connections per Area Category

Area	Frequency	Percentage (%)
Planned Area	55	50.5
Unplanned Area	54	49.5
Total	109	100

Table 4.5 shows that 50.5% of illegal connections are in the planned areas while 49.5% of illegal connections are found in the unplanned areas of the distribution network. Reduction of illegal water consumption reduces NRW and makes more water available for legal consumption thus increase revenue. The study expected to find more illegal connections in low income areas however, the result was different and this could be lack of punitive penalties that are not restrictive and bad moral uprightness. The results provided in Table 4.5 entails that BWB should give almost equal attention to both areas in planning door to door campaign in uprooting illegal connections.

4.6.4 Distribution of Illegal Connections per Customer Categories

Figure 4.11 shows a graphical representation of illegal connections per customer category in the distribution network.

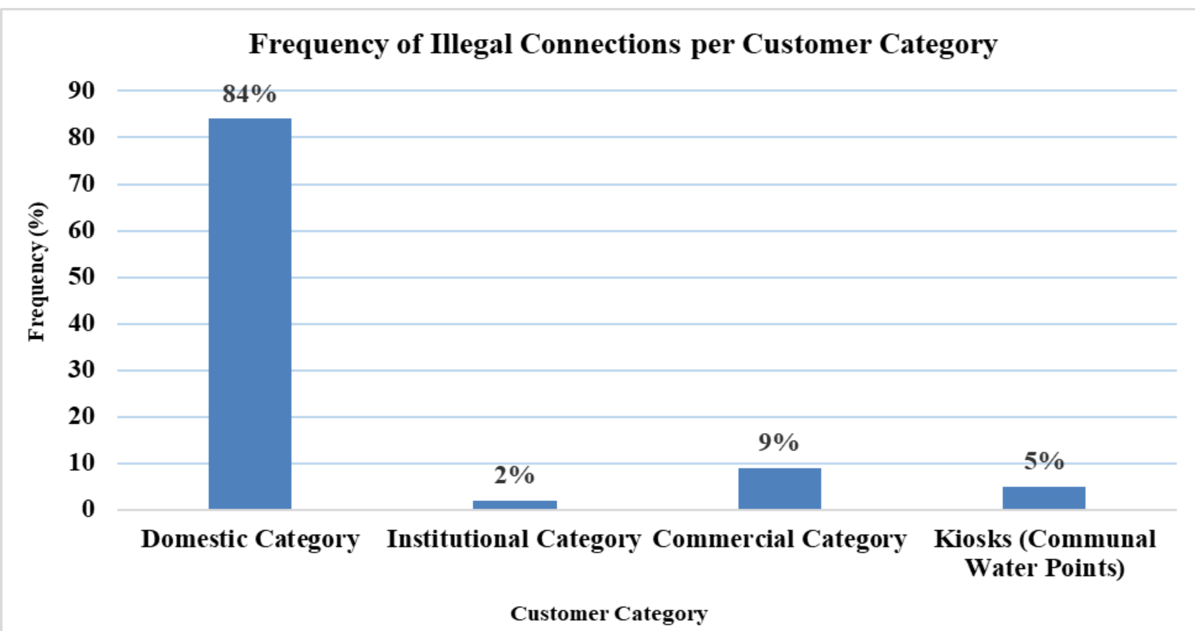

Figure 4.11: Distribution of Illegal Connections as per Customer Category

Figure 4.11 shows that the distribution of illegal connections per customer category as follows; domestic category (83.7%), commercial (8.7%), kiosks or communal water points (5.4%) and institutional contributes 2.2%. The presentation of results shows that there are many illegal connections within the domestic category. This finding is an agreement with the BWB Meter Validation Report 2017 in which 82% of the 219 illegal connections were found in the domestic category in the period of seven months, (BWB Meter Validation Report, 2017).

4.7 STATUS OF THE WATER DISTRIBUTION NETWORK

4.7.1 Level of Knowledge of NRW

Figure 4.12 shows a graphical representation of the respondents' knowledge of NRW in the distribution system of BWB.

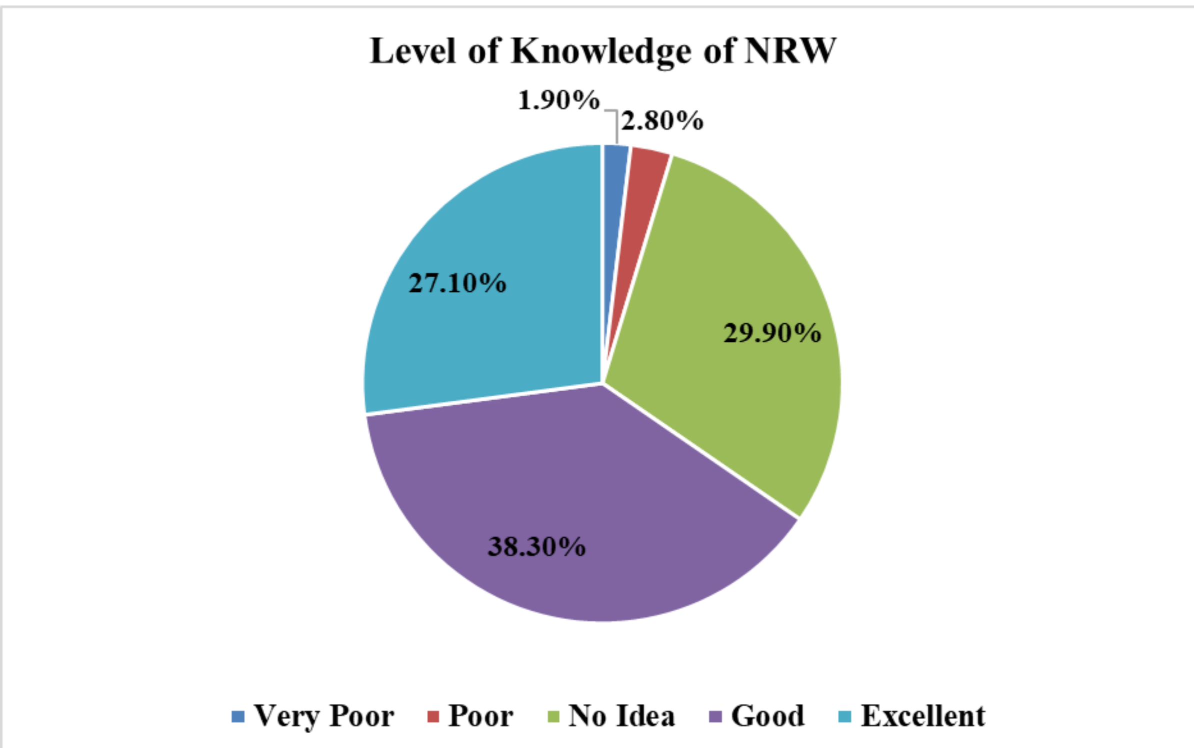

Figure 4.12: Level of Knowledge of NRW

Figure 4.12 shows that 38.3% rated good, 29.9% rated no idea and 27.1% rated excellent. The mean rate for these scores was found to be 3.86 which fall between 3.4 and 4.19 on the Likert Scale. The level of knowledge referred to the degree of awareness of the respondents about NRW reduction strategies. This means that the majority of the members of staff are aware of

NRW reduction strategies that the Board uses to fight water losses for both apparent and real losses.

4.7.2 Level of NRW

Figure 4.13 show a graphical representation of how respondents rate NRW within the distribution network.

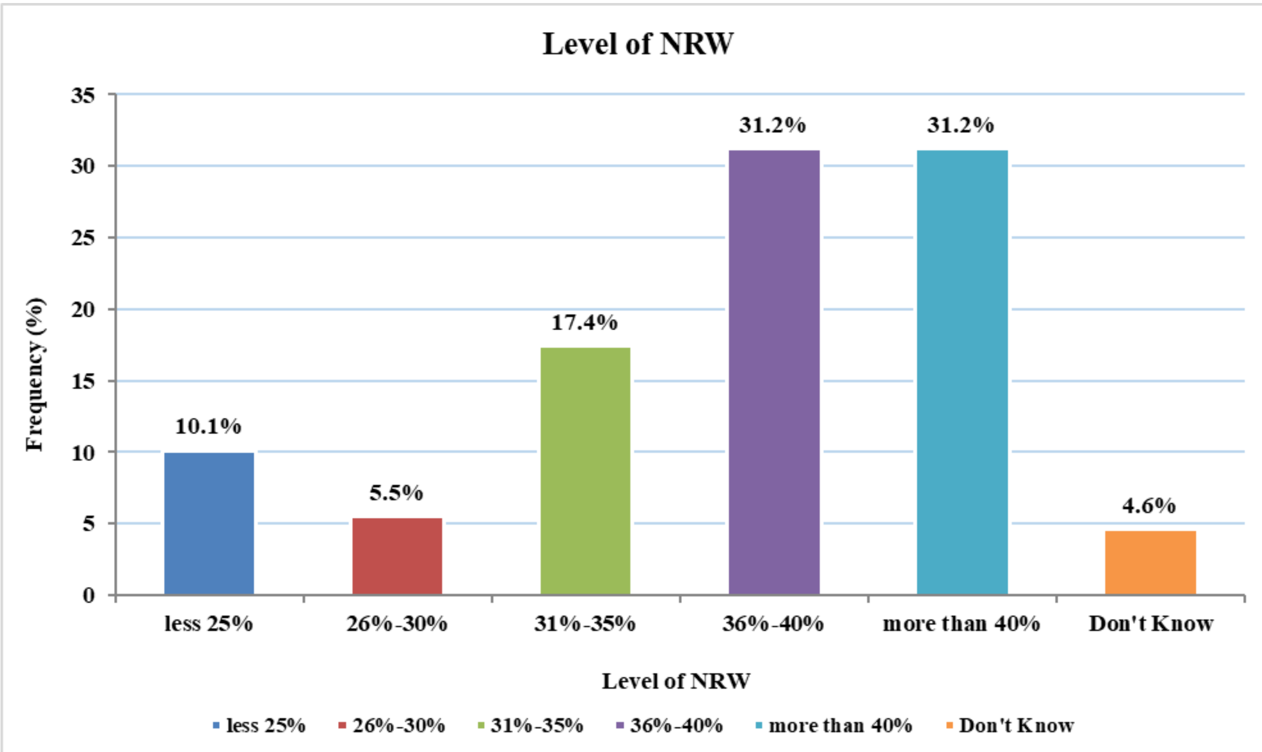

Figure 4.13: Level of NRW in the Distribution System

Figure 4.13 shows that 31.2% believe that level of NRW is in the range between 36% to 40% and another 31.2% believe NRW is more than 40%. The mean response for this rating is 3.82 which falls within 3.40 to 4.19 on the Likert Scale. This mean indicates that respondents believe that the level of NRW is within 36% to 40%. NRW for Blantyre Water Board is as high as 52%, (BWB Performance Progress Report, 2016). Having a large proportion of NRW in the distribution system makes water utilities challenged in meeting consumer demands. Since this water yields no revenue, heavy losses also make it harder to keep water tariffs at a reasonable and affordable level. In many low income countries, the level of NRW is represented by 50%-60% of water supplied to the distribution system with a global average estimated at 35% (Usher, 2010).

Conversely, successful water utilities address NRW by reducing physical and commercial losses. Taking these measures boost revenue by increasing the amount of water that can be billed while reducing wastage of the product. This increases profitability and improves the return on investment. With larger profits, the water utility can then reinvest retained earnings and improve its productivity, (Mugabi et al., 2007).

4.7.3 Causes of NRW in the Distribution Network

Figure 4.14 presents a graphical scenario of the factors that contribute to NRW in the water distribution network of BWB.

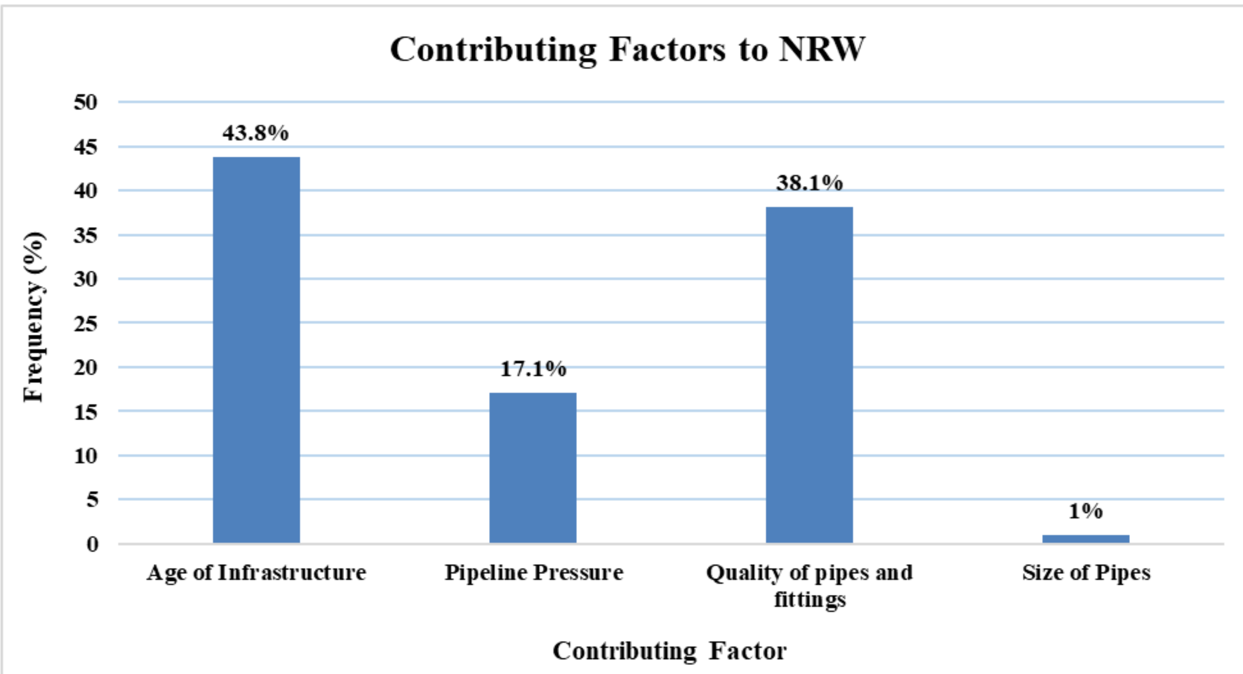

Figure 4.14: Factors Contributing to NRW

Age of the infrastructure (43.8%) was rated as the highest contributing factor to NRW seconded by the quality of pipe and fittings (38.1%) with pipeline pressure at 17.1%. BWB has most of the pipelines dated as back as 1960 and most of the main pipelines have outlived their design life (BWB Performance Progress Report, 2016). Carrying capacity of pipeline is strength dependent as such old pipelines are prone to bursting due to internal water pressure and external loading. To reduce frequencies of burst pipes BWB needs to replace most pipelines that have outlived the design life span and replace those that have high frequency of breakages due to substandard materials.

4.7.4 Status of Pipes in the Distribution Network

Table 4.6: Details of Pipeline Materials and Length

Pipe Materials	Length (m)	Percentage (%)
Asbestos Cement (AC)	558,880	47.47
Cast Iron (CI)	4,203	0.36
Cast Steel (CS)	98	0.01
Galvanized Iron (GI)	204,225	17.35
Polyvinyl Chloride (PVC)	232,935	19.78
Steel Pipe (SP)	275	0.02
High Density Polyethylene (HDPE)	176,723	15.01
Total	**1,177,339**	**100.00**

Source: BWB QGIS 2017

From the Table 4.6, it shows that the large part of the distribution network comprises of the Asbestos Cement pipes making up 47.5% of the supply system followed by Polyvinyl Chloride (19.78%), Galvanized Pipes (17.35%) and HDPE (15.01%). The life expectancy for AC pipe is 50 years and 96% of the BWB AC pipes were installed 52 years ago. This means that the frequency of pipe bursts is likely to increase since the pressure holding capacity has deteriorated over the period. AC pipes have proved to be a threat to human life as studies have shown that these pipes contribute to cancer. Asbestos fibres pose a risk to health if airborne, as inhalation is the main way that asbestos enters the body, (DAI, 2010).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter provides conclusions and recommendations of the findings of the assessment of the effectiveness of the strategies that Blantyre Water Board uses to reduce Non-Revenue Water in the distribution system. From the objectives and results of this research, the following conclusions and recommendations were deduced:

5.2 Conclusions

5.2.1 Efficiency of Fault Maintenance

I. It was revealed that many employees do not understand the Policy and Procedures that are required to guide them in repairing faults. This shows that lack of understanding and noncompliance to fault maintenance procedures results in high NRW as more faults are poorly done or left unattended to by the operational staff. The study established a direct relationship between understanding of PPS and level of compliance to PPS, the more employees understand the fault maintenance procedures the better they comply with the PPS.

II. The study established that pipe bursts are influenced by the usage of substandard materials, age of infrastructure which has outlived its design life of 20 years and high pressures which are beyond the design conveyance capacity in the distribution system.

III. The large part of the water distribution system in Kabula Zone (Chileka, Walker's Ferry, Kameza and Chirimba) experiences pressures of around 39 bars as they are supplied direct from the pumping mains. It was also established that these pressure variations in the distribution system results in creation of pressure surges of excessive magnitude of up to 69 bars. These high pressures lead to high frequency of pipe bursts.

5.2.2 Level of Resource Investment toward NRW Reduction

I. The study established that materials that are used in the maintenance of the pipe network are not durable. Pipes and fittings do not meet design specifications in terms of strength and workability as the staff expressed challenge utilizing them.

II. BWB is not allocating adequate financial resources to implement NRW reduction activities. Results from the study showed that with the increase in financial investment NRW decreases.

5.2.3 Extent of Illegal Connection

I. Analysis of the results showed that employees are not aware of the extent of illegal connections but are in agreement of the existence of illegal connections in the distribution system.

II. Illegal connections in the distribution system, are a result of corruption amongst employees and customers and a perceived high tariff.

III. Both areas (planned and unplanned) have high frequency of illegal connections however domestic customers have higher rate of illegal connections.

IV. Illegal connections are more prevalent within domestic customer category

5.2.4 Status of Distribution Network Infrastructure

I. The research established that employees at BWB have the knowledge of NRW in terms of the activities that are necessary to reduce water losses.

II. The NRW is high at 52% compared to 23% recommended by Tynan and Kingdom framework.

III. NRW in the distribution network of BWB is caused by old age of infrastructure, poor quality of pipes and fittings and high pipeline pressures.

IV. Large proportions of pipe are Asbestos Cement (52%), Polyvinyl Chloride (20%), Galvanized Iron (17%) and the rest is shared amongst Cast Iron, Cast Steel, Steel pipe and High Density polyethylene

5.3 Recommendations

From the findings and conclusions, the study recommends the following:

5.3.1 Efficiency of Fault Maintenance

I. The study recommends that staff should be given adequate training for them to understand the PPS and apply them when doing work. This will help staff understand the procedures of fault maintenance and provide required speed to faults maintenance and other queries that are related to NRW reduction activities as stipulated in the BWB Policy and Procedure Statements.

II. BWB should ensure that all materials used in the distribution network are sampled and tested to ensure compliance to the specifications. Compliance to specifications of materials would ensure durability and material strength.

III. BWB should ensure that all customers are fed from the tanks and not pumping mains which convey water at very high pressures. In cases where it is not possible to supply from the tanks pressure reducing valves should be installed to regulate water pressures.

5.3.2 Level of Resource Investment toward NRW Reduction

I. BWB should ensure that pipes and fittings that are used for maintenance are tested to ensure that they comply with design specifications. If the Board does not have the capacity Malawi Bureau of Standards can be engaged as an authority responsible for testing compliance of various materials in Malawi.

II. The Board should allocate adequate resources if efforts to reduce NRW from 52% is to be achieved. BWB should come up with a deliberate program that can ensure that old pipes are replaced in the distribution system

5.3.3 Extent of Illegal Connection

I. BWB should ensure that the employees are sensitized about dangers of corruption in line with the effect it has on NRW. Meter Validation exercise should be done annually and those discovered with illegal water usage should be given tough penalties to limit other customers from doing the same.

II. The Board should give equal attention to both planned and unplanned areas in carrying out door to door search of illegal connections.

III. BWB should develop a periodic campaign to fight against illegal connections with enough attention given to domestic customers.

5.3.4 Status of Distribution Network Infrastructure

I. BWB should maintain and employ competent and educated staff with periodic trainings to improve their performance and level of knowledge of NRW reduction activities.

II. BWB should ensure that it improves its compliance to NRW reduction strategies so that NRW is reduced to the proposed standard in the framework of Tynan and Kingdom which is 23% for developing nations.

III. The Board should ensure that old pipe lines are replaced with new pipe and this will improve network resilience and reliability in conveying water through pipes.

IV. BWB should ensure that Asbestos Cement Pipes are first to be replaced as they have been found to be a threat to health. The Asbestos Cement pipes have also outlived the deign life thus making them unable be bear pressure in the distribution network.

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Appendices:

Appendix 1 Tynan and Kingdom Framework, Variables and Sources of data

SOURCE	INDICATOR	VARIABLES	BENCHMARK	SOURCE OF DATA
Tynan and Kingdom Framework	Operational Efficiency	Number of staff Number of connections Population served	5staff per 1000 connection 2.1 staff per 1000 staff served	EDAMS (billing software) Reports
	Cost Recovery	Working Ratio	0.68	Finance Reports
	Commercial Performance	Debtors days	Less or equal to 30 days	Field test and Hydraulic Modeling
	Coverage and Access	Percentage of access	100%	FMS
	Asset Maintenance	Volume Input Billed Consumption (NRW)	Less than 23%	EDAMS QGIS Hydraulic Model
		Meter class		Meter Validation Reports
	Service Quality	Water availability duration	24 hours	Reports
	Price and Affordability	20 litres per day as a percentage of per capita GDP	0.2%	Finance Reports

Appendix 2 Questionnaire

Questionnaire No:……..

RESEARCH QUESTIONNAIRE FOR BLANTYRE WATER BOARD EMPLOYEES

Dear Participant,

*I am a student at the Polytechnic College of the University of Malawi pursuing a Master of Science Degree in Water Resources and Supply Management. I am conducting a research titled "**Assessment of the Effectiveness of Strategies used by Blantyre Water Board to reduce Non-Revenue Water**". The essence of this questionnaire is therefore to gather data that will help the researcher analyse the effectiveness of the strategies. Please note that data gathered through this questionnaire will be confidential and strictly used for academic purposes only.*

Yours Sincerely,

Bright Mziliwanda
Student.
Feedback: brightmziliwanda@gmail.com; +265 999 140 054

(Please tick only one response in the appropriate box)

Q1: Please indicate your gender.

Male	
Female	

Q2: Which of the following levels does your job belong to?

Management	
Supervisory	
Operational	
Labourer	

Q3: How many years have you been working with Blantyre Water Board?

0-5	6-10	11-15	16-20	21 or more

Q4: What is the highest level of your education?

Primary Education	
Secondary Education	
College or Tertiary Education	

Q5: How do you rate your understanding of Non-Revenue Water (NRW)?

Very Poor	Poor	Average	Good	Excellent

Q6: How much do you think is lost in Non-Revenue Water in terms of percentage in the distribution network of BWB?

20%-25%	26%-30%	31%-35&	36%-40%	More than 40%	I do not know

Q7: Which of the following factors has a greater contribution to NRW in the distribution network of BWB?

Factor	[redacted]
Age of infrastructure	
Pipeline pressure	
Quality of water pipes and fittings	
Size of pipes	

Q8. What is the level of your satisfaction in terms of durability and strength of the pipes and fittings BWB uses in its distribution network?

Very Unsatisfactory	Unsatisfactory	Fair	Satisfactory	Very Satisfactory

Q9: How do you rate the frequency of pipe bursts in the distribution network of BWB?

Very Low	Low	Moderate	High	Very High

Q10: Which of the following factors has a greater contribution to pipe burst?

Factors	
Age of infrastructure	
Pipeline pressure	
Quality of water pipes and fittings	
Size of pipes	
Workmanship	

Q11: How would you rate your understanding of the Policy and Procedure Statements (PPS) on maintenance practices of the distribution network of BWB?

Very Poor	Poor	Average	Good	Excellent

Q12: BWB Policy and Procedure Statements (PPS) recommends that Burst Pipes are repaired within ***four*** hours and Pipe Leaks are repaired within ***two*** days of reporting at most. Do you agree that burst pipes and pipe leaks are repaired according to BWB Policy and Procedures Statements?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Q13: How do you rate the level of illegal connections in the distribution network at BWB?

Very Low	Low	Moderate	High	Very High

Q14: What do you think is the major reason for illegal connections in the distribution network of BWB?

Reason	
High Water Tariffs	
Corruption	
Intermittent Water Supply	
Perception	

Q15: The distribution network is divided into two categories; Planned and Unplanned areas. Urban areas are regarded as planned while the rural areas are regarded as unplanned, which of the two location do you think has a higher frequency of illegal connections?

Location	
Planned Areas	
Unplanned Areas	

Q16. BWB has four customer categories; Domestic, Institutional, Commercial and Kiosks. Which of the following do you think has a high frequency of illegal connections?

Reason	
Domestic Category	
Institutional Category	

Commercial Category	
Kiosks (Communal Water Points)	

<u>Thank you so much for taking your precious time to answer this questionnaire</u>

Appendix 3 Correlation Table of Variables

		Gender	Job_level	Experience	Education_Level	Understanding_of_NRW	Rate_of_NRW	Contributing_Factors_to_NRW	Durability_and_Strength_of_Materials	Frequency_of_Pipe_Bursts	Contributing_Factors_to_Pipe_Bursts	How_BWB_Staff_Understand_the_PPS	Compliance_to_PPS_on_Fault_Maintenance	Level_of_Illegal_Connections	Reasons_for_Illegal_Connections	Areas_with_High_Frequency_of_Illegal_Connections	mer_Category_with_High_Frequency_of_Illegal_Connections
Gender	Pearson Correlation	1	-.144	-.175	.130	.003	-.085	.016	-.126	-.086	-.087	-.112	.021	.043	-.086	.030	-.155
	Sig. (2-tailed)		.142	.067	.180	.975	.379	.870	.191	.372	.382	.245	.828	.660	.383	.754	.141
	N	110	106	110	108	107	109	105	110	110	104	110	109	109	104	109	92
Job_level	Pearson Correlation	-.144	1	-.077	.368**	.340**	-.145	.228*	-.021	-.041	.073	-.005	-.024	-.493**	-.230*	-.279**	.000
	Sig. (2-tailed)	.142		.435	.000	.000	.141	.021	.827	.679	.471	.959	.805	.000	.021	.004	1.000
	N	106	106	106	104	103	105	102	106	106	100	106	105	105	100	105	89
Experience	Pearson Correlation	-.175	-.077	1	-.181	.048	.125	.127	-.081	.130	.212*	.010	.042	.166	-.014	-.016	-.007
	Sig. (2-tailed)	.067	.435		.060	.621	.195	.195	.400	.175	.031	.921	.663	.085	.889	.870	.948
	N	110	106	110	108	107	109	105	110	110	104	110	109	109	104	109	92
Education_Level	Pearson Correlation	.130	.368**	-.181	1	.136	-.150	-.151	-.370**	-.141	.143	-.141	-.222*	.131	.128	.066	-.174
	Sig. (2-tailed)	.180	.000	.060		.167	.124	.127	.000	.145	.150	.144	.022	.177	.198	.498	.100
	N	108	104	108	108	105	107	103	108	108	102	108	107	107	103	107	91
Understanding_of_NRW	Pearson Correlation	.003	.340**	.048	.136	1	-.024	-.063	-.047	.272**	-.104	.255**	.108	.276**	.098	.093	-.113
	Sig. (2-tailed)	.975	.000	.621	.167		.808	.526	.628	.005	.298	.008	.270	.004	.325	.344	.294
	N	107	103	107	105	107	107	102	107	107	102	107	106	106	102	106	89
Rate_of_NRW	Pearson Correlation	-.085	-.145	.125	-.150	-.024	1	-.116	-.052	.341**	-.057	-.019	-.075	.160	.128	.077	.082
	Sig. (2-tailed)	.379	.141	.195	.124	.808		.243	.592	.000	.566	.847	.438	.099	.197	.431	.439
	N	109	105	109	107	107	109	104	109	109	103	109	108	108	103	108	91
Contributing_Factors_to_N	Pearson Correlation	.016	.228*	.127	-.151	-.063	-.116	1	-.144	-.128	.463**	-.019	-.096	-.012	-.266**	.051	.000
	Sig. (2-tailed)	.870	.021	.195	.127	.526	.243		.142	.194	.000	.851	.333	.903	.007	.608	1.000
	N	105	102	105	103	102	104	105	105	105	102	105	104	104	102	104	89
Durability_and_Strength_of	Pearson Correlation	-.126	-.021	-.081	.370**	-.047	-.052	-.144	1	-.151	-.364**	.347**	.355**	-.113	-.142	-.025	-.093
	Sig. (2-tailed)	.191	.827	.400	.000	.628	.592	.142		.115	.000	.000	.000	.241	.150	.800	.379
	N	110	106	110	108	107	109	105	110	110	104	110	109	109	104	109	92
Frequency_of_Pipe_Burst	Pearson Correlation	-.086	-.041	.130	-.141	.272**	.341**	-.128	-.151	1	.035	.055	-.282**	.194*	.083	.007	.223*
	Sig. (2-tailed)	.372	.679	.175	.145	.005	.000	.194	.115		.728	.569	.003	.043	.405	.942	.033
	N	110	106	110	108	107	109	105	110	110	104	110	109	109	104	109	92

Cont ributi ng_	Pearson Correlation	-.087	.073	.212*	.143	-.104	-.057	.463**	-.364**	.035	1	-.058	-.306**	-.046	.041	-.078	.213*
Fact ors_	Sig. (2-tailed)	.382	.471	.031	.150	.298	.566	.000	.000	.728		.560	.002	.647	.682	.435	.046
to_P	N	104	100	104	102	102	103	102	104	104	104	104	103	103	101	103	88
How _BW B_St	Pearson Correlation	-.112	-.005	.010	-.141	.255**	-.019	-.019	.347**	.055	-.058	1	.545**	.019	.027	-.016	-.150
aff_ Und	Sig. (2-tailed)	.245	.959	.921	.144	.008	.847	.851	.000	.569	.560		.000	.846	.785	.871	.152
erst	N	110	106	110	108	107	109	105	110	110	104	110	109	109	104	109	92
Com plian ce_t	Pearson Correlation	.021	-.024	.042	-.222*	.108	-.075	-.096	.355**	.282**	-.306**	.545**	1	.100	-.032	.029	-.174
o_P PS_	Sig. (2-tailed)	.828	.805	.663	.022	.270	.438	.333	.000	.003	.002	.000		.301	.751	.764	.099
on_	N	109	105	109	107	106	108	104	109	109	103	109	109	108	103	108	91
Leve l_of_ Illeg	Pearson Correlation	.043	-.493**	.166	.131	.276**	.160	-.012	-.113	.194*	-.046	.019	.100	1	.275**	.208*	-.039
al_C onn	Sig. (2-tailed)	.660	.000	.085	.177	.004	.099	.903	.241	.043	.647	.846	.301		.005	.031	.716
ectio	N	109	105	109	107	106	108	104	109	109	103	109	108	109	103	108	91
Rea son s_fo	Pearson Correlation	-.086	-.230*	-.014	.128	.098	.128	-.266**	-.142	.083	.041	.027	-.032	.275**	1	.149	.001
r_Ille gal_	Sig. (2-tailed)	.383	.021	.889	.198	.325	.197	.007	.150	.405	.682	.785	.751	.005		.134	.993
Con	N	104	100	104	103	102	103	102	104	104	101	104	103	103	104	103	88
Area s_wi th_H	Pearson Correlation	.030	-.279**	-.016	.066	.093	.077	.051	-.025	.007	-.078	-.016	.029	.208*	.149	1	-.094
igh_ Freq	Sig. (2-tailed)	.754	.004	.870	.498	.344	.431	.608	.800	.942	.435	.871	.764	.031	.134		.374
uenc	N	109	105	109	107	106	108	104	109	109	103	109	108	108	103	109	91
Cust ome r_Ca	Pearson Correlation	-.155	.000	-.007	-.174	-.113	.082	.000	-.093	.223*	.213*	-.150	-.174	-.039	.001	-.094	1
tego ry_w	Sig. (2-tailed)	.141	1.00	.948	.100	.294	.439	1.000	.379	.033	.046	.152	.099	.716	.993	.374	
ith_	N	92	89	92	91	89	91	89	92	92	88	92	91	91	88	91	92

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 4 Pressure in the Transmission Mains

Identification: Chileka to Lunzu Minimum value 0.119 bar	SN/TD: 683515/DJZ-162 Maximum value 68.92 bar	Chileka-Lunzu Average value 39.3 bar	Chileka-Ndirande Average value 39.5 bar	Chileka-Nyambadwe Average value 39 bar
Time	**Date**	**Pressure [bar]**	**Pressure [bar]**	**Pressure [bar]**
14:00:00	09.03.2017	36.2	13.725	42.82
14:01:00		36.08	13.725	42.84
14:02:00		36.04	13.935	43.04
14:03:00		36.04	14.04	43.18
14:04:00		35.44	14.01	43.16
14:05:00		34.52	63.84	43.54
14:06:00		34.44	60.825	43.64
14:07:00		34.52	64.425	43.56
14:08:00		34.88	64.47	43.02
14:09:00		35.04	64.47	43.44
14:10:00		35.16	63.51	43.44
14:11:00		35.28	64.77	43.2
14:12:00		35.44	62.52	43.42
…	…	…	…	…
0:00:00	10.03.2017	57.72	56.92	70.82
0:01:00		57.8	57.00	70.7
0:02:00		57.24	56.45	70.9
0:03:00		55.12	54.36	70.9
0:04:00		50.64	49.94	70.82
0:05:00		46.92	46.27	70.78
0:06:00		46.8	46.15	70.92
0:07:00		46.96	46.31	70.9
0:08:00		47	46.35	70.9
0:09:00		46.92	46.27	70.8
0:10:00		47.64	46.98	70.94
0:11:00		47.68	47.02	70.88
0:12:00		47.92	47.26	70.88
…	…	…	…	…
0:00:00	12.03.2017	45.56	44.93	44.16
0:01:00		45.08	44.46	43.68
0:02:00		44.96	44.34	44.06
0:03:00		45.16	44.54	43.84
0:04:00		45.36	44.73	44.12
0:05:00		45.6	44.97	43.98
0:06:00		45.6	44.97	44.06
0:07:00		45.68	45.05	44.1
0:08:00		45.76	45.13	44.08
0:09:00		45.84	45.21	43.9
0:10:00		45.8	45.17	44.26
0:11:00		47.92	47.26	44.26
0:12:00		48.72	48.05	44.22
…	…	…	…	…
0:00:00	13.03.2017	42.72	42.13	25.38
0:01:00		42.96	42.37	25.36
0:02:00		42.52	41.93	25.36

0:03:00		42	41.42	25.36
0:04:00		41.48	40.91	25.36
0:05:00		41.2	40.63	25.34
0:06:00		41.48	40.91	25.36
0:07:00		41.6	41.03	25.32
0:08:00		41.88	41.30	25.36
0:09:00		41.92	41.34	25.38
0:10:00		41.28	40.71	25.36
0:11:00		41.6	41.03	25.34
0:12:00		41.84	41.26	25.36
…	…	…	…	…

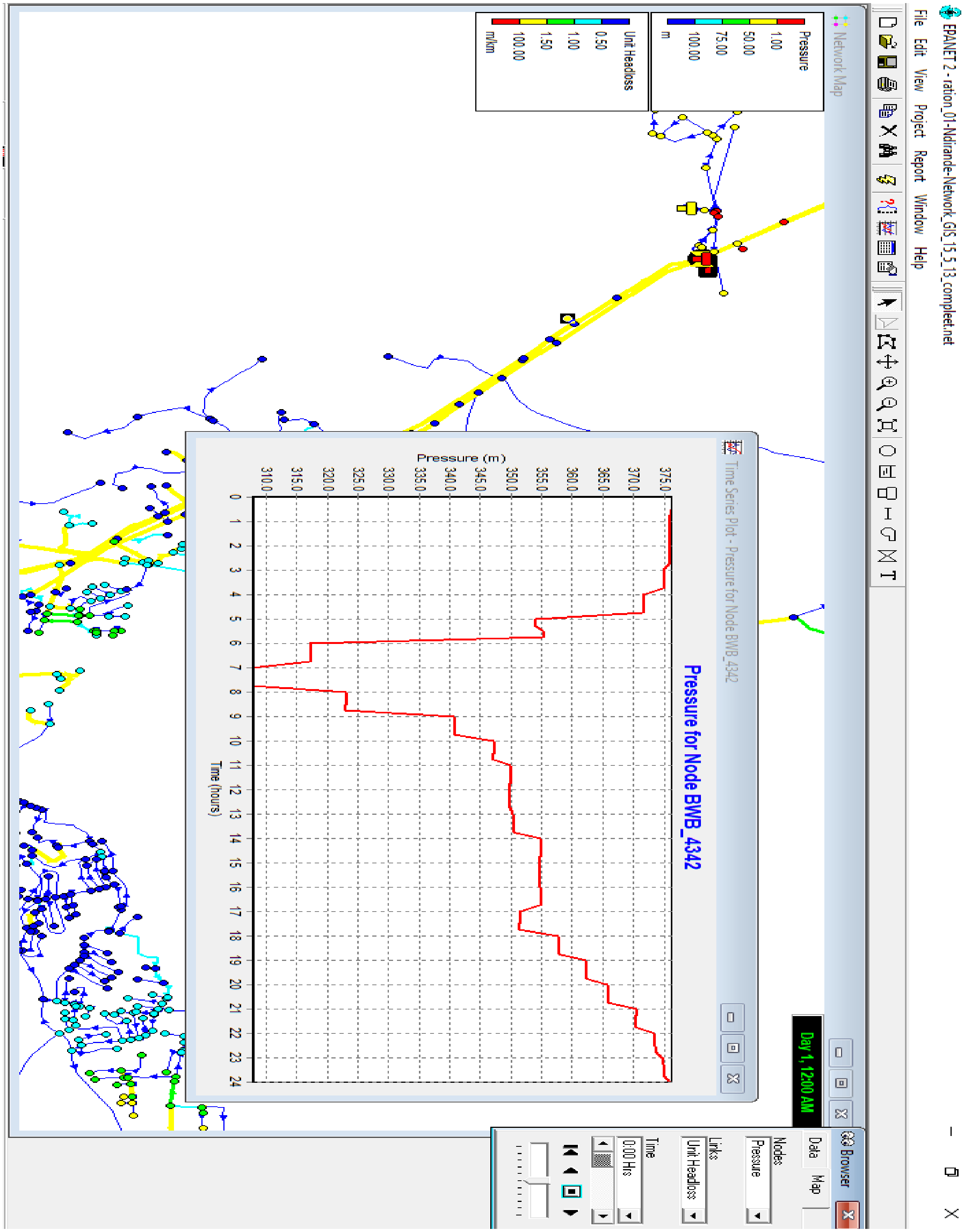
Appendix 5 Pressures in the Distributions Mains

Time	Bangwe Average value 3.459 bar Pressure [bar]	Kachere Average value 1.906 bar Pressure [bar]	Mpemba Average value 1.803 bar Pressure [bar]	Misesa Average value 0.983 bar Pressure [bar]	Nancholi Average value 3.102 bar Pressure [bar]	Min. Required Pressure
	24.3.2017					
14:00:00	2.526	0.869	2.141	0.905	0.915	1
14:01:00	2.47	0.873	2.142	0.902	0.915	1
14:02:00	2.45	0.88	2.152	0.901	0.929	1
14:03:00	2.416	0.882	2.159	0.901	0.936	1
14:04:00	2.366	0.887	2.158	0.886	0.934	1
14:05:00	2.324	0.889	2.177	0.863	4.256	1
14:06:00	2.3	0.889	2.182	0.861	4.055	1
14:07:00	2.249	0.893	2.178	0.863	4.295	1
14:08:00	2.22	0.894	2.151	0.872	4.298	1
14:09:00	2.208	0.894	2.172	0.876	4.298	1
14:10:00	2.204	0.897	2.172	0.879	4.234	1
14:11:00	2.189	0.899	2.16	0.882	4.318	1
14:12:00	2.167	0.899	2.171	0.886	4.168	1
…	…	…	…	…	…	…
	25.3.2017					
0:00:00	1.169	1.019	3.541	1.443	1.212	1
0:01:00	1.169	1.033	3.535	1.445	1.214	1
0:02:00	1.168	1.024	3.545	1.431	1.202	1
0:03:00	1.17	1.021	3.545	1.378	1.158	1
0:04:00	1.169	1.046	3.541	1.266	1.063	1
0:05:00	1.169	1.069	3.539	1.173	0.985	1
0:06:00	1.168	1.039	3.546	1.17	0.983	1
0:07:00	1.167	1.07	3.545	1.174	0.986	1
0:08:00	1.167	1.146	3.545	1.175	0.987	1
0:09:00	1.167	1.255	3.54	1.173	0.985	1
0:10:00	1.169	1.272	3.547	1.191	1.000	1
0:11:00	1.168	1.261	3.544	1.192	1.001	1
…	…	…	…	…	…	…
	26.3.2017					
0:00:00	7.478	0.374	1.657	0.928	0.780	1
0:01:00	7.493	0.375	1.626	0.929	0.780	1
0:02:00	7.505	0.375	1.653	0.931	0.782	1
0:03:00	7.512	0.376	1.675	0.93	0.781	1
0:04:00	7.521	0.376	1.638	0.93	0.781	1
0:05:00	7.528	0.376	1.685	0.93	0.781	1
0:06:00	7.535	0.377	1.683	0.931	0.782	1
0:07:00	7.545	0.377	1.692	0.929	0.780	1
0:08:00	7.55	0.378	1.697	0.93	0.781	1
0:09:00	7.556	0.378	1.705	0.93	0.781	1
0:10:00	7.56	0.378	1.735	0.931	0.782	1
0:11:00	7.567	0.378	1.727	0.933	0.784	1
…	…	…	…	…	…	…
	27.3.2017					
0:00:00	7.523	0.376	2.208	1.139	0.957	1
0:01:00	7.527	0.376	2.184	1.127	0.947	1
0:02:00	7.532	0.377	2.203	1.124	0.944	1
0:03:00	7.539	0.377	2.192	1.129	0.948	1

0:04:00	7.544	0.377	2.206	1.134	0.953	1
0:05:00	7.549	0.377	2.199	1.14	0.958	1
0:06:00	7.546	0.377	2.203	1.14	0.958	1
0:07:00	7.539	0.377	2.205	1.142	0.959	1
0:08:00	7.545	0.377	2.204	1.144	0.961	1
0:09:00	7.555	0.378	2.195	1.146	0.963	1
0:10:00	7.558	0.378	2.213	1.145	0.962	1
0:11:00	7.563	0.378	2.213	1.198	1.006	1
…	…	…	…	…	…	…
	28.3.2017					
0:00:00	7.102	0.355	1.269	1.068	0.897	1
0:01:00	7.114	0.356	1.268	1.074	0.902	1
0:02:00	7.123	0.356	1.268	1.063	0.893	1
0:03:00	7.134	0.357	1.268	1.05	0.882	1
0:04:00	7.141	0.357	1.268	1.037	0.871	1
0:05:00	7.149	0.357	1.267	1.03	0.865	1
0:06:00	7.154	0.358	1.268	1.037	0.871	1
0:07:00	7.158	0.358	1.266	1.04	0.874	1
0:08:00	7.162	0.358	1.268	1.047	0.879	1
0:09:00	7.166	0.358	1.269	1.048	0.880	1
0:10:00	7.171	0.359	1.268	1.032	0.867	1
0:11:00	7.175	0.359	1.267	1.04	0.874	1
…	…	…	…	…	…	…
	29.3.2017					
0:00:00	7.214	0.361	2.365	1.679	1.410	1
0:01:00	7.221	0.361	2.378	1.688	1.418	1
0:02:00	7.228	0.361	2.372	1.684	1.415	1
0:03:00	7.233	0.362	2.362	1.677	1.409	1
0:04:00	7.236	0.362	2.382	1.691	1.421	1
0:05:00	7.24	0.362	2.366	1.680	1.411	1
0:06:00	7.24	0.362	2.386	1.694	1.423	1
0:07:00	7.24	0.362	2.366	1.680	1.411	1
0:08:00	7.241	0.362	2.37	1.683	1.413	1
0:09:00	7.246	0.362	2.367	1.681	1.412	1
0:10:00	7.246	0.362	2.362	1.677	1.409	1
0:11:00	7.247	0.362	2.36	1.676	1.408	1
…	…	…	…	…	…	…
	30.3.2017					
0:00:00	6.837	0.342	1.31	0.930	0.781	1
0:01:00	6.842	0.342	1.309	0.929	0.781	1
0:02:00	6.85	0.343	1.31	0.930	0.781	1
0:03:00	6.854	0.343	1.31	0.930	0.781	1
0:04:00	6.86	0.343	1.31	0.930	0.781	1
0:05:00	6.865	0.343	1.31	0.930	0.781	1
0:06:00	6.872	0.344	1.309	0.929	0.781	1
0:07:00	6.879	0.344	1.31	0.930	0.781	1
0:08:00	6.886	0.344	1.309	0.929	0.781	1
0:09:00	6.89	0.345	1.309	0.929	0.781	1
0:10:00	6.893	0.345	1.309	0.929	0.781	1
0:11:00	6.895	0.345	1.31	0.930	0.781	1
…	…	…	…	…	…	…
	31.3.2017					
0:00:00	1.172	0.059	1.316	0.934	0.785	1
0:01:00	1.171	0.059	1.316	0.934	0.785	1
0:02:00	1.17	0.059	1.316	0.934	0.785	1

0:03:00	1.171	0.059	1.317	0.935	0.785	1
0:04:00	1.173	0.059	1.317	0.935	0.785	1
0:05:00	1.171	0.059	1.315	0.934	0.784	1
0:06:00	1.171	0.059	1.316	0.934	0.785	1
0:07:00	1.171	0.059	1.317	0.935	0.785	1
0:08:00	1.171	0.059	1.315	0.934	0.784	1
0:09:00	1.172	0.059	1.316	0.934	0.785	1
0:10:00	1.172	0.059	1.316	0.934	0.785	1
0:11:00	1.171	0.059	1.317	0.935	0.785	1
…	…	…	…	…	…	…

Appendix 6 Epanet Pressure Variations



Appendix 7 Pictorial view of old pipes, maintenance works and uprooting of Illegal Connections

7A: Leaking old transmission main at Walkers Ferry

7B: Emptying water from chamber for maintenance

7C: Search for a burst pipe in Limbe Zone

7D: BWB Plumber uprooting (meter bypass) Illegal connection in Ndirande Township