

**Determinants of Non-Revenue Water in Urban Water Supply:
The case of Adama City, Ethiopia**



Muktar Kasso Saddo

A Thesis Submitted to the Department of Water Resource Engineering
School of Civil Engineering and Architecture,

Presented in Partial Fulfillment of the Requirement of the Degree of Masters in Water
Resources Engineering (Specialization in Water Supply and Environmental Engineering)

Office of Graduate Studies
Adama Science and Technology University

June 2023
Adama, Ethiopia

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Advisor: Andinet Kebede (PhD)

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Declaration

I hereby declare that this Master Thesis entitled “Determinants of Non-Revenue Water in Urban Water Supply: the Case of Adama City, Ethiopia” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through Citation.

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I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Determinants of Non-Revenue Water in Urban Water Supply, the Case of Adama City, Ethiopia” prepared under my guidance by Muktar Kasso Saddo submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering (Specialization in Water supply and Environmental Engineering). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Major Advisor

Signature

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Approval Page of MSc Thesis

I, the advisor of the thesis entitled “Determinants of Non-Revenue Water in Urban Water Supply, the Case of Adama City, Ethiopia” and developed by Muktar Kasso Saddo, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

_____	_____	_____
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Muktar Kasso Saddo have read and evaluated the thesis entitled “Determinants of Non-Revenue Water in Urban Water Supply, the Case of Adama City, Ethiopia” and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Water Resources Engineering (Specialization in Water supply and Environmental Engineering).

_____	_____	_____
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LIST OF ACRONYMY AND ABBREVIATIONS

AWSSSE	Adama Water Supply and Sewerage Service Enterprise
AWWA	American Water Works Association
CARL	Current Annual Real Losses
EFY	Ethiopian Fiscal Year
IWA	International Water Association
MoWIE	Ministry of Water, Irrigation and Energy
NRW	Non-revenue Water
UARL	Unavoidable Real Loss
WB	Water Balance
WHO	World Health Organization
WSSSE	Water Supply and Sewerage Service Enterprise

ABSTRACT

The water loss problem is a challenge for water utilities in providing a satisfactory water supply to the rapidly growing population of urban settlements. A significant amount of water is lost in the form of Non-Revenue Water (NRW) annually. The global volume of NRW has been estimated to be 126 billion cubic meters per year. In Africa, NRW figures ranging from 5% (Saldanha Bay, South Africa) to 70% (LWSC, Liberia) have been reported. In the urban water supply of Ethiopia, only 45% of the urban Ethiopian population has been using water from safely managed water services in 2020. The water losses of Adama City were as high as 34.67 % to 34.05 % as per earlier literature. The overall objective of this study was to investigate Determinants of Non-Revenue Water (NRW) in Adama City's Water Supply System. The study used primary data and secondary data. A pre-determined information-oriented target population of a total of 35 members of the staff of the Adama Water Supply and Sewerage Service Enterprise (WSSSE) was considered for the study. International Water Association (IWA) water balance through American Water Works Association (AWWA) water audit software is used for analysis. The level of Non-Revenue Water in the 2014 Ethiopian Fiscal Year (EFY) was as high as 20% of the total system input water volume in the case of continuous 24 hours supply system while it is 40% in intermittent supply of average 12 hours run time. It is higher than the acceptable 15% NRW percentage set by the Federal Democratic Republic of Ethiopia (FDRE), Ministry of Water, Irrigation and Energy (MoWIE) design criteria. The findings of the study from respondents show that the key factors influencing NRW of the City water supply system are real losses (pipe bursts and leakages) followed by unauthorized consumption (illegal connections). The study also showed that Meter registration errors (inaccuracy) and unbilled unmetered consumption are additional factors contributing to the NRW consecutively. From AWWA Water Audit software similar outputs were observed indicating high pipe bursts and leakages followed by apparent losses and unbilled unmetered consumption. To reduce the NRW levels of the City, the management of Adama WSSSE and concerned body should develop and implement an NRW reduction strategy at the Adama water supply scheme that should include reduction of water lost through bursts and leakages, reduction of unauthorized consumption (illegal connections), meter registration accuracy enhancement and reduction of unbilled unmetered consumption.

Keywords: Adama City, Non-Revenue Water (NRW), Water loss, Water Supply system

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Water demand is getting increased rapidly due to urbanization, increase in population and Industrialization whereas water resources are diminishing. Problems in providing satisfactory water supply to the rapidly growing population are increasing from time to time (IWA, 2003). As defined by International Water Association (IWA), the system input water (water fed into a water supply system) is categorized into two sections as revenue and non-revenue water. Revenue water refers to all authorized estimated or non-estimated consumption that is billable while Non-Revenue water is the water lost in the system due to different factors. Portion of water supplied by water utility into the distribution system but could not generate revenue for utility is the Non-Revenue-Water (NRW). It consists of sum of Un-Billed authorized consumption, Apparent Losses and physical (Real) Losses. Water utilities are losing revenue because of the high levels of these NRW and intern affecting their financial viability.

Non-revenue water (NRW) remains one of the most pressing deficiencies for water utilities worldwide (Danilenko et al., 2014; Kingdom et al. 2006). There exists no water distribution system with 0% losses as all water distribution networks leak, but to different extents. Liemberger and Wyatt (2018) estimated the global level of NRW based on available NRW percentages in the database of the International Benchmarking Network (IBNET, 2020), along with global population estimates, country-based per capita consumption data, and population (%) with piped water data based on the WHO/UNICEF Joint Monitoring Program (WHO/UNICEF, 2017). These authors estimated the 2018 global volume and cost of NRW at 126 billion m³/year and US\$ 39 billion per year, respectively. From analyzing the global data published by Liemberger and Wyatt (2018), the estimated global NRW volume and cost in 2020 is 128 billion m³/yr and US\$ 40 billion per year, respectively. Approximately 74% of these losses occur in developing countries. With a business as usual scenario, Figure 1.1(a) shows the expected global volume and cost of NRW by 2050, which will be 176 billion m³/year and US\$ 55 billion per year, respectively. Figure 1.1(b) shows the range of NRW levels worldwide. Most of the global NRW data as a percentage of supplied water lie between 20% and 40%, with an average of 32% (Liemberger and Wyatt, 2018).

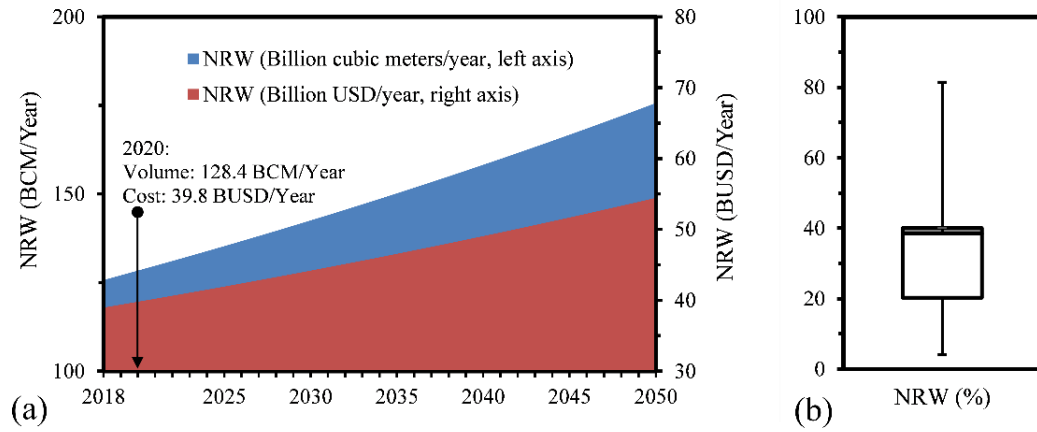


Figure 1.1 Global level of NRW: (a) volume and cost of NRW; (b) global range of NRW as a percentage of supplied water. (Source: Liemberger and Wyatt, 2018)

Despite its negative impacts, NRW is still high in many countries. Figure 1.2 shows the NRW percentages of different countries around the world, developed based on IBNET and WHO/UNICEF data published by Liemberger and Wyatt (2018). High NRW percentages are predominant in Africa, Asia, and South America. However, expressing the level of NRW as a percentage of supplied water is strongly criticized in NRW practitioners' circles because it is influenced by water consumption levels.

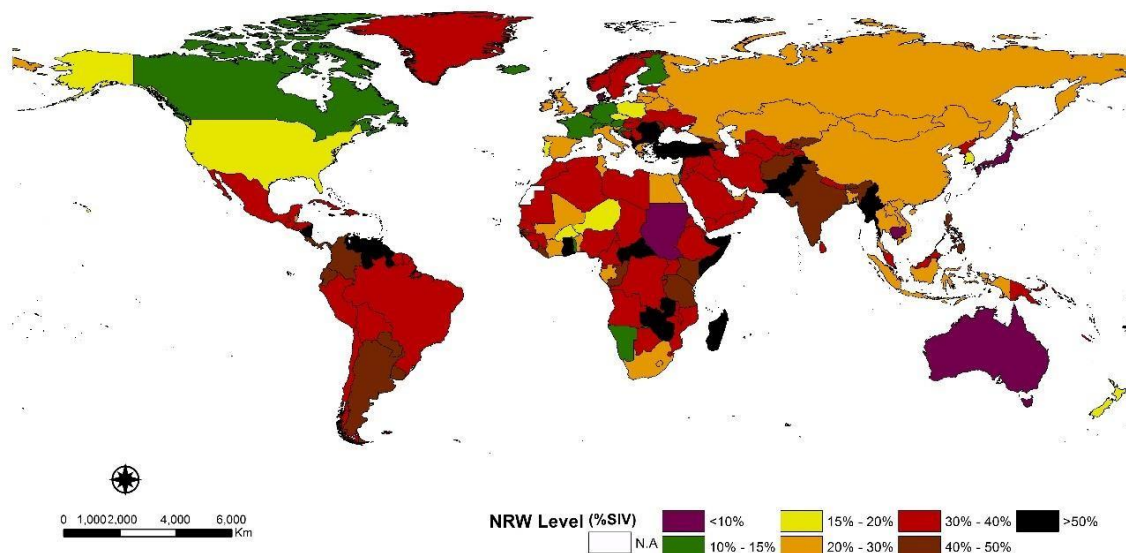


Figure 1.2 World map of NRW as a percentage of supplied water. (Source: Liemberger and Wyatt, 2018)

In Africa, NRW figures ranging from 5% (Saldanha Bay, South Africa) to 70% (LWSC, Liberia) have been reported (WSP 2009). The NRW problem is likely to be compounded

by the diminishing water resources, increasing costs of producing water, high rate of infrastructure deterioration, inadequate investment budgets, and increasing global change pressures (urbanization, climate change, population growth). Water utilities are under increasing scrutiny to use water resources more efficiently by reducing water losses in their distribution systems and ensure sustainable service delivery.

The reports of WHO indicate that the Sub-Saharan Africa (SSA) countries accounted for half of the global population without essential drinking water services in 2020, eighty percent (614 million) of those in SSA in 2020 lived in rural areas, and nearly half (351 million) of them came from the least developed countries (WHO, 2021). Water supply systems in urban areas are often unable to meet existing demands and are not available to everyone. One of the major challenges facing many water utilities in most developing countries including Ethiopia (MoWIE 2017) were managing and reducing losses of water at all levels of a distribution system.

Water utilities in Ethiopia are also facing challenges in supplying safe and adequate drinking water. In urban water supply water losses are the major concern for water utilities. In addition to the population growth, urbanization of towns and old infrastructure are causing more stress on water utilities in supplying quality water with adequate quantity. Access to potable water in Ethiopia has been growing compared to the previous years between 1990 and 2020, though still many people have no access to clean water in their homes (MoWIE, 2017). In 1990, only 17 percent of Ethiopia's population had access to clean water (MoWIE, 2017). According to WHO (2021), the national and urban coverage reached 50 percent (19.2 million) and 84 percent (71.7 million) of water provided from basic water services in 2020, respectively. Ethiopia is categorized under countries with a high scarcity of drinking water among SSA countries, especially at the rural and national levels. Only 45% of the urban Ethiopian population has been using water from safely managed water services in 2020 (WHO, 2021). According to earlier studies (Ismael and Sisay, 2019; Siraj 2020), the water supplied to Adama City was not only the problem of adequacy but also due to loss of water in the system. These papers described that water supply is mostly interrupted due to burst on the transmission and in the main lines. The water losses of Adama City were as high as 34.67 % (Ismael and Sisay, 2019) and 34.05 % Siraj (2020). According to these literatures the water supply is mostly interrupted due to burst in the transmission and the main lines.

1.2 Statement of the Problem

One of the major factor affecting water utilities in the developing countries is the difference between the quantity of water put into the distribution system and the amount of water billed to consumers (also referred to as Non-revenue Water) (IWA, 2003). The water losses of Adama City were as high as 34.67 % Ismael and Sisay, (2019) and 34.05 % Siraj (2020). Even though, the water supply system was designed continuous supply system, most of the service areas are not getting water supply for continuous 24 hours and are having water supply at varying interval hours. According to these literatures the water supply is mostly interrupted due to burst in the transmission and the main lines and loss has also created increase in operation and maintenance cost that in turn brought financial gap on Adama City Water Supply and Sewerage Service Enterprise (WSSSE). The literatures had tried to show the percentage amount of water loss due to pipe burst and leakage in the system. However, they have got limitations on the exhausting other possible factors for the loss of water in the system as a Non-Revenue water. Frequent pipe bursts and excessive leakages in the network due to the existence of old pipe lines have also decreasing the coverage capacity of the service.

The Urban water supply design criteria of FDRE Ministry of Water, Irrigation and Energy (MoWIE 2006) recommend that NRW is acceptable at 15%. It is based on these problems that this assessment of Determinants of Non-Revenue Water in Adama City Water supply System is considered for study.

1.3 Objective of the Study

1.3.1 General objective

The general objective of this study is to investigate factors influencing non-revenue water in the water supply system of Adama City.

1.3.2 Specific objectives

The following specific objectives are used as operational steps to realize the general objective.

- To investigate the extent to which physical losses (pipe bursts and leakages) in the distribution system contribute to non-revenue water
- To assess the level of influence of meter registration inaccuracy on non-revenue water
- To assess the extent of unbilled unmetered consumption influence on non-revenue water
- To assess the level of influence of unauthorized consumption (theft or illegal connections) to non-revenue water

1.4 Research Questions

In line with the specific objectives listed above, the study tries to get answers to the following research questions.

- To what extent did the pipe bursts and leakages in the distribution system contribute to Non-Revenue Water?
- To what level did water meter registration inaccuracies contribute to Non-Revenue Water?
- To what extent did unbilled unmetered consumption influence Non-Revenue Water?
- To what level did unauthorized consumption influence Non-Revenue Water?

1.5 Significance of the Study

Demand for water is growing significantly with all factors like Urbanization, industrialization and population growth which are rapidly increasing from time to time. Hence, to meet the required demand, it is necessary to exhaust all options that contribute to increase in quantity of water supply one of which is reducing Non-revenue water. This needs to be supported with proper Non-revenue water factors assessment, Physical, technical, managerial, and environmental factors are all known to influence non-revenue water (NRW). Hence, a better understanding of these factors is important if we are to intervene in water loss problems more effectively. This study, therefore, try to identify determinants of NRW for Adama City Water supply system. The findings will inform the water utility's management team or decision-makers regarding the specific impacts of NRW's critical factors and guide them to focus on these factors to further reduce NRW as well as set long-term benchmarks. The study is therefore, significant in contributing its

part in assessing the Determinants of NRW of Adama City water supply systems by which the town community will have better services. The finding of this research could also contribute to the enhancement of knowledge of NRW management and can also be used for other researchers to further work on the issue.

1.6 Scope

The study focuses on the water service delivery in Adama City with particular reference to examining the factors influencing the non-revenue water. The study will try to investigate their level of influence to the non-revenue water in Adama City water supply system. The study will focus on factors like pipe bursts and leakages in the distribution system, meter registration inaccuracy, unbilled unmetered consumption and unauthorized (illegal) consumption.

1.7 Limitations of the Study

Some of the considered factors to be assessed need further investigations by using different equipment and making tests. However, it was difficult to make those detail assessments due to absence of required equipment and cost it incurs. Undertaking of some real loss assessment methodologies like DMA (District Metered Area) was difficult due to its nature of assessment. It requires detailed field investigation using sophisticated equipment. The system does not have measuring Meters in the system that use for the assessment and it is difficult to get the required equipment to install in the selected area of the system. In addition, as there is high water shortage problem in the City, it is difficult to go through this method. The high cost of testing of water meters limits the level of its investigation. Therefore, the data collection instrument used was questionnaires. The Top down water balance approach for Non-Revenue real loss assessment was used instead. The study was focused on the four major factors for NRW: Leakages in the distribution system, meter registration inaccuracy, unbilled unmetered consumption and unauthorized (illegal) consumption influences on NRW levels in Adama Water Supply System.

1.8 Operational Definition

Operational definition is a description of a variable, term or object in terms of the specific process or set of validation tests used to determine its presence and quantity. The

operational definitions of variables employed in this study are presented in Table 1.1.

Table 1.1 Operational Definitions of Variables

Variable	Indicator (Measurement
Dependent	
Non-Revenue Water	Percentage of the volume of water unbilled to volume of water pumped into the distribution system
Independent	
Pipe leakages and bursts	Number of Age of pipes
	Type of pipes used
	Number or frequency of bursts
Meter registration inaccuracies	Number of meters which registered actual readings
	Number of meters that over registered
	Number of meters that under registered
Unmetered Consumption	Number of metered connections
	Number of metered connections
	Volume billed on metered connections
	Volume billed on unmetered connections
Illegal consumption	Number of illegal connections legalized
	Volume billed on illegal connections legalized
	Number of illegal connections identified
Water Tariff	Number of accounts disconnected due to water bill non-payment
	Number of accounts reconnected after disconnection due to water bill non payment
	Number of consumers comfortable with the current tariff

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

It is necessary to review the existing literatures to get a better view of the main issues involving non-revenue water. This chapter provides a review of works carried out by other scholars and researchers relevant to the problem of the study both globally and regionally. It focuses on relevant information from previous studies which have focused on components of NRW and the factors influencing NRW. The reviewed literature includes theoretical and empirical literature. The theoretical literature includes information from similar published documents. The empirical literature provides similar research work with this thesis which was done by other researchers. The chapter also has the theoretical and conceptual frame work of the study.

It is essential to review the existing literature to get a better view of the main problems regarding non-revenue water. This chapter affords an overview of works executed by using other scholars and researchers applicable to the problem of the study both globally and regionally. It specializes in applicable information from previous research that has centered on additives of NRW and the factors influencing NRW. The reviewed literature includes theoretical and empirical literature. The theoretical literature consists of facts from similar publications. The empirical literature provides comparable studies paintings with this thesis which changed into accomplished by means of other researchers. The chapter additionally has the theoretical and conceptual body framework of the study.

2.2 Determinants of Non-Revenue Water (NRW)

The initial step in evaluating NRW involves creating a water balance within the system to determine the amount of water used and paid for, as well as the amount of water lost and how it is lost. Water balances are commonly used by water utilities, but the different formats and evaluations of losses make it difficult to compare between utilities internationally (Lambert, 2003). Water balances are widely used to quantify and define the components of non-revenue water. According to the International Water Association (IWA) Task Force on Water Loss (IWA, 2003), Non-Revenue Water (NRW) is defined as "the difference between System Input Volume and Billed Authorized Consumption". System input refers to the annual input to a specific part of the water supply system, while

billed authorized consumption includes metered consumption, exported water, and billed unmetered consumption, according to the task force.

The IWA defines NRW as follows:

$$\text{NRW} = \text{System Input Volume} - \text{Billed Authorized Consumption}$$

This water balance is generally accepted for defining water losses. However, Alan (2010) argues that the water balance is more applicable in developed countries where most revenue billing for water services is collected. In developing countries, a significant amount of billing is never collected and can be considered as losses. Alan suggests an adjusted water balance to provide a more accurate picture in the developing world:

$$\text{NRW} = \text{System Input Volume} - \text{Paid For Billed Authorized Consumption.}$$

In most cases, NRW is expressed as a percentage of the system input volume expressed as:

$$\text{NRW (\%)} = (\text{NRW Volume} / \text{System Input Volume}) \times 100$$

While this percentage is commonly used to measure performance, Alan (2010) cautions that it may be misleading when used to show the actual trends and performance of a water utility over time.

NRW consists of three components: physical (or real) losses, commercial (or apparent) losses, and unbilled authorized consumption (IWA, 2008). Physical losses include leakage from the system and overflows at storage reservoirs, resulting from poor operations and maintenance, lack of active leakage control, and poor quality of underground assets. These losses are caused by physical failures in the distribution system, such as pipe leaks and bursts. Commercial losses are caused by customer meter under-registration, data-handling errors, and water theft in various forms. The commercial component is partly linked to the lack of accurate measurement, such as faulty meters. The IWA water balance is shown in Figure 2.1.

System input volume	Authorized consumption	Billed authorized consumption	Billed metered consumption (including water exported)	Revenue Water
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non- Revenue Water (NRW)
			Unbilled unmetered consumption	
	Water Losses	Apparent losses	Unauthorized consumption	
			Metering inaccuracies	
		Physical losses (Real losses)	Leakage on transmission and or distribution mains	
			Leakage and overflows at utilities storage reservoirs	
			Leakage on service connections up to point of customer metering	

Fig 2.1.: Standard IWA water balance structure showing NRW Components

2.2.1. Physical (Real) losses

Physical losses, also called actual losses, are the annual volumetric losses of transmission and distribution systems due to all types of leaks, ruptures and spills from service pipes, reservoirs and service connections, up to point of customer meter (IWA, 2003).). Most of these losses are due to system losses, which are also due to lack of maintenance or failure to update and replace old systems (Asset Management). Proper loss management provides both financial and social benefits to the water utility. Effective management of system losses ensures system sustainability and promotes community support for providing water affordably to consumers (Butler, 2006). Sometimes undetected leaks can be quite large, such as leaking directly into a sewer line or drain. A water utility that does not have an active and effective leakage control policy will always incur significant losses unless the

water system is new or in very good condition. Assessment of physical (actual) losses can be done in three ways (IWA, 2003).

Pipe bursts and Leakages in the system

Physical losses are essentially water losses due to pipe bursts and leaks. These leaks can be serious and go undetected for months or even years. Volume of losses will depend greatly on the characteristics of the pipeline network. Physical losses due to leaks in pipelines, service reservoirs and service connections up to the point of measurement at the customer. The amount lost each year from all types of leaks, breaks and spills depends on their frequency, speed and duration. Experience shows that the majorities of leaks occurs at service connections, and are usually due to improper construction. A pipe burst occurs when water suddenly or violently escapes from a water pipe, usually due to internal pressure. A water outlet is a means (usually an opening) through which a liquid escapes from a container or system containing a liquid (Fanner, 2009). Water losses during bursts and leaks can occur due to; Damaged pipelines and tank /reservoir networks resulting in leaks and breaks in transmission and/or distribution lines, leaks and overflows in connections up to customer meters Farley, M., Wyeth, G., Ghazali, Z., Istandar , A. & Sher, S., (2008). During maintenance, the pipeline must be completely drained before repairs can be made, and after repairs the pipeline must be flushed to prevent water contamination and dirt/debris clogging of the pipeline and dirt/debris intake meters (AWA), (2013).

Data gaps make it difficult to estimate commercial losses and determine the nature and location of physical losses. However, it should always be kept in mind that there may be errors in the water balance, so the actual losses are checked by one of the following two methods (i) component analysis and (ii) bottom-up estimation of the actual losses. With component analysis, Liemberger and Farley (2005) list the basic data required for component analysis of real water distribution system losses, e.g. Total pipe network length and number of service connections, average length of service connection between curb and customer meter, total number of distribution pipe repairs per year (reported and unreported) and total number of service connection repairs per year (reported and unreported). The others are; Average system pressure across the network, estimated lead times, location and duration of repairs, and estimates of leaks and overflows from utility

reservoirs. Calculation of reported and unreported bursts losses; Reported bursts are those events that are brought to the attention of the Water Company by the general public or by Water Company employees. Under normal circumstances, a burst or leak is usually reported to the water company. Unreported bursts are those detected by leak detection teams as part of their normal daily leak monitoring activities. After collecting annual numbers of bursts reported on main and utility connections, it is necessary to determine the flows and duration in cases where the utility did not study the average leak flow rates.

After calculating the volume of reported and unreported explosions, estimates of background losses and additional losses (current unreported losses) are added. Background leaks are discrete events (such as small leaks and cracked seams) that are too slow to be detected by an active leak detection survey. Eventually, they are discovered incidentally or after they have escalated to the point where active leak detection testing can detect them. Excess losses volume refers to the amount of water lost through leaks that are not detected and repaired under current runoff control policies (Liemberger and Farley, 2005). On the other hand, there is a bottom-up assessment of real losses. These include 24-hour zone measurements; assuming no DMA is set, parts of the distribution network are chosen to be temporarily isolated and supplied from only one or two entry points. Appropriate areas are selected in different parts of the distribution system to obtain a representative sample of the system. At these locations, inflow measurements are carried out in the 24 hour with portable flow meters. Flow measurements are always taken in conjunction with pressure measurements, recording the pressures at the zone entry point(s), mid pressure point and critical pressure point. In general, the more water lost through bursts and leakage, the less water is sold and the water is not paid for (Liemberger and Farley, 2005).

2.2.2. Apparent losses

Apparent losses constitute one of the three components of Non-Revenue Water to a water utility besides real losses and authorized unbilled consumption. The three types of connections by which apparent losses occur as per Vermersch (2005) are unregistered, metered and unmetered connections. He explains these as follows: unregistered consumers (illegal connections/consumption); underestimation of consumption when the water meter is out of operation; under-metering when the water meter is not appropriate; frauds on metered connections; and under-billing of unmetered registered customers.

Components of Apparent losses

Rizzo (2007) identifies four components of apparent losses as follows: Meter under-registration; Water accounting errors; Meter reading errors; and Water theft as shown in the Figure 2.2

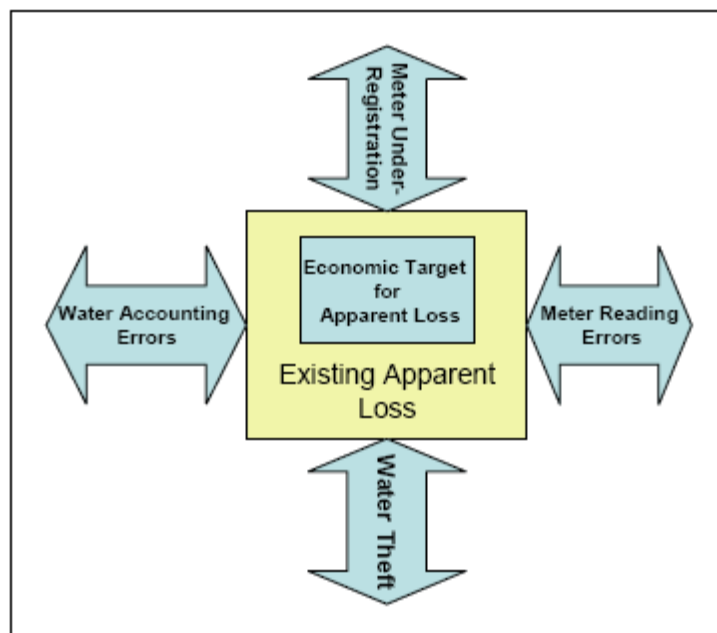


Figure 2.2: The four components of apparent losses (Source: Rizzo, 2007)

Meter registration inaccuracy

An under-registered meter means that the meter only reads part of the water passing through it, and therefore only that part is billed to the consumer. Riizzo (2008) linked under-registration of meters to water utilities; meter wear, improper meter installation practices, lack of meter maintenance or calibration, and incorrect meter sizing. Water meter inaccuracies are considered the most important and most difficult to quantify. Water meter errors increase in water-scarce networks, where consumers use private reservoirs to cope with intermittent water supplies. According to a study analyzing the effect of water meter age and private storage on meter performance in Palermo, Italy, it was found that the effect on the apparent loss of the meter starting flow increased rapidly with the age of the meter. Private water reservoirs, which are usually fed by a float valve, were over-registered, resulting in losses of 15% to 40% for the utilities analyzed in the study (Criminisi et al., 2009).

Sub-metering has been widely used as a tool to promote water conservation, particularly by the US AWWA (2000). Partial metering has been reported to reduce water consumption by 10-30%. The term "partial metering" refers to any metering downstream of a water utility's main meter to measure the water consumption of individual residents in apartments, condominiums, mobile home parking lots, and small mixed-use commercial properties. However, for water utilities in developing countries, universal and individual metering have not yielded much of the expected benefits, likely due to inefficiencies in metering. AWWA (2000) found that non-revenue water due to meter inaccuracies and mismanagement of water meters can be reduced by assessing meter performance and identifying root causes of failures.

According to Male et al. (1985), "calculating the optimal level of apparent losses due to inaccurate water meters", concluded that "the greater the volume used at low flows (which increases the rate of degradation of the weighted error from the readings), the higher the optimal level of error of the water meter and the higher the amount of utility consumption, the smaller the volume parameter (between the price of the meter and the product between the annual consumption and "water price") and the lower the optimal level of error of the water meter. It is widely accepted that the metrology of mechanical water meters becomes increasingly inaccurate throughout their lifetime due to the wear and tear of measurement components (Arregui et al., 2006b; Male et al., 1985).

Unauthorized Consumption (Illegal connections)

Illegal consumption is also called illegal use of water. These include illegal water withdrawals from fire hydrants, illegal connections, illegal reconnections and bypassing of consumption meters. Reducing illegal use reduces the amount of unprofitable water.

Illegal connection is divided into:

- Meter bypass when the user is a legitimate user with a meter. The customer has an alternative water pipe before the meter.
- Illegal connection when the user is not even a customer of the water network's customer database. It simply connects to the network without the knowledge of the water company.

- Taking water from a point before the meter - the customer consumes unmetered water by closing the cap, removing the meter, then connecting the hose to the mains and fetches the water. After the water is taken, the meter returned to its normal position.
- Meter reversal is a situation where customers install the counters in reverse order to count up to the desired readings. Satisfied, they turn the gauges to the correct position. Resetting the counter readings may involve manual resetting of the counter readings.

2.2.3. Unbilled Unmetered Consumption

Unbilled unmetered consumption is any form of legal consumption that's neither billed nor metered. This component usually consists of items that include firefighting, flushing of mains and sewers, road cleansing, frost safety, and many others. In a well-run utility it is a small issue which is very regularly notably overestimated. The ones components of authorized intake that are legitimate however now not billed and consequently do now not produce sales. It's far identical to Unbilled Metered consumption plus Unbilled Unmetered consumption.

2.3. Impacts of Non-Revenue Water

According to Farley et al. (2008), the "vicious cycle" of NRW is considered to be one of the main causes of poor water supply services, resulting in both physical and apparent losses. Leakage or physical leakage prevents valuable water from reaching customers and increases operating costs. They also involve larger investments than needed to increase network capacity. Obvious losses due to inaccurate customer meters, poor data management and illegal connections reduce revenue and financial resource generation.

According to Frauendorfer and Liemberger (2010), "no business can survive for long if it loses a large part of its marketable product", but this is exactly what happens to many water companies. A high level of NRW leads to a low level of efficiency. The loss of the service product (purified water) increases the cost of water collection, treatment and distribution, reduces water sales, and often prompts significant investment programs to meet ever-increasing demand. In short, the utility gets caught in a vicious cycle that fails to solve the underlying problem. The challenge for water company managers is to turn the

vicious circle into a "virtue". Indeed, reducing NRW frees up new sources of water and finance. By reducing excessive physical losses, more water is used and the need to invest in new sources is postponed. It also reduces operating costs. Similarly, reducing trading losses leads to more revenue (Farley et al., 2008).

According to Frauendorfer and Liemberger (2010), the main objective of a water company is to meet the needs of customers. High levels of NRW have a serious and direct impact on utilities' ability to meet this target, and therefore have a negative impact on customers. High physical losses often result in supply interruptions due to limited raw water availability or water rationing, which may require a reduction in supply hours (and thus water loss hours) per day. In addition to poor service, disrupted supplies pose significant health risks, as contaminated groundwater or even sewage can enter leaking pipes during periods of outages and very low pressure. Avoiding this major risk to public health should be reason enough to reduce losses and ensure continued delivery. High losses also increase flow rates in the pipeline network, which can cause unnecessarily large pressure drops affecting customers and often disrupting supply during peak hours.

2.4. Addressing Non-Revenue Water

Liemberger and Marin (2006) explain that although reducing non-revenue water should be a priority for water utilities, many still struggle to achieve acceptable levels of NRW. The reasons for the failure of NRW strategies range from a lack of understanding of the scale of the problem to a lack of financial or human resources. Managing non-revenue water is not a one-off task, but requires a long-term commitment and the involvement of all water companies. Many utility managers do not have access to network-level information that would allow them to fully understand the nature of NRW and its impact on utility operations, financial health and customer satisfaction. Reduction programs often fail when the complexity of NRW and the potential benefits of NRW mitigation are underestimated. Successful reduction of NRW is not about solving a single technical problem, but about overall resource management, operations, customer service, financial allocation and governance. However, utility managers' awareness of the institutional dimension of NRW has increased; new methodologies are emerging that more accurately estimate physical and commercial losses to support sustainable NRW mitigation Liemberger and Marin (2006). Liemberger and Marin (2006) identified factors influencing the extent of water

loss and demand management influencing the rate of change as follows; Rapid urbanization, environmental pollution, aging infrastructure, declining water supplies, inadequate management and maintenance policies, including inefficient logging systems, inadequate engineering skills and technologies, and increasing financial constraints, including inadequate rate structures and/or tax collection policies, are emerging. A better understanding of the causes of leaks and the factors that influence them is key to developing a water loss strategy. Therefore, methods and procedures tailored to network specificities and local influencing factors can be developed to address each cause in order of priority. Only after quantifying the NRW and its components, calculating the relevant performance indicators and converting the lost water volumes into monetary values, can the NRW situation be correctly understood and the necessary measures taken. According to Liemberger and Farley (2005), the first step in developing an NRW strategy is to ask some questions about network characteristics and operational practices, then use available tools and mechanisms to propose appropriate solutions that are then used in the strategy.

2.5. Systematic Determination of the Non-Revenue Water Components

Globally, non-revenue water in urbanized settlements is one of the main factors affecting water supply services due to loss of revenue and higher water supply costs (AL-Washali et al., 2016; Liemberger and Wyatt, 2019). Reducing NRW is a challenge for water utilities and water service providers due to the difficulty in identifying causes and funding gaps (Kanakoudis and Gonelas, 2016). NRW is the unbilled portion of the input volume of a water supply system, which consists of unbilled authorized consumption, commercial losses, and physical losses (Vermersch et al., 2016; Jang, 2018). NRW components are best assessed using the International Water Association (IWA) Water Balance (WB), provides an internationally recognized benchmark for NRW management (Liemberger, 2010; Al Washali). etc.; 2016). The initial IWA water balance can be determined using flow and pressure measurements, volumetric analysis of billed consumption, and meter accuracy tests (Lambert, 2003a, Lambert, 2003b). Changes to the IWA WB, which include unbilled consumption and the impact of the minimum tariff differential, require further analysis of billing data to determine the virtual water thus created or lost (Kanakoudis and Tsitsifli, 2014). For effective management of North Rhine-Westphalia, all these components of the water balance must be quantified and understood (Liemberger, 2010; Gungur-Demirci et al., 2018).

The first logical step in the IWA decomposition method is to estimate physical losses using the minimum night flow (MNF) analysis method (Lambert, 2003a, Lambert, 2003b). Water audits are then used to assess the components of apparent losses and unbilled authorized consumption (Gungor-Demirci et al., 2018). Water companies that base their revenue on billed quantities may not count unpaid water as NRW, although this will result in less money being spent on maintaining their infrastructure. However, according to study organization practice, revenue received but not collected is still revenue until it is written off as bad debt. The organization rarely cancels its debts because it is wholly owned by the government. Due to fixed costs, water companies also underestimate the impact of North Rhine-Westphalia (Kanakoudis et al., 2014). Many water companies and utilities around the world still report their NRW as an incremental percentage rather than quantifying and analyzing their components. As a result, their NRW mitigation strategies fail to direct proportionate efforts and financial resources to the underlying factors (Kanakoudis and Tsitsifli, 2012; Hoko and Chipwaila, 2017). NRW levels can be used as performance indicators of financial and technical efficiency of water companies, where a high NRW indicates poor corporate governance in a water company (Frauendorfer and Liemberger, 2010). This is because corporate governance affects pricing policies, revenue collection and equipment maintenance, infrastructure aging, data storage and management, and relevant workforce skills and technology. High levels of NRW result in lost sales due to customers not being billed or physically lost in the water transport and distribution system, or due to quantity being underestimated due to measurement and data processing errors (Vermersch et al., 2016). . . High losses are attributed to water quality degradation due to the entry of contaminated groundwater into water pipes through leaks when pressure is reduced due to water supply disruptions (Lee and Schwab, 2005; Kanakoudis and Tsitsifli, 2016). According to Frauendorfer and Liemberger (2010), the loss of treated water increases the cost of water production and supply, while sales decrease and investments are made to meet growing demand. This cycle continues and the main problem of stopping water leakage is not addressed. Farley et al. (2003) in their book *Losses in Water Distribution Networks* described the following five steps as guidelines for determining NRW components.

a) System Input Volume

IWA working groups have recently developed an international best practice standard method for water balance calculations (Figure 2.1) with definitions of all relevant terms as an essential first step in practical water loss management (Hirner and Lambert, 2000; Alegre et al., 2000). The annual system input volume is equal to the sum of the measured system input measurements for a fully metered system. Ideally, input meters are checked for accuracy using flow measuring devices. If discrepancies are found between meter readings and instantaneous readings, the problem should be investigated and, if necessary, the recorded quantity adjusted to reflect the actual situation.

b) Authorized Consumption

According to Lambert (2001), permitted uses include things like firefighting and training, draining pipelines and drains, cleaning supply reservoirs, filling water reservoirs, drawing water from fire hydrants, cleaning streets, watering communal gardens, public fountains, frost protection, construction water, etc. Depending on local practice, they may or may not be billed, assessed or unbilled.

c) Unbilled Unmetered Consumption

Unbilled unmetered consumption, which traditionally includes water used by utilities for operational purposes, is often seriously over estimated. This may be due to simplifications (a certain percentage of the total system input) or deliberate overestimation to "minimize" water losses. The components of unbilled unmetered use are determined and evaluated individually. For example, mains flushing, backwashing in treatment plants and firefighting.

d) Estimating Apparent Losses

According to Lambert (2001), apparent losses consist of unauthorized consumption (theft and misuse), metering and data handling errors. These quantities should preferably be calculated on the basis of structured sampling or estimated using a reliable local procedure (to be defined for audit purposes). Some figures from national reports on apparent losses (as a percentage of system import volume (SIV)): Malaysia apparent loss 9% SIV, Korea apparent loss 9.2% SIV in 1998. and Australian apparent losses of 1-3 percent SIV. Lambert (2001) also recommends that each utility attempt to estimate and manage the components of apparent losses for its own systems, rather than assuming that apparent

losses are a nominal percentage of the system's input volume based on other utilities' in numbers.

e) Unauthorized Consumption

It is difficult to provide general guidelines on how to assess unauthorized use. Estimating abuse is always a complex task and is done in a transparent and component-based manner so that assumptions can be easily reviewed later. According to Frauendorfer and Liemberger (2010), illegal consumption can be determined by subtracting the total volume of unbilled authorized, actual losses and metering inaccuracies from the the volume of non-revenue water.

2.6. Empirical Literature

Great progress has been made in developing technical strategies (pressure management, flow monitoring) and operational management to reduce physical losses, but managing water losses is more difficult for developing countries. According to Kingdom et al (2006), poor infrastructure and equipment that have not been maintained for a long time, high unbilled water due to fraud and illegal connections, or public buildings still enjoy benefits such as free water supply, as major challenges for developing countries. Many water utilities in low-income countries have tried to reduce water losses with ballanced results, and most of them face the same obstacles in implementing NRW reduction strategies. Water companies that are financially viable have greater access to external funding, including grants and loans from designated international financial institutions or organizations. Affordable water services are the most efficient and effective services that provide their customers with services that meet their needs at the lowest possible cost (Frauendorfer and Liemberger, (2010).

2.7. Theoretical and Conceptual Framework

The study was based on the water balance theory of the International Water Associations. This theory proposes that the input volume of a water supply network can be divided into two components, i.e. authorized consumption and water loss. The theory further divides authorized consumption into billed authorized consumption and unbilled authorized consumption. The theory also suggests a further division of water losses into apparent (commercial) and real losses. Finally, the theory states that billed authorized use is

revenue water, while the total unbilled authorized use, apparent losses, and real losses constitute non-revenue water.

These factors are believed to have affected the day-to-day provision of water services and thus the level of non-revenue water in the Adama water supply system. The relationship between these variables is shown in the research concept. In order to facilitate the study of the determinants of NRW in water utilities, a conceptual framework was developed to show the determinant relationship between various factors. A conceptual framework capturing the determinants of NRW in water utilities is formulated as shown in Figure 2.3.

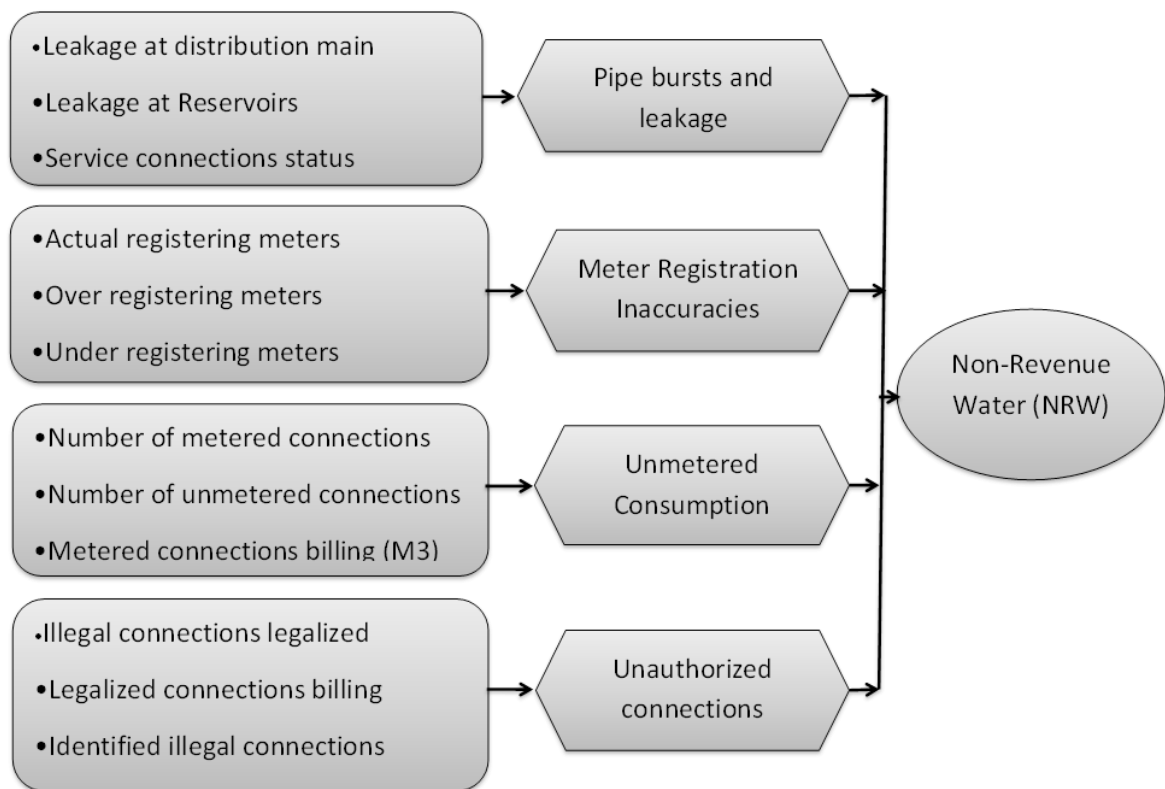


Figure 2.3 Conceptual Framework

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the Study Area

Adama City is located at 8.39° to 8.43° North latitude and 39.31° to 39.34° East longitude, and 100 km from Addis Ababa in the eastern direction. The City has an elevation between 1600 and 1700 m amsl and covers an area of 130 km². Further, the City's total population is estimated to be 529,883 out of which 264,358 are Male and 265,525 are Female as per CSA projected population (2022). The water supply of Adama City is from the Awash River, 17 km far to the southwest direction of the City and the water is delivered from the treatment plant to the end-user through pumping and gravity methods (ATWSSE, 2021). The map that describes the location of the study area is shown in figure 3.1.

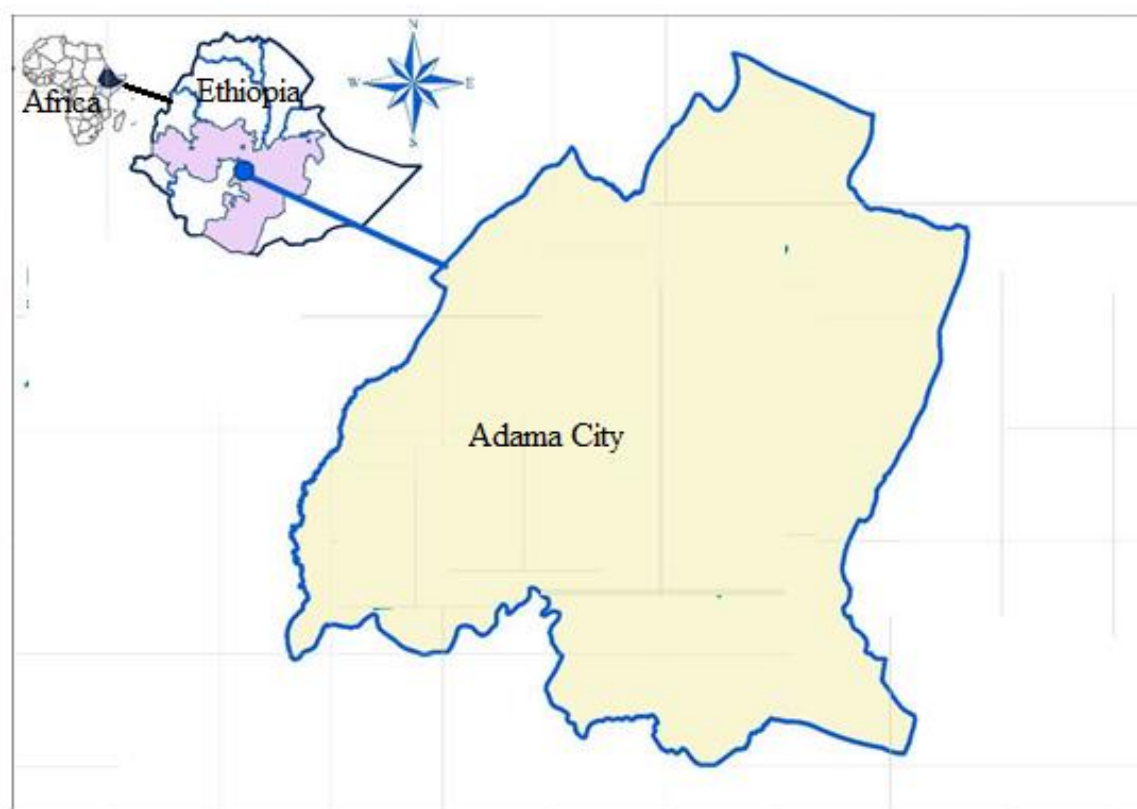


Figure 3.1 Location Map of the Study Area (Source: Adama City feasibility study report July 2012)

3.2. Existing Water Supply System of the City

Adama City water supply system was commissioned and inaugurated in November 2002. It has a modern water supply system which is managed by Enterprise and Board of administration. It was designed and implemented to cover the water demand of the town in two phases. As the 1st phase design of the system has been completed by the end of 2013; implementation of the second phase of the project on going. The system is serving both Adama City and Wonji town. The existing Water Supply System Components are summarized in the following sections (Adama Town Water Supply Feasibility study OWWDSE, 2011). At present the principal source of drinking water for the town of Adama is Awash River, located west of the City at about 11 km from the City.

The transmission main, although it may have a small number of service connections on it, it is used to convey the majority of flow from the source, treatment plant, and/or storage facilities to the distribution system where the majority of service connections are located. It is designed to transport the maximum day demand of water to service reservoirs and for peak hour demand from reservoir to distribution network. It should also be designed for peak hour demands where direct pumping is required from source and/or treatment plant to distribution system.

In general, the water distribution system includes the following significant system components.

- Service reservoirs, which are used for balancing the variable demands of the town.
- The distribution network, which distributes water to customers through its primary, secondary and tertiary components with a flow of gravity.
- Booster pumping Stations which are pumping water to the higher levels of the town where gravity flow could not have achieved by lower reservoirs.

The water pumped from Awash River of Clear pump station enters into Lugo and Abba Geda Reservoirs, which are the main storages and supply zone of the town.

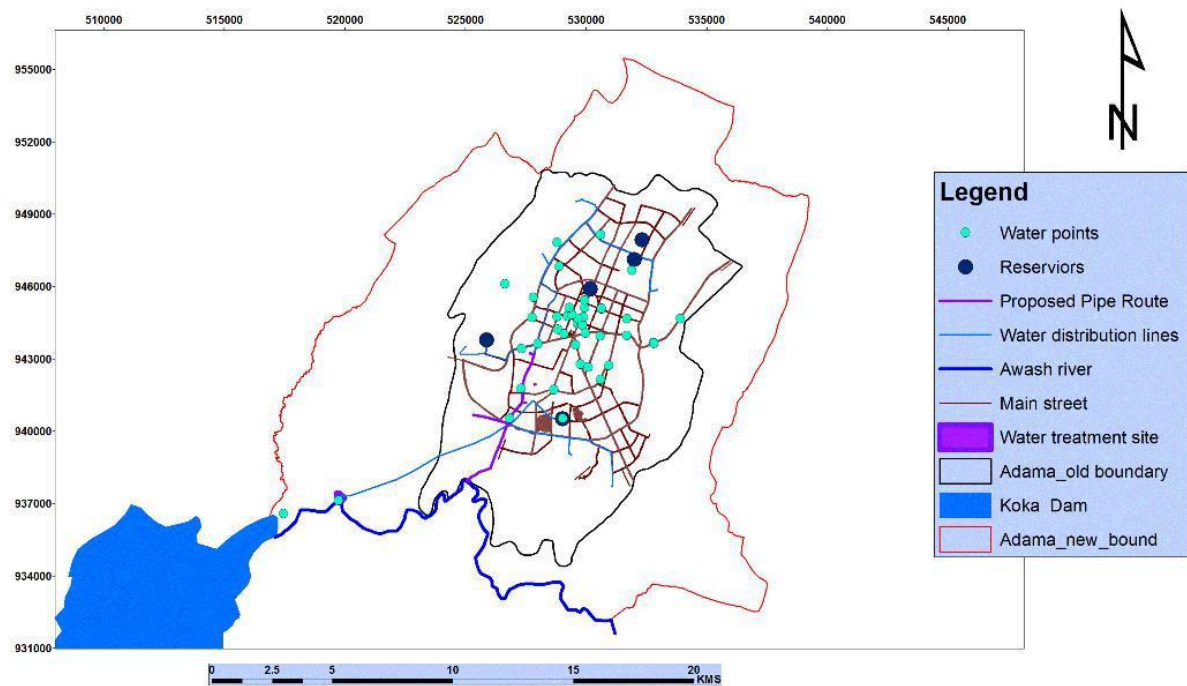


Figure 3.2: Layout and supply zones of distribution system (Source: Adama City feasibility study report July 2012)

It has been mentioned that the distribution system has been divided into 5 pressures zones. Each supply zone has been commanded and governed by the location and ground level of respective reservoir. In general, 7 (seven) existing and recently constructed reservoirs are found. Their respective locations have been summarized and presented in Table 3.1.

Table 3.1: Location of Reservoirs

No	Name	Ground level (masl)	Size (m ³)	Location		
				Elevation	X(m)	Y(m)
1	Lugo Reservoir-1	1685	2000	1685.00	529,025.00	940,545.82
2	Lugo Reservoir-2	1685	4000	1,721.21	531,884.64	946,978.20
3	Adama University Reservoir	1720	1000	1,746.46	532,321.27	947,944.74
4	Dhaka Adi Reservoir	1745	1000	1,715.99	531,083.29	937,715.69
5	Boku Reservoir	1715	500	1,632.05	531,048.19	939,371.53
6	Gelma Aba Gada Reservoir	1750	200	1,659.00	530,205.21	945,920.17
7	Gelma Aba Gada Reservoir(2)	1757	4000	1,640.00	526,897.80	943,403.76
8	Kebele 02 Reservoir	1650	1000	1,757.00	525,885.00	943,783.00

The existing and under construction distribution Systems covers around 50% or 2575 hectares of Adama Town. The network configuration is a combination of both branched and looped type. However, a looped system is dominating due to the convenient plan of the town. The general layout of the system has been presented in Figure 3.3.

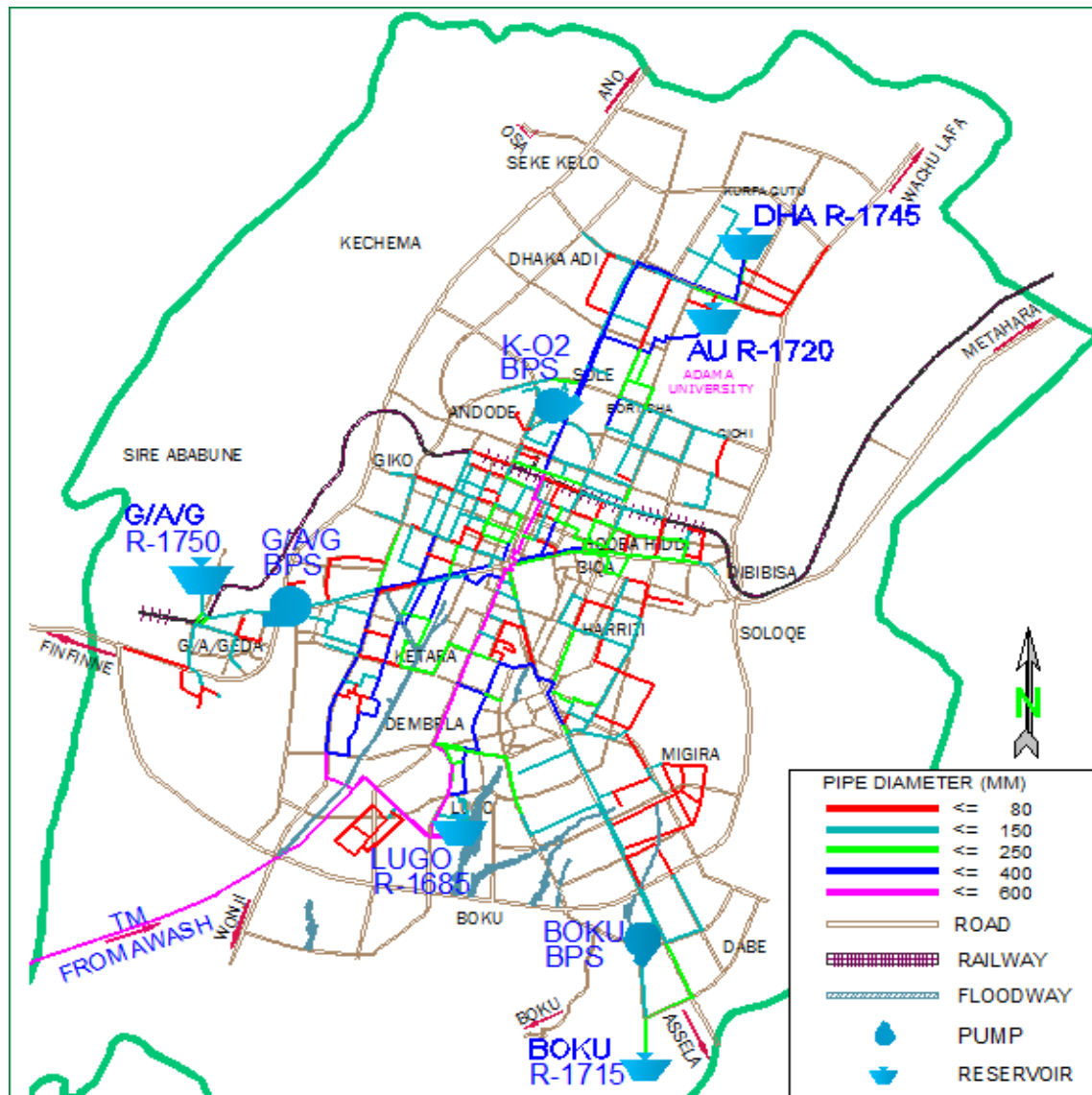


Figure 3.3: Layout and distribution system (Source: Adama City feasibility study report July 2012)

The total length of existing network is around 153.70 km. The total estimated quantities of existing and pipes new constructed are summarized in Table 3.2.

Table 3.2: Quantities of existing pipe network

Sr No	Diameter, DN (Mm)	Length (m)
1	40	870
2	50	11,020
3	65	1,440
4	80	23,770
5	100	22,530
6	150	30,670
7	200	23,480
8	250	390.
9	300	17,940
10	400	3,300
11	500	3,880
12	600	14,410
	Total	153,700 m

3.3. Research Design

According to Mugenda (2003), survey research can involve descriptive, exploratory or extended statistical analysis. The study adopted a descriptive research design. According to Orodho (2009), the survey method is ideal for gathering information through the administration of questionnaires. The project was appropriate because it used a predetermined population, in this case staff, to understand the cause of water loss. This chapter discusses the overall research design, sample size, sampling techniques used to select respondents, nature of the study, data collection techniques, tools used to collect relevant information, and data analysis. The study will be carried out by the use of literature review and field work as they have their own unique contribution to the success of the study. These two approaches will be employed in the current study work. Then again there are several methods and tools which can be used to carry out both the desk study and the fieldwork. These include; interviewing, observation, questionnaires, document reviews and direct correspondence. This research tried to thoroughly examine the factors for NRW at Adama City Water Supply service. The research also used system input water and billed water to assess the factors to determine water being lost.

3.4. Target Population

In this study the target population was the staff of Adama City Water Supply and Sewerage Service Enterprise. A total of 35 members of staff of AWSSE from Administration, Technical and Finance departments were targeted in this study. The target population is as shown in Table 3.3.

Table 3.3 Target Staff of Adama Water Supply and Sewerage Service Enterprise

Department	Number of staff
Administration	7
Technical	26
Finance	2
Total	35

3.5. Methods of Data Collection

The study used both primary and secondary data sources. To obtain the primary data, questionnaires and face to face interviews were used. Semi structured questionnaires designed to comprise queries focusing at general understanding of water lost. Observations on some process and operational systems have been made to collect information on how the system is working by taking all necessary information. The secondary sources include AWSSE reports, past research and documents. Different Operational and Management books, journals and other research materials were also reviewed. Using a questionnaire lets in every player to get a comparable assessing device to complete which may also bring about standardized responses. All through the questionnaire of completion method, if any trouble arises, the researcher or the assistants are available despite the fact that they continue to be inside the heritage (De Vos, 2001). The usage of a questionnaire also gets rid of a scenario in which the researcher is to be had but the respondent to be interviewed isn't to be had as when the usage of an interview in a qualitative observes (Burns, 2000).

Primary Data Collection

According to Mugenda (2003), survey research can involve descriptive, exploratory or extended statistical analysis. The study adopted a descriptive research design. According to Orodho (2009), the survey method is ideal for gathering information through the

administration of questionnaires. The design was appropriate because it uses a predetermined population. In this case, the employees are the target group that provides information about the cause of the water loss. The questionnaire method of data collection is used to collect primary information. Interviews were also conducted with selected employees, focusing on the incoming water of the system, the distribution system, the charged water and the overall performance of the water supply system. From the Questionnaire designed and distributed to individual respondents of Adama City Water Supply and Sewerage Service Enterprise, the extent of factors influencing non-revenue water in the system were identified and prioritized depending on their level of influence. Field visits were conducted as supplementary tools for descriptive data collection and observation. Field visits were made to Koka Treatment plant site and distribution pipe line sites to observe the operation of the systems.

Secondary Data Collection

Data on population of Adama City, Adama Water Supply and Sewerage Service Enterprise customer category and quantity, annual water production and Consumption (billed or revenue water) of the last five years including 2015 EFY nine month. Water loss figures were referred from previous literatures and articles.

3.6. Sampling Techniques

Sampling is the process of selecting a certain number of individuals or targets from a population so that the selected individuals become representative of the population as a whole (Mugenda and Mugenda, 2003). Descriptive sampling was used in this study of 35 employees. The study used a predetermined population; in this case the workers were the target population to provide information about the cause of non-revenue water.

In this study, the target population is staffs of the Adama Water Supply and Sewerage Service Enterprise. Management staff members and technical staff were included in the samples. Since the research method is case study, the research uses information-oriented sampling instead of random sampling. Questionnaire was designed and distributed to individual respondents of Adama City Water Supply and Sewerage Service Enterprise. A total of 35 members of the Utility staff were considered for the study. These are composed of Head office and six sub-offices in the Adama City, Wonji sub-office and Koka sub-office. Eight heads of offices from all sub offices and one head of Technical unit from

Head office participated in the questionnaire data collection. In addition, twenty three technical staffs with varying number of composition and two financial staffs from Head office were participated.

3.7. Methods of Data Analysis

The questionnaires were edited to check on completeness, clarity and consistency in answering research questions. The data was coded, tabulated and analyzed. Descriptive statistics and correlations were computed and study findings were presented using tables, charts and percentages. Both quantitative and qualitative data analyses were applied. The data thus tabulated and analyzed on descriptive statistical methods to summarize the understanding and existing situation. Focus was made to compare the data output with the international best practices to arrive at the reliable conclusions. The model of WB (Water Balance) was used to evaluate the current practice of water losses. The current water losses figures were compared with the international average, with African average and with Federal Republic of Ethiopia water loss figures MoWIE (2006). AWWA Water Audit software was used for data analysis.

Liemberger and Farley (2005), listed the key data required for a real loss component analysis of a water distribution system as; Total length of pipe network and number of service connections, average service connection length between curb-stop and customer meter, total number of distribution mains repairs per year (reported and unreported) and total number of service connection repairs per year (reported and unreported). Average system pressure across the entire network is estimates of the time periods for awareness, location and repair duration and estimates of utility storage tank leaks and overflows.

The water audit method recommended by the International Water Association and the American Water Works Association (IWA\AWWA) is implemented to quantify the amount of water supplied from the service tank throughout the distribution system, customer consumption, and apparent and actual loss amounts. The analysis used a top-down approach to the water audit process to gather information from existing records, procedures, data and other information systems.

Top- down Water Balance

Using the IWA “best practice” standard water balance, real loss is the difference of

volume when the volumes of authorized consumption and apparent losses are taken from the system input volume. To cater for errors and uncertainties in the calculated values, 95% confidence limits are usually used in the calculations.

Procedure for the assessment of NRW adopted as explained below.

- i. Quantify the volume of water supplied to the distribution system: The water supplied volume was calculated automatically by the Audit Software after the individual inputs of volume from own sources, water imported, water exported and their respective master meter error adjustments are quantified and input by the auditor.
- ii. Quantify Authorized Consumption: Authorized consumption is any water delivered for consumptive purposes that are authorized or approved by the water utility, thereby providing a benefit to the community. The Authorized Consumption volume is calculated by the Audit Software as the sum of the four subcomponents of Billed Metered Consumption, Billed Unmetered Consumption, Unbilled Metered Consumption and Unbilled Unmetered Consumption.
- iii. Calculate water losses and quantify Apparent and Real Losses: Water losses are made up of apparent losses and real losses. Apparent Losses are comprised of systematic data handling errors, customer metering inaccuracies and unauthorized consumption. The audit software calculates Current Annual Real Losses simply as total water losses minus apparent losses.
- iv. Calculate Non-Revenue Water: NRW consists of the sum of Unbilled Metered and Unbilled Unmetered Consumption, Apparent Losses and Real Losses. NRW can also be calculated as the water supplied minus the sum of Billed Metered and Billed Unmetered consumption.
- v. Collect Distribution System and Cost Data: In this task length of mains, the number of active and inactive service connections, average length of customer service line, average operating pressure, total annual cost of operating water system and customer retail unit cost to be calculated.
- vi. Determine System Attributes: Unavoidable Annual Real Losses (UARL) which represents the minimum level of leakage that could be achieved in a system that is well managed and in good condition, at a given average pressure level and cost impact of apparent and real losses are to be calculated.

Calculation and Analysis of Important Performance Indicators

The establishment of a standardized water balance provides the water utility with reliable figures for the amount of real and apparent losses in their water supply system.

Operational Efficiency Performance Indicators (OPI)

a) Apparent Loss per Service Connection:

It was an important operational indicator in order to determine the volume of apparent losses per service connection in the distribution system. Also, it was very essential to compare and contrast among distribution system.

$$\text{Apparent loss (l/con/day)} = A_{\text{pparent}} / N_c$$

Where A_{pparent} is Volume of apparent loss per day (m^3/day), N_c is Number of service connections.

b) Real Losses per Service Connection:

The importance of this performance indicator is to calculate competence of water supply system.

$$\text{Real loss (l/con/day)} = V_{\text{real}} / N_c$$

Where: V_{real} is the volume of real loss per day (m^3/day). N_c is Number of service connections.

Leakage management practitioners around the world are well aware that Real Losses will always exist even in new and well managed systems. It is just a question of how high these unavoidable losses will be. The first IWA Water Loss Task Force developed and published, in 1999, the following equation for predicting the UARL for well-maintained systems with infrastructure in good condition. The UARL is used to calculate the Infrastructure Leakage Index (ILI), a non-dimensional performance indicator for operational management of Real Losses.

$$\text{UARL (liters/day)} = (18 \times L_m + 0.8 \times N_c + 25 \times L_p) \times P$$

Where:

L_m = Mains length (km);

N_c = Number of service connections;

L_p = Total length of private pipe, property boundary to customer meter (km);

P = Average pressure in (m).

- vii. Real Loss Performance Indicators: The IWA/AWWA Audit Method published

in Performance Indicators for Water Supply Services (Alegre et al. 2000) includes a highly useful array of performance indicators, which represent one of the greatest strengths of the method. With this methodology, multiple indicators of varying detail became available to water utilities, allowing a realistic assessment of water loss standing. Water Audit suggested two types of performance indicators like Financial Performance Indicators comprises non-revenue water by volume and non-revenue water by cost and Operational Performance Indicators comprise apparent losses and real losses performance indicators in which ILI is the best real losses performance indicator for comparisons among systems.

$$ILI = CARL/UARL$$

Where: ILI = Infrastructure Leakage Index

CARL = Current Annual Real Losses in m³ and

UARL = Unavoidable Annual Real Losses in m³

- viii. Compile the Water Balance: After all data was entered into the audit software quantities from the key consumption and loss components can be shown on the water balance.
- ix. Assess the Data Validity Score: After all the data was entered into the audit software and performance indicators were reviewed, the data validity score was reviewed which was calculated for the water audit.

3.8. Ethical Consideration

Dealing with a water problem is sensitive issue there could be some resistance from the sample respondents in answering and filling some of the questions in the questionnaires by forwarding their real opinion. To avoid or minimize the expected resistance by some of the respondents in filling and describing the questions genuinely, the objective of the study was explained to create positive attitude and also avoid any negative impressions that can be created on the participants. Acknowledge the participants that the study is to serve for academic purpose only. Ensuring the participants that the information they gave is kept confidential and as there is no need of writing their name or personal descriptive. The respondent's information was not passed to any third party. The respondent's names were also not written on the questionnaires.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter deals with result and discussions of findings collected from Adama Water Supply and Sewerage Service Enterprise (AWSSSE) staff based on assessment of determinants of non-revenue water in water supply services in Adama City, Ethiopia. The study sampled 35 AWSSSE staff members. The data was interpreted as per the research questions. The analysis was done through descriptive and inferential statistics. The findings were presented in form of frequency tables and percentages. Data has been organized, analyzed, presented, interpreted and discussed as per the objectives of the study and demographic information of respondents handled comprehensively.

4.2 Questionnaire Response Rate and Demographic Characteristics of Respondents

A total of 35 staff members of AWSSSE were sampled and 32 were returned dully filled. Hence, the questionnaire response rate was 91.4% as shown in table 4.1.

Table 4.1: Questionnaire Return Rate

Department	Sample size	Questionnaire return		Percentage of sample return rate
		Returned	Not	
Administration	8	7	1	87.5
Technical	23	21	2	91.3
Finance	2	2	0	100
Total	35	32	3	91.4

The study sought to find out the background information of the demographic characteristics of the respondents. This was meant to provide the basis of understanding the composition of the respondents and to determine their Sex, Age brackets, Educational status, work experience in the Utility and their department category. These social attributes were relevant to the study since they enabled the respondent to provide information that is valid, reliable and relevant to the study. The responses are shown in Tables below.

Most of the respondents participated in the assessment are staffs in the technical department which are made up of technicians or technical assistants. This department

deals with water supply operation and maintenance. Therefore, it is central in providing data related to factors influencing NRW in the water sector in Adama City Water Supply and Sewerage Services Enterprise. Some Administrative (Head of sub-offices and Unit) staffs and financial staffs working on the issue under study were also included in the selected respondents as shown in the Table 4.2 and Table 4.3.

Table 4.2: Respondents by Department (Unit) and by Sex

Department	Male	Female	Total
Management	7	0	7
Technical	23	0	23
Financial	1	1	2
Total Sum			32

Table 4.3: Respondents by Educational Level and Service Year

Respondent	Education Level			Service Year			
	Diploma	BSc/BA	MSc/MA	<2	2-5	6-10	>10
Quantity	2	26	4	1	4	18	9
%	6.25	81.25	12.5	3.12	12.5	56.25	28.13

Majority of the respondents (56.25%) had worked at Adama WSSSE for the duration of between 6 to 10 years followed by respondents (28.13%) which had worked for more than 10 years in the Utility. These results show that majority of the employees at Adama WSSSE have worked for longer periods and have knowledge on the NRW and its contributing factors. They were, therefore, able to respond satisfactorily to questions in the questionnaire for the study. The distribution of respondents' year of experience is shown in Table 4.3.

4.3 Customer Category of Adama City WSSSE

The study sought to find out more about customer category as a third characteristic. There are Domestic, Commercial, Industrial, Organizational, Public Institutions; Community water taps (Bonos) and NGO category. Out of the total 79,827 customers the

majority are Domestic customers that are 74,290 (93.06%) while the remaining are non-domestic totaling 5,537 (6.94%) customers. Analysis of the consumer category of the City was carried out and shown in Table 4.4.

Table 4.4: Adama City WSSSE Customer Category and Quantity of users

Sr. No.	Customer category	Number of Active customer	%
1	Domestic consumer	74290	93.06
2	Commercial consumer	3868	4.85
3	Industrial consumer	126	0.16
4	Organization /Company	1061	1.33
5	Public institution /Mosque, Church/	118	0.15
6	Community(Bono)	272	0.34
7	NGO	92	0.12
	Total Active Customers	79827	100

4.4 Factors determining Non-Revenue Water of Adama Water supply system

The questionnaire distributed to individual respondents of Adama City Water Supply and Sewerage Service Enterprise filled and returned within specified time frame given with a response rate of 91.4% (32 from 35). The respondents asked in the questionnaire to identify the influencing factors from Pipe bursts and leaks, Meter Registration inaccuracy (Metering errors), Unbilled unmetered consumption, Unauthorized consumption (illegal connections) and others (if any). They were also asked to prioritize them depending on their level of influence by ranking. Therefore, the extent of factors influencing non-revenue water in the system were identified and prioritized depending on their level of influence.

In addition, from the field visits were made to Koka Treatment plant site and distribution pipe line sites operation of the Treatment plant, pipe bursts and leaks in the distribution system were observed. At the Koka Treatment plant, it has been briefed by the operators

on the water loss due to backwash, silt and evaporation but difficult to measure as the Supervisory Control and Data Acquisition (SCADA) was not working at the time of the visit. About 1900 m³/hour raw water is entering in to the treatment plant from Awash River source.

From the findings in Table 4.7, the respondents indicated that bursts and leaks influence the level of non-revenue water in the organization to a great extent as expressed by a 32.8% followed by unauthorized (illegal) connections 22.4%, Meter registration inaccuracy 20.7% and unbilled unmetered consumption 31%. Depending on the respondents' response, the overall level of influence of each factor considered in the study summarized in the Table 4.5 from the detail in Annex-2.

Table 4.5: Extent of factors influencing the level of the Non-revenue water in Adama WSSSE

Factors	Response	Frequency	Percentage
Pipe Bursts and leaks	Yes	19	32.8
Meter registration inaccuracy	Yes	12	20.7
Unbilled unmetered consumption	Yes	9	15.5
Unauthorized connections	Yes	18	31
Total		58	100

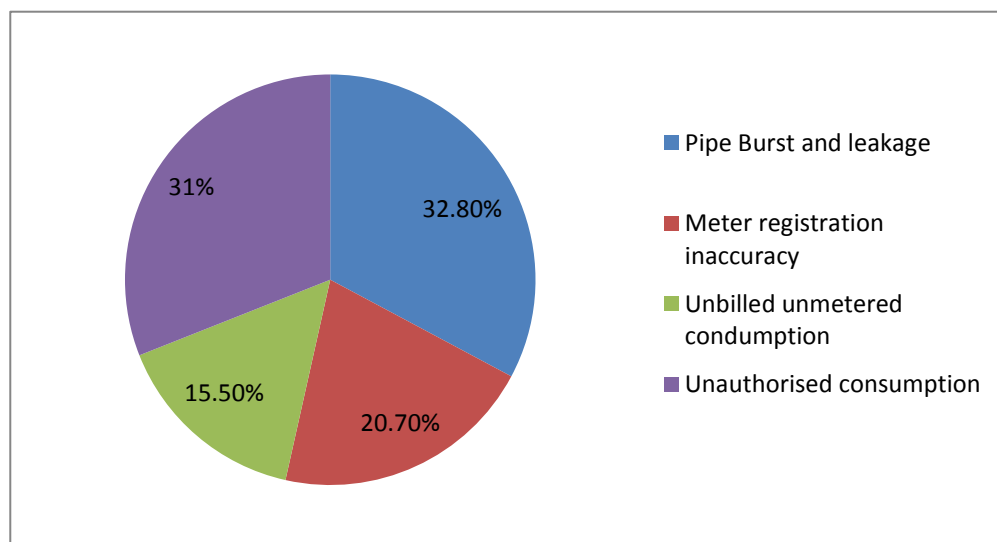


Figure 4.1: Respondents percentage of determinants of NRW of Adama WSSSE

4.4.1 Physical loss (Pipe bursts and leaks)

The first objective of the research study is to establish the extent to which water bursts and leaks influence non-revenue water in Adama Water Supply System. To achieve this objective, respondent were asked to respond to several statements intended to establish whether the number of bursts and leaks are to the magnitude to actually affect non-revenue water and also to assess the level of responsibility among the public when they come across them. Data collected was analyzed under the question how water bursts and leaks influence non-revenue water in Adama water supply system. The study sought to establish the level of contribution of bursts and leakages to the overall level of NRW in the organization. The findings are shown in Table 4.6.

Table 4.6: Factors for Pipe bursts and leakage in Adama WSSSE

Factors	Response	Frequency	%
Age	Yes	16	38.1
Pressure	Yes	11	26.2
Quality	Yes	11	26.2
Others	Yes	4	9.5
Total		42	100

4.4.2. Meter Registration Inaccuracies

The second objective of the study sought to assess the extent to which water meter registration inaccuracies-related factors such as meter class, meter brand, meter age and meter material influenced non-revenue water at Adama water supply scheme. This section therefore presents findings from respondents on the influence of water meter registration inaccuracies to non-revenue water as in the Table 4.7.

Table 4.7: Factors for meter registration inaccuracy in Adama WSSSE

Factors	Response	Frequency	Percentage
Meter reading error	Yes	20	42.6%
Billing error	Yes	15	31.9%
Corruption	Yes	8	17%
Others	Yes	4	8.5%
Total		47	100%

4.4.3. Unbilled Unmetered Consumption

The third objective of the study sought to establish how unbilled unmetered consumption influenced non-revenue water at Adama water supply scheme. The respondents response on issues related to unbilled unmetered consumption were analyzed and conclusions were made based on the frequency of opinions made per item in relation to non-revenue water against the respective non-revenue water levels recorded. This section therefore presents findings on the relationship between unbilled unmetered consumption and non-revenue water as in Table 4.8.

Table 4.8: Factors for unbilled unmetered consumption in Adama WSSSE

Factors	Response	Frequency	%
Illegal connections	Yes	19	46.3
Meter bypass	Yes	12	29.3
Poor billing collection system	Yes	8	19.5
Others	Yes	2	4.9
Total		41	100

4.4.4. Unauthorized Consumption (Illegal connections)

The fourth objective of the study sought to examine how unauthorized (illegal) consumption influenced non-revenue water levels at Adama water supply scheme. During the study, respondents opinion on issues related to unauthorized (illegal) consumption were analyzed and conclusions were made based on the frequency of opinions made per item in relation to non-revenue water against the respective non-revenue water levels

recorded. This section therefore presents findings on the relationship between unauthorized consumption and non-revenue water shown in Table 4.9.

Table 4.9: Factors for unauthorized (illegal) consumption in Adama WSSSE

Factors	Response	Frequency	%
High water tariff	Yes	9	22
Corruption	Yes	12	29.3
Intermittent water supply	Yes	8	19.5
Individual perception	Yes	6	14.6
Others		6	14.6
Total		41	100

4.5 Data Analysis using AWWA Water Audit Software

American Water Works Association (AWWA) Water audit software was used for the analysis. The International Water Association water balance is an approach applied worldwide for determining and analyzing water losses in water distribution systems (WDS) up to the point of customer metering. Thus, water losses occurring ‘before’ a customer meter are at the expenses of the water utility while water lost or wasted ‘after’ the meter is paid for by the customer. Data from Adama City WSSSE (Water Supply and Sewerage Service Enterprise) was used to go through the system analysis considering IWA Water Balance components. The system input and Billed Metered Consumption were used in the software to estimate the remaining IWA Water Balance components. The International Water Association (IWA) developed a standard international water balance structure, a concept that has been adopted by national associations in many countries across the world. Table 4.10 shows Adama City Water produced consumed and lost for the year 2014 EFY.

The supply time is another issue to be considered in the calculation and analysis of the NRW in a given water supply system. The volume of water lost from existing system at a given pressure depends on the leak run time (Rudolf F et al).

Table 4.10 Water Production, consumption and Loss of AWSSSE (2011 -2015 EFY)

Year	Water Production (m ³ /year)	Water Consumption (m ³ /year)	Loss (NRW)	NRW (%)
2011	13,782,322	10,787,558.40	2,994,763.60	21.73%
2012	14,289,935	11,332,657.50	2,957,277.50	20.12%
2013	14,576,609	11,661,287.20	2,915,321.80	20%
2014	14,842,289	11,873,831.00	2,968,458.00	20%
2015 (9 month)	12,031,732	9,668,160.00	2,363,572.00	19.64%

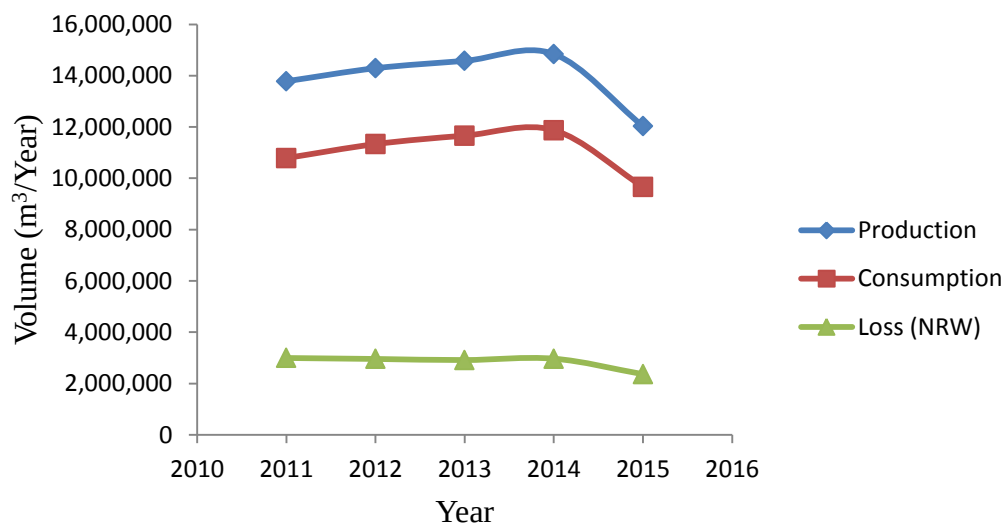


Figure 4.2 Yearly Water Productions, Consumption and Loss for 2011 – 2015 EFY

Considering continuous water supply system, the amount of water that was distributed and consumed by customers of Adama City based on the data from 2011 to 2015 EFY is as shown in the Table 4.12 above. The percentages of water loss or NRW for these years were almost the same ranging from 19.64% in nine months of the 2015 EFY to 21.64% in 2011 EFY with average water loss or NRW amount of 20.4%. Since, the data for 2015 EFY is only that of nine months, 2014 EFY data is considered for analysis.

NRW = System Input Volume – Billed amount

NRW = 14,842,289 – 11,873,831.00 = 2,968,458.00 m³/year.

The value of NRW in percent can be calculated as:

$$\text{NRW (\%)} = \frac{(\text{Volume of Input System} - \text{Billed Official Consumption})}{\text{Volume of Input System}} \times 100\%$$

$$\text{NRW (\%)} = (2,968,458.00/14,842,289) \times 100\% = 20\%$$

In this continuous water supply system consideration, the percentage of NRW was 20% of the water distributed. The result shows that NRW is greater than the acceptable amount of 15% of the distributed water and can be classified as high level (MoWIE 2006).

In Top down Water Balance method, first, the Apparent Loss components are estimated and the Real Loss volume is then calculated from the volume of Water Loss. After determining the system input volume and billed consumption (BC), the NRW volume can be calculated using Eq. (1). The WL volume is then calculated by subtracting the UAC from the NRW volume [Eq. (2)]. The AL is then estimated by investigating and/or assuming its subcomponents, that is, the meter inaccuracies, data handling errors, and unauthorized consumption (UC) (Arregui et al., 2007; AWWA, 2016).. The water balance can indicate the level and amount of water loss both physically and non-physically in a water supply system. Its calculation has the following steps:

Step 1: Determine the system input volume

$$\text{System input volume} = 14,842,289 \text{ m}^3/\text{year} \text{ ----- A}$$

Step 2: Determine the Billed authorized consumption (Revenue Water)

$$\text{The Billed authorized consumption} = 11,873,831.00 \text{ m}^3/\text{year} \text{ ----- B}$$

Step 3: Calculate the water loss

$$\text{The water loss} = 14,842,289 - 12,059,359.61 = 2,782,929.39 \text{ m}^3/\text{year} \text{ ----- C}$$

Step 4: Calculate Apparent Loss

Apparent losses are water meter inaccuracies, data handling errors and unauthorized consumptions.

- Customer Metering Inaccuracies = 29,758.98
- Unauthorized Consumption = 37,105.72

$$\text{Therefore, AL} = 29,758.98 + 37,105.72 = 66,864.73 \text{ m}^3/\text{year} \text{ ----- D}$$

Step 5: Calculate physical loss

The physical loss= (C) – (D) = 2,782,929.39 - 66,864.73 = 2,716,064.66 m³/year ... E

Step 6: Calculate the water balance /Non-Revenue Water

Figure 4.8 present the amount of NRW which was 2,968,458 m³/year (20%) with high level of water loss that was 2,782,929.39 m³/year (19.8%). The water loss was divided in to physical water loss 2,716,064.66 m³/year (19.22%) and Apparent Loss 66,864.73 m³/year (0.58%). Computation of the components of Non-Revenue Water for Adama WSSSE using AWWA Water balance software was done based on the International Water Association (IWA) and the results are summarized in the Figure 4.3.

The current water supply time for the Adama water supply system was not fully 24 hours continuous supply system. In most of the City's, the users are getting water at varying time interval and it is an intermittent supply with an average run time of 12 hours supply per day. The volume of water lost from existing system at a given pressure depends on the leak run time. As the system is operating intermittently a 20% loss indicated in a system with 12 hours supply per day means that the loss level of the system, assuming 24/7 service, would be doubled and it is 40% loss.

Water Supplied	Authorized Consumption 12,059,359.61 m³	Billed Authorized Consumption 11,873,831 m³	Billed Metered Consumption (inc. water exported) 11,873,831 m³	Revenue Water 11,873,831 m³
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption 185,528.61 m³ (1.25%)	Unbilled Metered Consumption 0.00	Non-Revenue Water (NRW) 2,968,458 m³ (20%)
			Unbilled Unmetered Consumption 185,528.61 m³ (1.25%)	
	Water Losses 2,782,929.39 m³ (18.75%)	Apparent Losses 66,864.73 m³ (0.45%)	Unauthorized Consumption 37,105.72 m³ (0.25%)	
			Customer Metering Inaccuracies 29,758.98 (0.2%)	
			Systematic Data Handling Errors	
		Real Losses 2,716,064.66 m³ (18.3%)	Leakage on Transmission and/or Distribution Mains Leakage and Overflows at Utility's Storage Reservoirs Leakage on Service Connections	

Figure 4.3: AWWWA Water Balance showing NRW components for the year 2014 EFY

Top-Down Water Balance approach AWWA/ IWA used to quantify real and apparent losses. The quality of the water audit is directly dependent upon the quality of the input data. The system input was 14,842,289 m³/year with 11,873,831.00 m³/year Billed metered consumption were used from the Utilities annual report and put in to the software and the software result the annual NRW of 2,968,458.00 m³/year constituting 20.00%. From the result total water loss in the year was 2,782,929.39 m³/year (18.75%) and unbilled unmetered water consumption was 185,528.61 m³/year (1.25%). Physical losses (Real losses) constitute 2,716,064.66 m³/year (18.3%) while components of Apparent losses like Meter registration inaccuracy 29,758.98 (0.2%) and Unauthorized connection 37,105.72 (0.25%). The quantity of Revenue Water and Non-Revenue Water for 2014 EFY are shown in Table 4.11 and also the NRW components quantity from AWWA Water Audit software is as in Table 4.12.

Table 4.11: Amount of Revenue Water and Non-Revenue Water for year 2014 EFY

Component	Quantity (m³/Year)	Percentage (%)
Revenue Water	11,873,831.00	80
Non-Revenue Water	2,968,458.00	20

Table 4.12: Percentage of components of NRW from AWWA water audit software

Component	Quantity (M³/Year)	%
Physical (Real) Loss	2,716,064.66	18.3
Meter registration inaccuracy	29,758.98	0.2%
Unbilled unmetered consumption	185,528.61	1.25%
Unauthorized connections	37,105.72	0.25%
Total NRW		20%

Step 7: Determine System Attributes:

- a) Apparent loss per service connection

$$\text{Apparent loss (l/con/day)} = V_{\text{apparent}} / N_c$$

$$= 66,864,730 \times 10^6 / 365 \times 79827 = 66,864,730,000 / 29,136,855$$

$$= 2294.85 \text{ l/conn/day}$$

- b) Real loss per Service connection

$$\text{Real loss (l/con/day)} = V_{\text{real}} / N_c$$

$$= 2,716,064.66 \times 1000 / 79827 \times 365 = 2,716,064,660 / 29,136,855$$

$$= 93,217.5 \text{ l/conn/day}$$

Real loss per service connection per head = Real loss (l/con/day)/60 = 1553.63
l/conn/day/m

- c) UARL (m³/year) = (6.57 x Lm + 0.292 x Nc + 9.132 x Lp) x P

Lm = mains length (km),

Nc = number of service connections (main to property line)

Lp = total length of underground pipes, property line to meter = Nc x lp/1000 (km),

= 79827*0.006, P = average pressure (metres)

$$\text{UARL (m}^3\text{/year)} = (6.57 \times L_m + 0.292 \times N_c + 9.132 \times L_p) \times P$$

$$= (6.57 \times 153.7 + 0.292 \times 79827 + 9.132 \times (79827 \times 0.006)) \times 60$$

$$= (1,009.81 + 23,309.45 + 4,373.88) \times 60 = 28693.14 \times 60 = 1,721,588.4 \text{ m}^3\text{/year}$$

- d) CARL = 2,716,064.66 m³

- e) Infrastructure Leakage Index (ILI)

ILI is the measure of how well a distribution network was managed, maintained, repaired, and rehabilitated for the control of real loss, at the current operating pressure.

It can be calculated as:

$$ILI = CARL / UARL$$

Where:

ILI = Infrastructure Leakage Index

CARL = Current Annual Real Losses and

UARL = Unavoidable Annual Real Losses

$$ILI = CARL / UARL = 2,716,064.66 / 1,721,588.4 = 1.577 = 1.6$$

4.6. Discussions

The study utilized a total of 35 purposive respondents selected based on the knowledge of the issue under study and their direct involvement with operation, management and maintenance of the City water supply system. The selected respondents are from main Office and six sub offices in Adama City, Wonji town water supply Office and Koka sub office. 32 of the 35 respondents with 91.4% response rate able to discuss, fill and return the Questionnaire prepared for primary data collection.

The study established that the level of contribution of pipe bursts and leakages due to mostly age of the distribution system to the overall level of non-revenue water in the organization was high as indicated in the respondents result with 32.8% rate. It indicates that meter registration inaccuracy also determine the overall level of non-revenue water in the organization with 20.7%. Unbilled unmetered consumption constitutes 15.5% and unauthorized consumption determines the overall level of non-revenue water in the organization to significant level of 31%.

As shown in the assessments with the questionnaire and observations made, the major factor influencing the non-revenue of Adama City water supply system was physical (real) loss which is pipe bursts and leakages due to age, quality and existing pressure of the distribution system. The unauthorized consumption (illegal connections) due to corruption, water tariff, intermittent water supply and deliberate action (theft) of water were the other factor influencing the non-revenue of the town water supply system. The other factors influencing the non-revenue water of the City water supply system are meter registration inaccuracy due to water meter reading error, billing error and corruption constituting 20.7% and Unbilled unmetered consumption with 15.5% of the total Non-Revenue Water due to illegal connection, meter bypass and poor billing collection system. The result of the AWWA Water Audit Software also shows that physical losses (pipe bursts and leaks) are the major factors influencing the NRW followed by unbilled unmetered consumption, Meter registration inaccuracy and Unauthorized connections with 18.3%, 1.25%, 0.25% and 0.2% respectively. Therefore, the NRW percentage in the case of continuous water supply system is 20% while in the case of intermittent supply due to the water supply run time of average 12 hour, the water loss per day (24 hour) will be doubled and is 40%.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The study found out that the level of contribution of Pipe bursts and leakages to the overall level of non-revenue water in the Adama Water supply system was high with 32.8% respondent. Age and quality of pipes as shown by their degree of influence were high contributors for Pipes bursts and leakages in the system. The study found out also that unauthorized connection influences the overall level of non-revenue water in the organizations to extent of 31% respondents due to corruption, individual perception and tariff of water mostly at illegal settlements locally called “charaka houses”. Water meter registration inaccuracy was the third in influencing the overall level of non-revenue water in the system by 20.7% due to water meter reading error, billing error and corruption followed by Unbilled unmetered consumption was the fourth factor with 15.5% response. These were due to contributing factors including Illegal connection, meter bypassing and poor billing collection systems.

The AWWA Water Audit software result showed NRW of 2,968,458 m³/year constituting 20%. From the result total water loss in the year was 2,782,929.39 m³/year (18.75%) and unbilled unmetered water consumption was 185,528.62 m³/year (1.25%). Physical losses (Real loses) constitute 2,716,064.66 m³/year (18.3%) while components of Apparent losses like Meter registration inaccuracy 29,758.98 (0.2%) and Unauthorized (illegal) connections 37,105.72 m³/year (0.25%).

The actual water supply time for the Adama water supply system was not fully 24 hours continuous supply system. In most areas the users are getting water at varying time interval of an average run time of 12 hours supply per day which is an intermittent supply. As the system is operating intermittently a 20% loss indicated in assumed continuous supply system of 24/7 would be doubled and is 40% loss.

5.2 Recommendations

Based on the findings of this study, the following recommendations are made. In order to reduce the NRW levels at Adama water supply system, the management of Adama Water Supply and Sewerage Service Enterprise should develop and implement a NRW reduction strategy at Adama water supply scheme which should include reduction of water lost through bursts and leakages, reduction of unauthorized consumption, meter registration accuracy enhancement and reduction of unbilled unmetered consumption.

The distribution pipeline network age is a significant factor that needs rehabilitation. Improving the quantity of water supplied so that the users will get enough amount of water without interruption to avoid intermittent supply. (A new Water Supply Project is under construction to solve this problem). Improvement of water meter' reading and enhancement of billing system are also other contributors to reduce the non-revenue water. Unauthorized connections have to be avoided as much as possible by developing a mechanism by which the water distribution system serves all needy ones. Unauthorized connection has significant positive influence on non-revenue water at Adama water supply scheme; the Utility should carry out periodic customer base audit by reconciling office consumer database with field connections. Adama WSSSE should sensitize its staff on influence of unauthorized connection, on the sustainability of the company and its reflection on the integrity of the staffs. In addition, carrying out public awareness campaigns against unauthorized connection is also important. The Utility need to aware all unauthorized water users to legalize their consumption to before they get into legal action against all defaulters tracked.

REFERENCES

- AL-Washali, T., Sharma, S., and Kennedy, M. (2016). "Methods of Assessment of Water Losses in Water Supply Systems: a Review." *Water Resources Management*, 30(14), 4985-5001.
- Alegre, H., Hirner, W., and Baptista, J. (2000). *Performance Indicators for Water Supply Services. Manual of Best Practice*, IWA Publishing, London, UK.
- Arregui, F., Cabrera, E., Cobacho, R. & Garcia, J. 2006 (a), Reducing apparent losses caused by meters inaccuracies. *Water pract. Technol*, 1(4).
- Arregui, F., Cabrera, E. & Cobacho, R. 2006 (b), *Integrated water meter management*. IWA publishing, London.
- Arregui, F., Cabrera Jr, E., Cobacho, R., 2007. *Integrated Water Meter Management*. IWA Publishing, London, UK.
- AWWA (2000), *Water Sub Metering and Billing Allocation: A discussion of issues and Recommended Industry Guidelines*. An AWWA Draft White Paper, American Water Works Association, Denver, Colorado.
- AWWA. , 2003 *Development of a Strategic Planning Process*, AWWA research foundation, Denver.
- AWWA, 2016. *M36 Water Audits and Loss Control Programs*, fourth edition. American Water Works Association, USA.
- Butler, D. & Memon, F. (Eds), (2006). *Water demand management. City water system improvement* (2004), www.sequimwa.gov/index.aspx?NID_342.04/03/2013.
- Criminisi, A., Fontanazza, C.M., Freni, G. & La Loggia, G. (2009), Evaluation of the apparent losses caused by water meter under-registration in intermittent watersupply. *WaterSci.Technol*.60(9)2373-2382.
- Danilenko, A., Van den Berg, C., Macheve, B., and Moffitt, L. J. (2014). *The IBNET water supply and sanitation blue book 2014: The international benchmarking network*

for water and sanitation utilities databook, The World Bank, Washington, USA.

Fanner, P., and Lambert, A. "Calculating SRELL with pressure management, active leakage control and leak run-time options, with confidence limits." Proceedings of 5th IWA Water Loss Reduction Specialist Conference 2009, Cape Town, South Africa, 373-380.

Farley, M. (2003), "Non-revenue water - international best practice for assessment, monitoring and control" presented to 12th annual CWWA water, wastewater & solid waste conference 28th September – 3rd October, 2003 - Atlantis, Paradise Island, Bahamas. Oxfordshire UK Paper.

Farley, M., and Liemberger, R., 2005, "Developing a non-revenue water reduction strategy: planning and implementing the strategy", Water Science and Technology: Water Supply, Vol. 5 No.1, pp 41-50, IWA publishing

Farley, M., Wyeth, G., Ghazali, Z., Istandar, A. & Sher, S. "The Manager's Non-Revenue Water handbook", (2008).

Frauendorfer, R. and R. Liemberger (2010). The issues and challenges of reducing non-revenue water. Mandaluyong City, Philippines

Ismael F. (2019). Performance Evaluation of Adama City water supply system, Oromia, Ethiopia. Civil and Environmental Research, 11(9).

Kanakoudis, V., and Tsitsifli, S. (2014). "Using the bimonthly water balance of a non-fully monitored water distribution network with seasonal water demand peaks to define its actual NRW level: the case of Kos town, Greece." Urban Water Journal, 11(5), 348-360.

Kingdom, B., Liemberger, R. & Marin, P (December 2006), The challenge of reducing non revenue water in developing countries. A water supply and sanitation sector board discussion paper series, paper no.8.

Lambert, A., 2003, "Assessing non-revenue water and its components: A practical approach", Water, 21, 51-52.

- Lambert, A. "What do we know about pressure-leakage relationships in distribution systems." IWA Conference in Systems approach to leakage control and water distribution system management 2001, Brno, Czech Republic.
- Liemberger, R. & Marin, P (December 2006), The challenge of reducing nonrevenue water in developing countries. A water supply and sanitation sector board discussion paper series, paperno.8.
- Liemberger, R. "Recommendations for Initial Non-Revenue Water Assessment." IWA Water Loss 2010, São Paulo, Brazil.
- Liemberger, W. R. and Marin, P. (2006). The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries).
- Male, J. W., Noss, R. R. & Moore, I. C. (1985), Identifying and reducing losses in water distribution systems. Noyes Publications, New Jersey
- Rizzo, A. (2008), Apparent water loss control: Theory and application
- Rudolf, F., and Roland, L. (2010), "The Issue and Challenges of Reducing Non-Revenue Water" Asian Development Bank, Phillipines.
- Limberger R.; A. Wyatt (2019) Quantifying the global non-revenue water problem Water Supply (2019) 19 (3): 831–837. <https://doi.org/10.2166/ws.2018.129>
- Siraj A. (2020). Assessment of Urban water supply Situation of Adama town, Ethiopia. Journal of Civil Engineering Research 2020, 10(1): 20-28. DOI: 10.5923/j.jce.20201001.03
- Vermersch, M., Carteado, F., Rizzo, A., Johnson, E., Arregui, F., and Lambert, A. (2016). "Guidance notes on apparent losses and water loss reduction planning." LeaksSuit Library, UK.
- WHO/UNICEF. (2017). "Joint Monitoring Program for Water, Sanitation and Hygiene." World Health Organization, Geneva, Switzerland.
- World Bank, December 2006: The Challenges of Reducing Non-Revenue Water in Developing Countries

ANNEX -1 AWWA WLCC Free Water Audit Software Reporting Worksheet

AWWA WLCC Free Water Audit Software: Reporting Worksheet				Back to	
Copyright © 2010, American Water Works Association. All Rights Reserved. WAS v4.2					
Water Audit Report for: Adama WSSSE Reporting Year: 2021/22 7/2021 - 6/2022					
Please enter data in the white cells below. Where available, metered values should be used; if metered values are unavailable please estimate a value. Indicate your confidence in the accuracy of the input data by grading each component (1-10) using the drop-down list to the left of the input cell. Hover the mouse over the cell to obtain a description of the grades					
All volumes to be entered as: MEGALITRES (THOUSAND CUBIC METRES) PER YEAR					
WATER SUPPLIED					
<< Enter grading in column 'E'					
Volume from own sources:	6	14,842,289.00	Megalitres/yr (or ML/Yr)		
Master meter error adjustment (enter positive value):			ML/Yr		
Water imported:			ML/Yr		
Water exported:			ML/Yr		
WATER SUPPLIED:		14,842,289.00	ML/Yr		
AUTHORIZED CONSUMPTION					
Billed metered:	5	11,873,831.00	ML/Yr		
Billed unmetered:	6		ML/Yr		
Unbilled metered:	9		ML/Yr		
Unbilled unmetered:		185,528.613	ML/Yr		
Default option selected for Unbilled unmetered - a grading of 5 is applied but not displayed					
AUTHORIZED CONSUMPTION:		12,059,359.613	ML/Yr		
WATER LOSSES (Water Supplied - Authorized Consumption)					
		2,782,929.388	ML/Yr		
Apparent Losses					
Unauthorized consumption:		37,105.723	ML/Yr		
Default option selected for unauthorized consumption - a grading of 5 is applied but not displayed					
Customer metering inaccuracies:	8	29,758.975	ML/Yr		
Systematic data handling errors:	7	0.030	ML/Yr		
Apparent Losses:		66,864.727			
Real Losses (Current Annual Real Losses or CARL)					
Real Losses = Water Losses - Apparent Losses:		2,716,064.660	ML/Yr		
WATER LOSSES:		2,782,929.388	ML/Yr		
NON-REVENUE WATER					
NON-REVENUE WATER:		2,968,458.000	ML/Yr		
= Total Water Loss + Unbilled Metered + Unbilled Unmetered					
SYSTEM DATA					
Length of mains:	9	153.7	kilometers		
Number of active AND inactive service connections:	8	79,827			
Connection density:		519	conn./km main		
Average length of customer service line:	6	6.0	metres		(pipe length between curbstop and customer meter or property boundary)
Average operating pressure:	5	60.0	metres (head)		
COST DATA					
Total annual cost of operating water system:	7		\$/Year		
Customer retail unit cost (applied to Apparent Losses):	6				
Variable production cost (applied to Real Losses):	8		\$/Megalitre		
PERFORMANCE INDICATORS					
Financial Indicators					
Non-revenue water as percent by volume of Water Supplied:		20.0%			
Non-revenue water as percent by cost of operating system:					
Annual cost of Apparent Losses:					
Annual cost of Real Losses:					
Operational Efficiency Indicators					
Apparent Losses per service connection per day:		2294.85	litres/connection/day		
Real Losses per service connection per day*:		93,217.50	litres/connection/day		
Real Losses per length of main per day*:		N/A			
Real Losses per service connection per day per meter (head) pressure:		1,553.62	litres/connection/day/m		
Unavoidable Annual Real Losses (UARL):		1,721.39	ML/year		
From Above, Real Losses = Current Annual Real Losses (CARL):		2,716,064.66	ML/year		
Infrastructure Leakage Index (ILI) [CARL/UARL]:		1,577.83			
* only the most applicable of these two indicators will be calculated					
WATER AUDIT DATA VALIDITY SCORE:					
*** YOUR SCORE IS: 64 out of 100 ***					
A weighted scale for the components of consumption and water loss is included in the calculation of the Water Audit Data Validity Score					
PRIORITY AREAS FOR ATTENTION:					
Based on the information provided, audit accuracy can be improved by addressing the following components:					
1: Volume from own sources					
2: Billed metered					
3: Customer retail unit cost (applied to Apparent Losses)					
For more information, click here to see the Grading Matrix worksheet					

ANNEX -2 NRW Factors level of influence Prioritized by Respondents

Respondents	Factors for NRW			
	Pipe Burst and Leakage (A)	Meter Registration Inaccuracy (B)	Unbilled Unmetered Consumption (C)	Unauthorized Connection (D)
1	1	2		3
2	1	3		2
3	3	2		1
4	2	4	1	4
5	2	4	3	1
6	1			
7	1	4	3	2
8	1	2	4	4
9	2		1	3
10	1	4	3	2
11	1	4	3	4
12	1	2	4	4
13	1	2	4	4
14	1	2	4	3
15	1	4	3	2
16	3	4	2	1
17	3	2	4	1
18	2			1
19	2	4	3	1
20	1			2
21	1	3	2	4
22	1	4	3	2
23	1	3	4	2
24	1	3	4	2
25	3	4	1	2
26	2	4	3	1
27	1	4	3	2
28	5	3	1	4
29	1	3	4	2
30	1	3	4	2
31	4	3	2	1
32	4	2	3	1
Rank	Summary			
1 st	19	0	4	8
2 nd	6	8	3	18
4 th	5	8	9	7
3 rd	2	12	11	1

NB: In the Annex-2, the numbers 1, 2, 3, & 4 alongside each respondent represents priority order of factors in A, B, C & D that are influencing NRW and ranked with the summary.

ANNEX -3 Different images /photos taken during field visit /observation

Image-1: Pipe Leakage on Transmission line at area called Shekla Factory



Image-2: Illegal connection in Kebele 09 caught due to pipe burst



Image -3 Images of Water Treatment Plant at Koka

