Addis Ababa University

Addis Ababa Institute of Technology

School of civil and environmental Engineering

Stream (Water supply and environmental Engineering)

"ASSESSMENT OF NON-REVENUE WATER AND INFRASTRUCTURE LEAKAGE INDEX (ILI) APPLICABILITY: A COMPARATIVE STUDY IN ETHIOPIAN TOWNS - ADAMA, BISHOFTU, AND MOJO"

A thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil and Environmental Engineering

(Water Supply and Environmental Engineering)

Prepared By: Zelalem Tamyalew

ID: GSR/9902/14

Advisor Dr.-Ing. Geremew Sahilu

Feb, 2024
Addis Ababa, Ethiopia

DECLARATION

I, Zelalem Tamyalew Werku, hereby declare that the thesis titled "ASSESSMENT OF NON-REVENUE WATER AND INFRASTRUCTURE LEAKAGE INDEX (ILI) APPLICABILITY: A COMPARATIVE STUDY IN ETHIOPIAN TOWNS - ADAMA, BISHOFTU, AND MOJO" is entirely my original work. I affirm that this thesis has not been submitted for a degree at Addis Ababa University or any other academic institution. I acknowledge that all sources and materials used in this thesis have been duly recognized and credited.

APPROVAL

Signed by the examining Committee

1) ---------------------------------- ---------------------------------- -----------------------
Internal Examiner Signature Date

2) ---------------------------------- ---------------------------------- ---------------------
External Examiner Signature Date

3) --------------------------------- ----------------------------- ------------------------
Advisor Signature Date

4) ---------------------------------- ---------------------------------- ------------------------
Chairman Signature Date

ACKNOWLEDGEMENT

First of all, I would like to thank the almighty GOD for bestowing me with health, courage and all his blessings, throughout my life and this thesis work.

My earnest appreciation goes to my advisor Dr.-Ing. Geremew Sahilu, for his valuable support, encouragement, and criticisms.

Special thanks goes to employees of Adama water supply and sanitary enterprises, Bishoftu water supply and sanitary enterprises, and Mojo water supply and sanitary enterprises, for cooperating generously in providing important documents for this study.

I would also like to express my deepest gratitude for all my friends who supported me in this research.

Finally, yet importantly, I would like to thank my family, for their ceaseless love and unconditional support.

ABSTRACT

Water utilities in Adama, Bishoftu, and Mojo towns are experiencing significant water losses in their supply systems. To improve their efficiency, utilities need to be able to measure and assess the performance of their water supply systems. One frequently used performance indicator (PI) is the Infrastructure Leakage Index (ILI). However, the applicability of ILI performance indicators in the water utilities of these towns depends on their current conditions. This study aims to check the suitability of using the Infrastructure Leakage Index (ILI) in Adama, Bishoftu, and Mojo towns in Ethiopia. The primary and secondary data were collected to analyze the water balance and evaluate ILI. Secondary data included system input volume, authorized consumption, and unauthorized consumption, while primary data included water meter inaccuracies, customer water meter inventory, and measurement of pressure in the water supply system for the calibration of Water Gems Connect Edition update 2. The analysis revealed that the non-revenue water (NRW) is high, reaching up to 32.6%, 38.33%, and 47.33%, respectively, as a percentage of system input volume. Additionally, the total water loss for Adama, Bishoftu, and Mojo is 32%, 37.3%, and 45%, respectively, as percentage of system input volume. Of the total water loss in each town, 80.8%, 81%, and 88.33% are real losses, while the remainder is apparent losses. The study also indicates that the ILI result of the town water supply system is excellent, with values of 3.7, 4.4, and 3.3 for Adama, Bishoftu, and Mojo, respectively. However, this result contrasts with the current water loss and NRW, indicating that the ILI does not fully capture the specific challenges faced by Ethiopian towns, such as poor asset management and supply intermittency. Therefore, it is necessary to check the applicability of using ILI in Ethiopia before using it as a system performance indicator.

Key words: Ethiopia, Infrastructure leakage index, non-revenue water, Performance indicator, Water loss.

TABLE OF CONTENTS

DECLARATION I

APPROVAL II

ACKNOWLEDGEMENT III

ABSTRACT IV

TABLE OF CONTENTS V

LIST OF TABLES X

LIST OF FIGURES XII

LIST OF APPENDIXES XIV

ACRONYMS AND ABBREVIATIONS XV

1. INTRODUCTION 1
   - 1.1. Background 1
   - 1.2. Statement of the problem 2
   - 1.3. Research objective 3
     - 1.3.1. General objective 3
     - 1.3.2. Specific objective 3
   - 1.4. Research questions 3
   - 1.5. Significance of the study 4
   - 1.6. Scope and Limitations of the Study 4

2. LITERATURE REVIEW 6
   - 2.1. International Water Balance 6
   - 2.2. Non-revenue water 7
     - 2.2.1. Non-revenue water reduction strategies 10
   - 2.3. Water loss 14
     - 2.3.1. Water Losses 14

2.3.2. Factors Influencing Real Losses ... 14

2.3.3. Performance Indicators for Management of Real Losses ... 15

2.3.4. Apparent loss ... 17

2.3.5. Water loss assessment methods ... 19

2.4. Water Distribution System ... 28

2.4.1. Introduction ... 28

2.4.2. Components of A Water Supply System ... 28

2.4.3. Types of water distribution system ... 29

2.4.4. Hydraulic Models ... 30

2.4.5. Types of Hydraulic Model Software and their features ... 30

2.4.6. Applications of Water Distribution Models ... 32

2.4.7. Model calibration and validation ... 34

2.5. Infrastructure asset management (IAM) ... 35

2.5.1. Introduction ... 35

2.5.2. Integrated IAM approach ... 36

2.5.3. Water distribution system asset management ... 37

3. MATERIALS AND METHODS ... 40

3.1. Description of the study area ... 40

3.1.1. Existing water supply system ... 41

3.2. Materials and tools ... 44

3.2.1. Materials used ... 44

3.2.2. Tools used ... 44

3.3. Data collections ... 45

3.3.1. Primary data collection ... 45

3.3.2. Secondary data collection ... 45

3.4. Demand and population analysis 45
3.4.1. Population projection 45
3.4.2. Water demand 46
3.5. Hydraulic model of the water supply system 52
3.5.1. Creation of water distribution network system model and data entry 53
3.5.2. Steady-state simulation 53
3.5.3. Extended period simulation 54
3.6. Calculation of average operating pressure (AOP) 54
3.7. Model calibration and validation 55
3.7.1. Sampling Design for Calibration and Validation 55
3.8. Assessment of water loss 58
3.8.1. Minimum night flow (MNF) 58
3.8.2. Component analysis of the leakage 58
3.8.3. Water and wastewater balance method 59
3.8.4. Top-down water balance 59
3.8.5. Apparent loss analysis 60
3.9. Infrastructure leakage index (ILI) analysis 61
3.9.1. Analysis of CARL and UARL 64
3.10. Infrastructure asset management (IAM) analysis 65
3.11. Research process 65
4. RESULT AND DISCUSSION 66
4.1. Demand and population analysis 66
4.1.1. Population analysis 66
4.1.2. Water demand 66
4.2. Junction demand allocations 68

4.3. Calibration and validation of hydraulic model 70
4.4. Hydraulic model of the water supply system 77
4.5. Analysis of average operating pressure 78
4.6. Assessment of water loss 79
4.6.1. System input volume (water production) 79
4.6.2. Authorized consumption 79
4.6.3. Water loss analysis 82
4.6.4. Water balance and non-revenue water analysis 91
4.7. Assessment of Infrastructure Leakage Index (ILI) 93
4.7.1. Current annual real loss (CARL) 93
4.7.2. Unavoidable Annual Real Losses (UARL) 94
4.7.3. Infrastructure leakage index (ILI) 94
4.8. Analysis of infrastructure asset management (IAM) 97
4.8.1. Product quality 97
4.8.2. Infrastructure Strategy and Performance 97
5. CONCLUSION AND RECOMMENDATION 99
5.1. Conclusion 99
5.2. Recommendations 99
REFERENCES 101
APPENDIX 107
Appendix 1 questionary for all water utility offices and water meter inventory questionary 107
Appendix 2 Adama town Domestic water demand 110
Appendix 3 Bishoftu town Domestic water demand 111
Appendix 4 Mojo town Domestic water demand 112
Appendix 5 Total water demand analysis for Adama town 113

Appendix 6 Total water demand for Bishoftu town 115

Appendix 7 Total water demand for Mojo town 117

Appendix 9 unauthorized consumption for all study areas 118

Appendix 10 Mojo town 2013 E.C water balance 121

Appendix 11 Mojo town 2014 E.C water balance 122

Appendix 12 Mojo town 2015 E.C water balance 123

Appendix 13 Bishoftu town 2013 E.C water balance 124

Appendix 14 Bishoftu town 2014 E.C water balance 125

Appendix 15 Bishoftu town 2015 E.C water balance 126

Appendix 16 Adama town 2011 E.C water balance 127

Appendix 17 Adama town 2012 E.C water balance 128

Appendix 18 Adama town 2013 E.C water balance 129

Appendix 19 Adama town 2014 E.C water balance 130

Appendix 20 Adama town 2015 E.C water balance 131

Appendix 21 calculation of average operating pressure for Adama 132

Appendix 22 calculation of average operating pressure for Bishoftu 146

Appendix 23 calculation of average operating pressure for Mojo 156

LIST OF TABLES

Table 1.4-1research questions ... 3
Table 2.1-1 international standard water balance and terminology- IWA ... 7
Table 2.2-1-NRW volume and cost/value per region ... 8
Table 2.3-1Methods for water loss component assessment ... 26
Table 2.4-1Model calibration standard ... 35
Table 3.4-1population growth rate ... 46
Table 3.4-2urban per-capita per day water demand in liters (Adama, Bishoftu, and Mojo) ... 48
Table 3.4-3climate adjustment factor based on altitude and mean annual temperature ... 49
Table 3.4-4socio-economic adjustment factor ... 49
Table 3.4-5Water Demand Peak Factors ... 52
Table 3.9-1Components of water balance ... 62
Table 4.1-1Adama, Bishoftu, and Mojo town population forecast ... 66
Table 4.3-1 Calibration of model result with field measured data for Adama town ... 71
Table 4.3-2 Validation of model result with field measured data for Adama town ... 72
Table 4.3-3 Calibration of model result with field measured data for Bishoftu town ... 73
Table 4.3-4 Validation of model result with field measured data for Bishoftu town ... 74
Table 4.3-5 Calibration of model result with field measured data for Mojo town ... 75
Table 4.3-6 Validation of model result with field measured data for Mojo town ... 76
Table 4.4-1Pressure @ ADD for all study areas ... 78
Table 4.6-1Billed unmetered consumption ... 81
Table 4.6-2Unbilled metered consumption ... 81
Table 4.6-3Unbilled unmetered consumption ... 82
Table 4.6-4Total water loss for Adama, Bishoftu and Mojo towns ... 82
Table 4.6-5Average percentage of total water loss as system input volume ... 83
Table 4.6-6Unauthorized consumption ... 84
Table 4.6-7Adama town water meter inventory ... 85
Table 4.6-8Adama, Bishoftu and mojo towns amount of water loss by water meter inaccuracies ... 90
Table 4.6-9Average percentage of apparent loss as total water loss ... 90
Table 4.6-10Average percentage of real loss as total water loss ... 91

Table 4.6-11Average percentage of non-revenue water (NRW) as system input volume 91
Table 4.7-1Adama, Bishoftu and Mojo CARL (current annual real loss).................................... 93
Table 4.7-2 Adama, Bishoftu and Mojo town Unavoidable annual real losses (UARL) 94
Table 4.7-3Adama, Bishoftu and Mojo towns infrastructure leakage index (ILI) 95

LIST OF FIGURES

Figure 2.2-1 Regional NRW levels 9
Figure 2.2-2 Levels of % non-revenue water (NRW) for selected countries in Sub-Saharan Africa. 9
Figure 2.2-3 Strategies to reduce NRW 11
Figure 2.3-1: The Four Basic Methods of Managing Real Losses 16
Figure 2.3-2 Water loss assessment stages 19
Figure 2.4-1Types of water distribution systems 30
Figure 2.5-1General IAM approach 37
Figure 3.1-1 Selected study areas 41
Figure 3.1-2Adama existing water supply system 42
Figure 3.1-3 Bishoftu town existing water supply system 43
Figure 3.1-4Existing mojo water supply system 43
Figure 3.7-1 Locations of pressure test in Bishoftu town 56
Figure 3.7-2 Location of pressure test in Mojo town 57
Figure 4.1-1Domestic water demand analysis of Adama, Bishoftu, and Mojo 67
Figure 4.1-2Average Day demand analysis of Adama, Bishoftu, and Mojo 68
Figure 4.2-1Adama town junction water demand allocation 69
Figure 4.2-2Bishoftu town junction water demand allocation 69
Figure 4.2-3Mojo junction water demand allocation 70
Figure 4.3-1 Calibration correlated plot for Adama 71
Figure 4.3-2 Validation correlated plot for Adama 72
Figure 4.3-3 Calibration correlated plot for Bishoftu 73
Figure 4.3-4 Validation correlated plot for Bishoftu 74
Figure 4.3-5 Calibration correlated plot for Mojo 75
Figure 4.3-6 Validation correlated plot for Mojo 76
Figure 4.3-7 Field pressure measurement 77
Figure 4.6-1Adama, Bishoftu, and Mojo town water production 79
Figure 4.6-2Adama, Bishoftu, and Mojo town billed metered water consumption 80
Figure 4.6-3Mojo town water meter brand inventory 86
Figure 4.6-4Mojo town water meter age inventory 86

Figure 4.6-5 Bishoftu town water meter brand/model inventory 87
Figure 4.6-6 Bishoftu town water meter age inventory 87
Figure 4.6-7Adama town SIV, Billed Authorized and NRW 92
Figure 4.6-8Bishoftu town SIV, Billed Authorized and NRW 92
Figure 4.6-9Mojo town SIV, Billed authorized and NRW 93
Figure 4.7-1ILI and its indications for developed and developing countries 96
Figure 4.7-2International and local comparison of ILI values 96

LIST OF APPENDIXES

Appendix 1 questionary for all water utility offices and water meter inventory questionary 101
Appendix 2 Adama town Domestic water demand 104
Appendix 3 Bishoftu town Domestic water demand 105
Appendix 4 Mojo town Domestic water demand 106
Appendix 5 Total water demand analysis for Adama town 107
Appendix 6 Total water demand for Bishoftu town 109
Appendix 7 Total water demand for Mojo town 111
Appendix 9 unauthorized consumption for all study areas 112
Appendix 10 Mojo town 2013 E.C water balance 115
Appendix 11 Mojo town 2014 E.C water balance 116
Appendix 12 Mojo town 2015 E.C water balance 117
Appendix 13 Bishoftu town 2013 E.C water balance 118
Appendix 14 Bishoftu town 2014 E.C water balance 119
Appendix 15 Bishoftu town 2015 E.C water balance 120
Appendix 16 Adama town 2011 E.C water balance 121
Appendix 17 Adama town 2012 E.C water balance 122
Appendix 18 Adama town 2013 E.C water balance 123
Appendix 19 Adama town 2014 E.C water balance 124
Appendix 20 Adama town 2015 E.C water balance 125
Appendix 21 calculation of average operating pressure for Adama 126
Appendix 22 calculation of average operating pressure for Bishoftu 140
Appendix 23 calculation of average operating pressure for Mojo 150

ACRONYMS AND ABBREVIATIONS

ALE	Apparent Loss Estimation
AL	Apparent Loss
AOP	Average Operating Pressure
ATWSSE	Adama Town Water Supply and Sewerage Enterprise
BC	Billed Consumption
BW	Billed Water
BTWSSE	Bishoftu Town Water Supply and Sewerage Enterprise
CARL	Current Annual Real Loss
DCI	Ductile Cast Iron
EPS	Extended Period Simulation
GS	Galvanized Steel
HDPE	High Density Poly Ethylene
IAM	Infrastructure Asset Management
ILI	Infrastructure Leakage Index
IWA	International Water Association
MNF	Minimum Night Flow
MTWSSE	Mojo Town Water Supply and Sewerage Enterprise
NDT	Non-Destructive Testing
NRW	Non-Revenue Water
OWWDSE	Oromia Water Works Design and Supervision Enterprise
PHD	Peak Hour Demand
PI	Performance Indicator
PM	Pressure Management
RL	Real Loss
SIV	System Input Volume
UAC	Unbilled Authorized Consumption
UARL	Unavoidable Annual Real Loss
uPVC	Unplasticized Polyvinyl Chloride
WL	Water Loss
WLTF	Water Loss Task Force

1. INTRODUCTION

1.1. Background

Water is a vital resource for survival, progress, and all human activities. With the limited and decreasing water supply, it is important to manage water resources prudently to meet the needs of the growing population. However, it is a challenging task to provide clean water and protect water resources because a significant amount of water is lost due to leaks or theft from distribution networks, which prevents it from reaching its intended users (T. AL-Washali et al., 2020).

Researchers and engineers have concluded that water loss (WL) is not just about financial loss but also refers to the depletion of water resources, which requires significant investments in time, money, and effort from the water network and distribution system. Leakage also raises concerns about the water supply system's reliability, stability, and serviceability. Water loss is not just an inconvenience for management but also a common issue for the water utility system (Bhagat et al., 2019). The WL can be either leakage or real loss occurring in pipes, storage reservoirs, and customer connections or apparent loss occurring due to customer meter under-registration, errors in data handling and billing, or unauthorized use (T. AL-Washali et al., 2016).

Water loss is a big problem for developing countries, as they cannot afford to lose any more of their valuable water. According to calculations, the yearly volume of non-revenue water (NRW) in the distribution networks of developing nations is approximately 45 million cubic meters. The total annual cost attributed to water loss is nearly $3 billion. If half of those losses were saved, it would be possible to provide water to about 90 million people (Bhagat et al., 2019).

In addition to low coverage, water losses (physical loss) in the urban water supply account for more than 50% of the supplies and are primarily caused by: Leaking of pipes, joints, and valves Overflowing service reservoirs Waste of water through unauthorized connections, and non-metered house connections Although leaks are one of the main reasons for water loss in a network distribution system, unauthorized connections and inoperable meters also contribute significantly and demand careful management and monitoring (Desalegn, 2005). In order to deliver water to their customers more efficiently and effectively, utilities must be able to measure and assess the performance of their water supply systems against set management objectives (H. Mutikanga et al., 2010). The task of measuring and evaluating performance is accomplished by performance assessment systems through well-defined performance indicators (PI), infrastructure leakage index (ILI) is one of the performance indicators (H. Mutikanga et al., 2010).

The Infrastructure Leakage Index (ILI) is a performance indicator that measures actual (physical) water loss from the supply network of water distribution systems. The Infrastructure Leakage Index (ILI) was created by the Water Loss Task Force (WLTF) of the International Water Association (IWA) and was first released in 1999. A minimum of 50 nations throughout the world have used it. ILI is the ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL), or ILI = CARL / UARL. Being a ratio, the ILI has no units, thus facilitating comparisons between countries using different measurement units (metric, U.S., British).

This study aims to investigate the levels of non-revenue water (NRW) and evaluate the applicability of the Infrastructure Leakage Index (ILI) in Ethiopian towns, with a specific focus on Adama, Bishoftu, and Mojo..

1.2. Statement of the problem

The Infrastructure Leakage Index (ILI) is a performance indicator used to define and calculate components of water balance and select the most appropriate performance indicator for different components of non-revenue water (NRW) and water loss (WL). It was first created using a reference data set of 27 different water distribution systems in 20 countries, including Australia, Brazil, Denmark, Finland, France, Germany, Gibraltar, Greece, Iceland, Japan, Maltese Islands, Netherlands, New Zealand, Singapore, Spain, Switzerland, Sweden, UH, USA, and West Bank (Palestine)) (Lambert et al., 1999). The ILI is calculated as the ratio of current annual real loss (CARL) and unavoidable annual real loss (UARL), ILI = CARL/UARL. The UARL is derived from the length of the main pipes, the length of the service connection, the number of connections, and the average operating pressure. This performance indicator is used in over 50 countries worldwide (Taylor, n.d.), but most of them are developed countries like Europe, Australia, and America, where water distribution networks and water loss management systems are well-managed. Before implementing ILI in Ethiopia, it is crucial to assess its applicability in the local context. Failing to do so may result in an inaccurate performance assessment, leading to financial losses and hindering the implementation of necessary mitigation measures by water utilities. Therefore, it is essential to validate the applicability of ILI for Ethiopia.

1.3. Research objective

1.3.1. General objective

The main objective of this research is to investigate the levels of non-revenue water (NRW) and evaluate the applicability of the Infrastructure Leakage Index (ILI) in Ethiopian towns, with a specific focus on Adama, Bishoftu, and Mojo.

1.3.2. Specific objective

Taking the main objective as mentioned above, the following specific objectives are expected to be achieved:

- To determine the non-revenue water (NRW) in the water distribution system for the selected study areas.
- To determine the apparent loss in the water distribution system for the selected study areas.
- To determine the real losses in the water distribution system for the selected study areas.
- To determine the key parameters required for the calculation of ILI.
- To recommend whether the ILI is applicable in the context of Ethiopia's selected towns or not.

1.4. Research questions

Table 1.4-1research questions

Specific objective	**Research question**
To determine the non-revenue water (NRW) in the water distribution system for the selected study areas.	How much water is produced and distributed to the network system? How much water is billed from the total produced water?
To determine the apparent loss in the water distribution system for the selected study areas**.**	How much water is unauthorized consumption from NRW? How much water is lost due to meter inaccuracy from NRW?

To determine the real losses in the water distribution system for the selected study areas.	How much water is lost due to leakage on service connections from the NRW? How much water is lost due to leakage on transmission and/or distribution systems from the NRW?
To determine the key parameters required for the calculation of ILI.	What is the average operating pressure on the system? How many numbers of service connections are in the distribution system? What is the length of the mains (without service pipes) and total length of service connections (distance between a property line and customer water meter)?
To recommend whether the ILI is applicable in the context of Ethiopia's selected towns or not.	What is the actual water loss in the water distribution system? What is the result of ILI for the selected study areas?

1.5. Significance of the study

This paper discusses the performance indicator ILI and its relevance to Ethiopian towns. The study aims to provide water utilities in Ethiopia with guidance on which performance indicator to use for measuring water loss. It also intends to assist water utilities in implementing measures to reduce water loss and financial loss resulting from inaccurate performance indicators. The study includes important recommendations on the suitability of ILI for different-sized Ethiopian towns, such as ADAMA, BISHOFTU, and MOJO. Furthermore, this study can serve as a secondary data source for researchers and aspiring scientists.

1.6. Scope and Limitations of the Study

The main objective of the study is to assess whether ILI is applicable or not in Ethiopia towns by taking representative towns of ADAMA, BISHOFTU, and MOJO. Therefore, the research work is limited to assessing the ILI in Ethiopian towns of ADAMA, BISHOFTU, and MOJO in the eastern Oromia region and finding the important key parameters used to estimate the performance indicator ILI. Also, this study analyzed the important parameters used to compare ILI with real loss like NRW, real loss, and apparent losses in the study areas. To find the key parameter operating pressure the Water Gems hydraulic model is used, and to calibrate and validate this hydraulic model field pressure measurements are taken in the representative selected sample areas. This representative sample pressure taken and water quality analysis is limited due to a lack of enough budgets, resources/ logistics, and distance of the study area.

2. LITERATURE REVIEW

2.1. International Water Balance

Measurements or estimates of (I) water generated, (ii) water imported and exported, (iii) water used, and (iv) water lost form the basis of the water balance. The water balance calculation serves as a reference to determine how much water is lost through network leakage (also known as "real" losses) and how much is lost owing to other types of losses (also known as "apparent" losses). The practitioner can determine how much water is being lost by using this calculation (Winarni W, 2009). The IWA has created an international standard of water balance structure and terminology as indicated in Table 2.1-1 to address the issue of various water balance formats and methodologies.

Definitions of principal components of the IWA water balance are as follows:

- System Input Volume is the annual volume input to a particular part of the water supply system.

- Authorized Consumption is the annual volume of metered and/or non-metered water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorized to do so. It includes water exported, leaks, and overflows after the point of customer metering.

- Non-Revenue Water (NRW) is the difference between System Input Volume and Billed Authorized Consumption. NRW consists of:

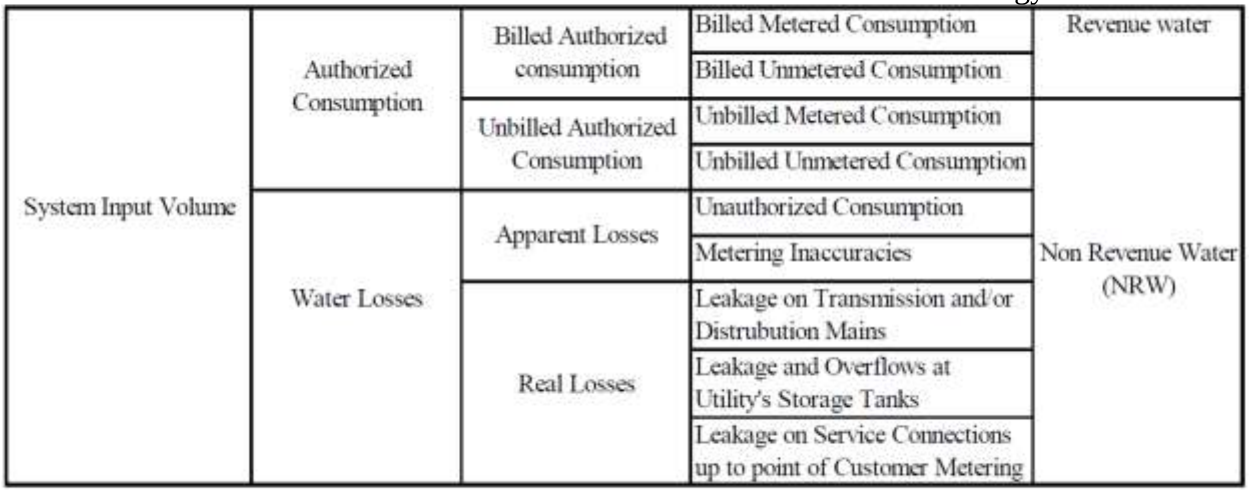
  1. Unbilled Authorized Consumption (usually a minor water balance component).
  2. Water Losses.

- Water Loss is the difference between System Input Volume and Authorized Consumption, consisting of Apparent Losses and Real Losses.

- Apparent Losses consist of unauthorized consumption due to all types of metering Inaccuracies.

- Real Losses are the annual volumes lost through all types of leaks, bursts, and overflows on mains, service reservoirs, and service connections, up to the point of customer metering.

Table 2.1-1 international standard water balance and terminology- IWA



System Input Volume	Authorized Consumption	Billed Authorized consumption	Billed Metered Consumption	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	
		Real Losses	Leakage on Transmission and/or Distrubution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer Metering	

2.2. Non-revenue water

Water that enters the distribution system but does not generate any money for the utility is referred to as non-revenue water. Real and apparent losses are included in NRW and unbilled authorized consumption. The water balance typically only consists of a minimal amount of unbilled authorized consumption. It covers things like combating fires, flushing water mains and tankers, maintaining public hydrants, sweeping streets, watering city gardens, maintaining public fountains, protecting against cold, etc. Depending on the custom in the area, they could be metered or unmetered (Winarni W, 2009).

As stated (Liemberger & Wyatt, 2019) According to estimates, there are 126 billion cubic meters of NRW in the world annually, or 346 million cubic meters every day. The cost and value of water wasted annually comes to USD 39 billion, assuming a conservative valuation of just USD 0.31 per cubic meter. In addition to being a major financial burden, higher NRW prevents water utilities from meeting their objectives of providing full-service coverage at a dependable quality of service at a reasonable cost during a period of growing scarcity and climate change. Providing for 800 million people would only need a one-third reduction in the global NRW volume (assuming daily use of 150 liters). However, lowering NRW will also enhance water quality, supply water to urban poor populations, and water service reliability. It will also save energy costs and, in certain situations, postpone the construction of water supply capacity.

Table 2.3-1 and figure 2.3-1 below show NRW volume and cost/value per region and Regional NRW levels for the selected areas respectively.

Table 2.2-1-NRW volume and cost/value per region

	Volume of NRW		Average level of NRW liters/capita/day	Cost/value of NRW billion USD/year
	Million m^3/day	Billion m^3/year		
Sub Saharan Africa	14.1	5.2	64	1.4
Australia and New Zeeland	1.0	0.3	36	0.1
Caucasus and Central Asia	8.0	2.9	1.52	0.8
East Asia	53.0	19.3	42	6.2
Europe	26.8	9.8	50	3.4
Latin America and the Caribbean	69.5	25.4	121	8.0
Middle east and northern Africa	41.2	15.0	96	4.8
Pacific Islands	0.5	0.2	211	0.1
Russia, Ukraine, and Belarus	9.5	3.5	65	1.1
South Asia	63.4	23.2	93	6.0
Southeast Asia	18.4	6.7	81	2.0
USA and Canada	40.7	14.8	119	5.7
Total	346	126	77	39

Source: (Liemberger & Wyatt, 2019)

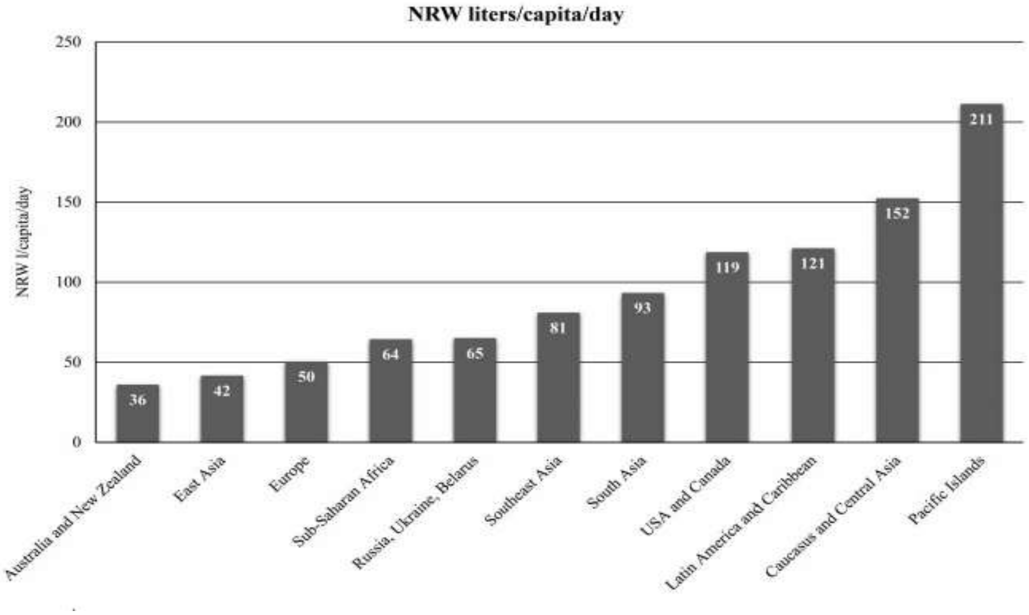


Figure 2.2-1 Regional NRW levels
Source: (Liemberger & Wyatt, 2019)

According to (Macharia et al., 2020) the figure 2.3-2 below shows the levels of non-revenue water (NRW) for selected Sub-Saharan African countries like Ethiopia.

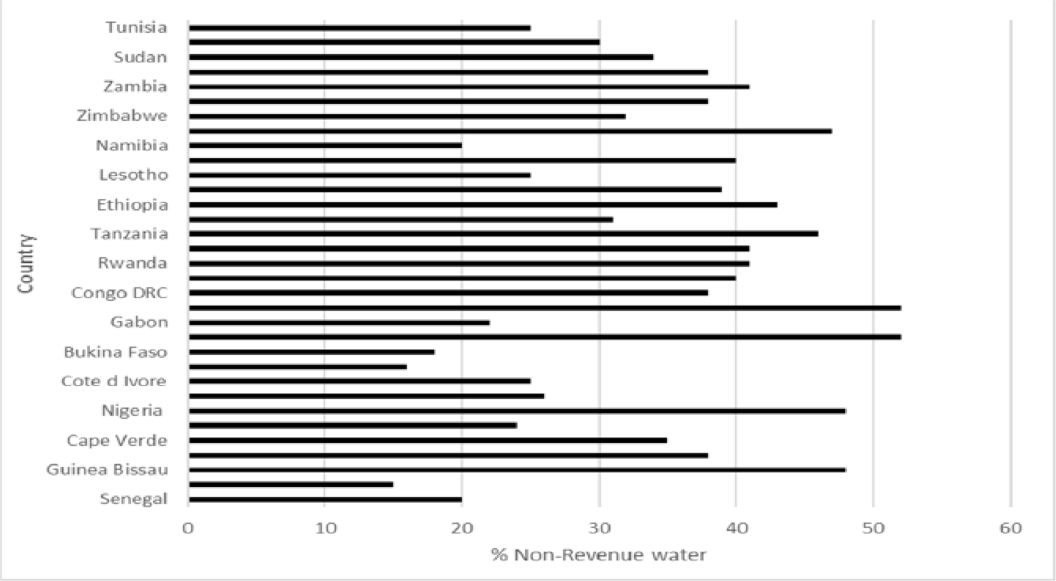


Figure 2.2-2 Levels of % non-revenue water (NRW) for selected countries in Sub-Saharan Africa.

As shown in Figure 2.2-1 NRW includes unbilled authorized consumption (this may be metered or unmetered), apparent loss, and real loss.

2.2.1. Non-revenue water reduction strategies

As (Farouk et al., 2023) state NRW reduction strategies can be grouped into three main categories according to their main aim; namely, targeting the reduction of (1)WL, (2) AL, and (3) RL. Figure 2.3-3 shows the relationship between NRW components and reduction strategies.

2.2.1.1. Water loss (WL)

Develop management processes- Since NRW is a measure of WDN performance, appropriate WDN management can also be shown to be a useful strategy for addressing NRW problems. WDN management has numerous facets, including (1) asset management ; (2) dynamic modeling, which is based on a method that selects the best management actions; (3) operation and maintenance, which is applied to boreholes and hand pumps within a WDN; (4) record keeping ; (5) programs such as GIS and management information system tools, which help in decision making and WDN management ; (6) budget management and the prioritization of NRW activities; (7) the shift from traditional top-down approaches toward bottom-up approaches in certain WDNs, which emphasizes the involvement of multiple-stakeholders; (8) organizations that control the activity of utilities. WDN management's primary advantages are a decrease in WL and an overall NRW (Farouk et al., 2023).

Monitor network performance- Numerous environmental, physical, and operational aspects affect a WDN's performance, necessitating ongoing observation. It is possible to monitor WDN performance by combining database integration with PM. Making ensuring that the network flow, volume, pressure levels, and pumps are functioning as intended is the primary goal of WDN monitoring. Hydraulic sensors that detect water pressure and flow can be used for monitoring.

The most popular control system for keeping an eye on WDNs is supervisory control and data collection (Farouk et al., 2023).

According to (Farouk et al., 2023) monitoring of network performance makes it easier to identify unusual flows and water usage brought on by theft or network problems. Additionally, ongoing monitoring lowers WDN leakage, which limits the WL and total NRW.

Also Increasing staff motivation, expanding staff competency, utilizing decision support system (DSS) tools, and promoting public awareness are non-revenue water reduction strategies grouped in water loss reduction strategies.

2.2.1.2. Apparent loss (AL)

Improve water metering systems- Customers' water use from WDN is measured by water meters. Water metering issues can lead to substantial water loss and have a major role in AL (Bhagat et al., 2019; Rizzo & Cilia, 2005). Additionally, the fact that many cases involve metering mistakes greater than 50% compounds the challenges associated with water metering. Errors in calculating the total registered volume and the lack of water meters are other reasons for metering errors (Moahloli et al., 2019). As a result, utilities need to replace and repair water meters as part of any effort to reduce NRW (Farouk et al., 2023).

Resolving metering problems can enhance water billing and the effectiveness of the city's revenue collection. Therefore, by reducing AL and the overall NRW, water metering system improvements can enhance overall water service. Prepaid smart watering systems, in which users pay for water in advance, may also benefit in lowering metering errors. Prepaid smart water metering systems are seen to be a more convenient payment option for consumers and have financial advantages, but the introduction of these systems should be planned carefully because they can be costly and cause more issues for low-income urbanites and local government agencies (Farouk et al., 2023). Additionally advised are alarms for meter replacement and inspection during the advised intervals for meter replacement (Moahloli et al., 2019) Finally, industry professionals can quickly identify the location of water meters by using optical capturing reading (Farouk et al., 2023).

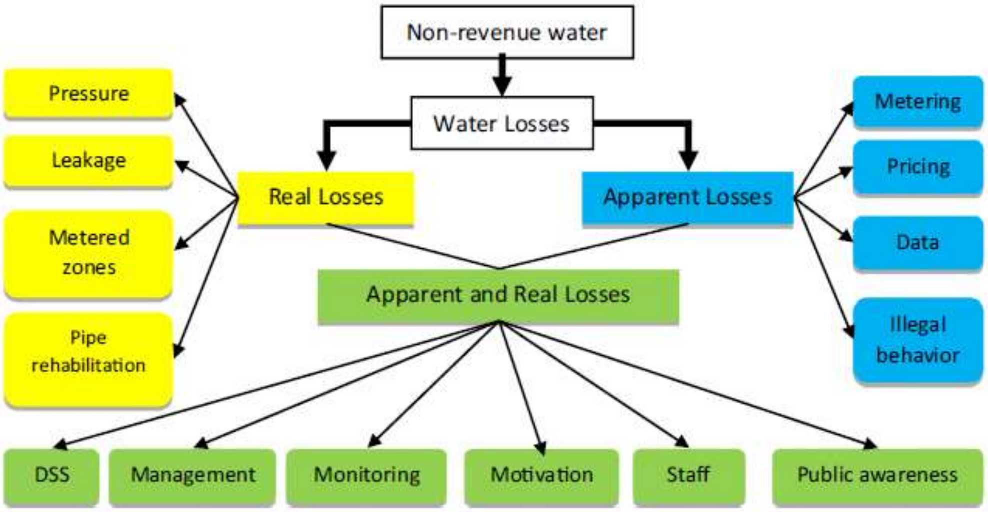


Figure 2.2-3 Strategies to reduce NRW
Source (Farouk et al., 2023)

Intercept illegal behavior- Another successful AL reduction tactic is to stop unlawful activity such as water theft, meter reading tampering, illicit water connections, and bribes. In general, water theft occurs more frequently than usual in areas of poverty. Furthermore, it can be challenging to stop such illicit activities since they directly benefit utility employees who accept payments in exchange for lowering meter readings. Furthermore, significant contributing factors to high AL values and high overall NRW rates are meter tampering and illicit connections. Strict fines for water theft, the detection of unauthorized connections, the inspection of meters reading zero or below average, and the detection of tampering operations are some of the specific tactics used to curb unlawful activity (Farouk et al., 2023).

Manage data effectively- Managing data effectively is essential for solving NRW issues. Data handling mistakes and data unavailability are the two main problems with managing AL data (Bhagat et al., 2019; Farouk et al., 2023). The availability of data on unbilled permitted use, illegitimate consumption, and metering faults can also be impacted by data mismanagement. When administering the WDN, incomplete data can result in erroneous assumptions. Additionally, incomplete data makes it more difficult to analyze water balances, makes assumptions about network connections, and makes it more difficult to adopt NRW reduction techniques, such as updating and replacing water pipes. It is necessary to create dependable and efficient data management systems to handle these different data-related issues. Utilities can create NRW reduction initiatives that are more effective by utilizing sophisticated data management systems (Farouk et al., 2023).

Revise water pricing- Pricing is thought to be one of the main reasons NRW reduction projects are delayed since it directly affects NRW's worth. Customers are billed under fixed-charge pricing whether or not the appropriate water volume is used. As such, it is socially unfair and may give misleading insights into the true volume of NRW (Bhagat et al., 2019). Although changing the price of water decreases revenue loss, utilities may be less inclined to enhance current systems to lower NRW (Bhagat et al., 2019). Furthermore, network performance is typically decreased when water prices are lowered. As a result, steps need to be taken to resolve these pricing concerns (Farouk et al., 2023).

2.2.1.3. Real losses

Control network pressure- Since network pressure directly affects water leakage, it is an essential parameter for determining (RL). Consequently, to keep the pressure within a WDN constant, the network pressure needs to be monitored constantly. The average zone pressure (AZP) is one way to determine the network pressure. The primary reasons for high pressure in a WDN are sudden alterations in pump flow velocity and intermittent supply (peak hours). Furthermore, the number of burst mains and the rate of leakage are directly impacted by pressure. To preserve pressure inside the WDN, pressure management, or PM, is used (Farouk et al., 2023).

A common strategy for implementing PM is to install pressure-reducing valves. Other strategies include installing brake pressure tanks, matching pump output curves to distribution demands, and rezoning supplied areas to match the input head to the topography to minimize system losses (Farouk et al., 2023).

Prevent water leakage - One of the most important factors influencing NRW is leakage, which is the fundamental element of RL. Leakage can occur in several WDN components, including joints, valves, fire hydrants, transmission and distribution pipes, and joints. It can squander natural resources and money while also endangering public health. The enormity of the issue is demonstrated by the fact that, on average, high leakage levels account for more than 25% of the energy wasted within WDNs. Estimating the overall leakage inside a specific WDN is the first step in leakage management. Typical techniques for evaluating leaks include the total integrated flow and total night flow approaches (Hussein et al., 2017).

In addition, AI tools can predict leakages before they occur (Bhagat et al., 2019). An indicator of WDN performance, the ILI is the ratio of the current annual RL to the unavoidable annual RL (Winarni W, 2009). In a WDN, leak-detection software can be crucial in locating unreported and hidden leaks (Farouk et al., 2023).

Establish metered zones- DMAs are WDN boundaries that are kept apart by boundary valves. It is therefore possible to measure the amount of water entering and exiting the region.

Partitioning the network into manageable segments is the purpose of DMAs. They make it possible to monitor the pressure and flow inside certain zones, which aids in determining which parts are the most difficult. DMAs specifically make it possible to control the pressure in each zone by figuring out what pressure is appropriate for each zone. DMAs are a useful technique for WL reduction since they facilitate the quicker identification of leaks and bursts. As a result, DMAs can help with NRW problems. Furthermore, by combining PM and databases, DMAs improve WDN performance and provide a substantial return on investment (Farouk et al., 2023; Hussein et al., 2017).

Rehabilitate pipes- older pipes that have outlived their anticipated lifespan have a higher failure rate, which leads to more leaks and bursts and poorer service.

Pipe rehabilitation, which entails replacing or repairing pipes inside a WDN, primarily focuses on physical losses to address these issues. Consequently, it offers an additional approach to NRW issue-solving.

According to (Farouk et al., 2023) WDN rehabilitation reduces the NRW in systems by boosting water and energy savings, enhancing system performance and reliability, improving hydraulic performance, and maintaining optimal pressure. The lack of need for past pipe burst data, which is frequently unavailable in developing nations, is another benefit of WDN rehabilitation. Rather, all that is needed is a calibrated model of the WDN, which is more easily obtained than historical data.

2.3. Water loss

2.3.1. Water Losses

In addition to the description given above, another definition of water loss is the difference between NRW and unbilled authorized consumption. Since not all losses are the consequence of leaking pipes and inadequate infrastructure, it is crucial to distinguish between water loss and leakage. Table 2.2-1 illustrates the distinction between apparent losses (non-physical losses and managerial losses) and real losses due to water (physical losses).

The main cause of water loss in modern nations is typically leakage. However, in developing nations, where unauthorized connections, meter problems, or metering errors are frequently more substantial, this is not always the case. Local customs, coupled with pricing structures or insufficient metering policies, frequently lead to water theft and unauthorized connections.

2.3.2. Factors Influencing Real Losses

Performance in managing real losses is constrained by several local circumstances. Based on a reference data set of 27 different water distribution systems from 20 different countries used by Lambert et al., it was discovered that these factors—namely, the length of mains, the number of service connections, the placement of customer meters on service connections, the average operating pressure, and the continuity of supply—can vary significantly between individual distribution systems (Lambert et al., 1999).

2.3.3. Performance Indicators for Management of Real Losses

The following IWA Best Practices are used to compare the effectiveness of managing water losses: -

- Water losses and real losses as a percentage of system input volume.
- Water losses per house connection.
- Water losses per km of mains per day (density of connections < 20 per km of mains).
- Infrastructure Leakage Index (ILI).

2.3.3.1. Percentage of System Input Volume

This is a classic indicator of water losses as a percentage of system input is straightforward to calculate and undoubtedly the one that non-specialists, such as politicians and the media, use most frequently (Winarni W, 2009).

This indicator is inappropriate for determining how effectively the distribution system is managed since the percentage NRW values are: -

- Heavily influenced by consumption (and changes in consumption).
- High pressure (above average pressure) has an impact.
- Complicated to interpret in cases of erratic supply.
- Losses that are actual and perceived cannot be distinguished.

2.3.3.2. Water Losses per House Connection

As a result of the numerous joints and fittings on service connections between the main and the edge of the street, experience from practitioners demonstrates that the frequency of leaks and bursts, as well as the annual volume of real losses, are several times higher on service connections than on mains. The largest volume of annual real losses typically occurs on service connections in most systems, even though average burst flow rates are higher for mains than for service connections when typical proportions of unreported bursts and average durations of different types of bursts are taken into account (Winarni W, 2009).

2.3.3.3. The Infrastructure Leakage Index, ILI

Although comparing systems with different levels of supply is possible using the standard indicator "volume/service connection/day when the system is pressurized," this indicator still does not account for operational pressure, which is a significant drawback. Additionally, it is impacted by differences in connection densities and customer meter distances from streets and boundaries.

The ILI, which was initially only used by a small number of insiders, is now generally accepted and employed by practitioners all over the world because it accurately captures the effectiveness of real loss control for water utilities. It is a gauge of how effectively a distribution network is maintained, repaired, and rehabilitated under the current operating pressure to control real losses (Winarni W, 2009).

Consider the huge rectangle in Figure 2.4-1 as the current annual volume of Real Losses (CARL) for a distribution system. This volume will gradually rise as new leaks emerge each year unless all four fundamental approaches to managing Real Losses (shown by the four arrows) are successfully used. The amount of current annual Real Losses depicts the typical picture over a 12-month period in which leakage control efforts have a larger or smaller impact on the natural rate of increase of leakage (Lambert, 2002a).

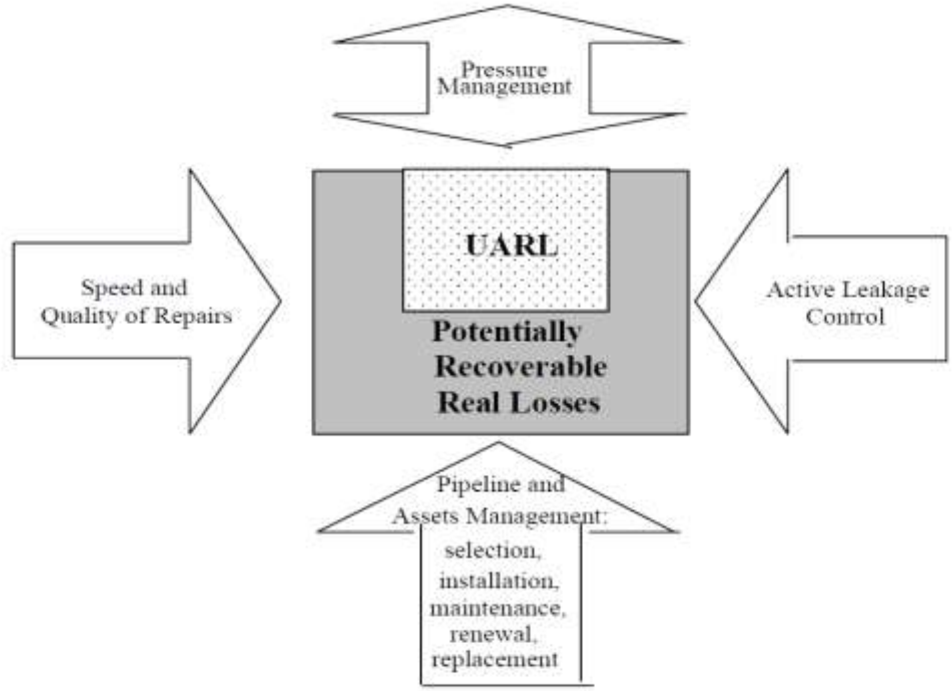


Figure 2.3-1: The Four Basic Methods of Managing Real Losses

Source (Lambert, 2002a)

Practitioners of leakage management are well aware that Real Losses cannot be completely avoided. The narrower inner rectangle in Figure 2.4-1 represents the volume of Unavoidable Annual Real Losses (UARL), which is the lowest technically possible annual Real Losses for a well-maintained and well-managed system.

The dimensionless ratio of the bigger rectangle to the smaller rectangle, defined as CARL/UARL, is known as the infrastructure leakage index (ILI). The East, South, and West arrows in Figure 2.4-1 represent the three "Infrastructure Management" methods of Real Losses, and their total performance is measured by this performance indicator under the current pressure management regime (Lambert, 2002a).

2.3.4. Apparent loss

Apparent losses are financial rather than physical. They result from illegal usage and inaccurate metering (Lambert, 2002a).

According to Figure 2.4-2, there are four components to apparent water losses: The first, meter under-registration, maybe the most straightforward to visualize. In this case, a revenue meter will not precisely measure the water provided to a dwelling. Water theft is a second apparent loss that occurs when water is taken from a water distribution network, frequently through a meter bypass or an unauthorized service connection. A third apparent loss results from inaccurate meter reading or collection, while a fourth apparent loss is brought on by inaccurate water billing and accounting (Rizzo & Cilia, 2005)

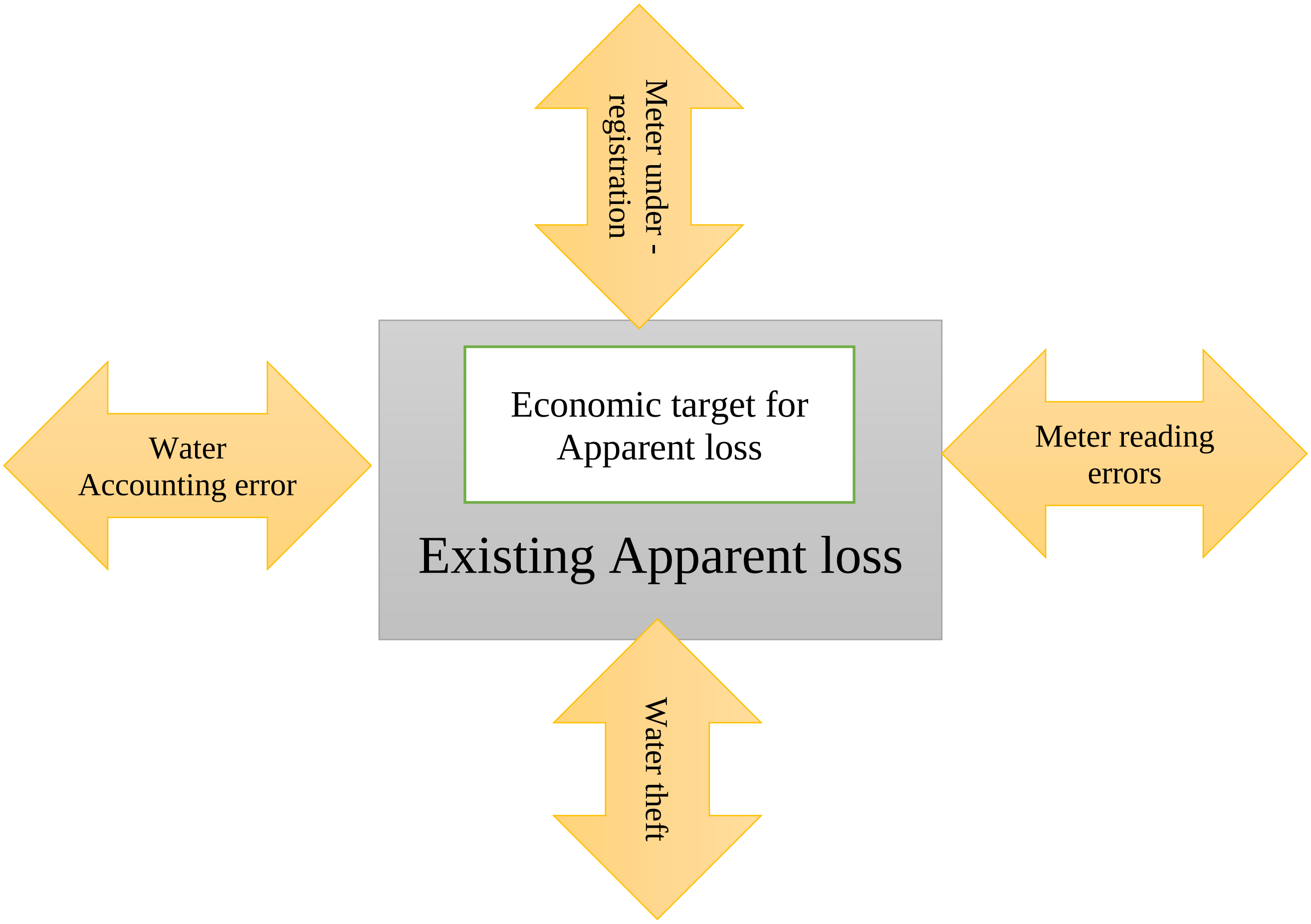


Figure 2.3-2 The four components of Apparent Water Loss
Source (Rizzo & Cilia, 2005)

Water meters can become inefficient for a variety of reasons, including meter wear and tear, improper installation procedures, a lack of upkeep or calibration, the wrong meter type and class for the application, incorrect meter sizing, demand profiles, or demand-type issues. The meter typically becomes unregistered due to aging or excessive wear and tear on its working parts (Criminisi et al., 2009). If there is a private roof tank between the revenue meter and the user, the under-registration of water due to the meter aging will rise. Discontinuous water distribution and water resource rationing are frequently employed as the primary solution to cope with water scarcity since network operating conditions under water shortages are substantially different from design conditions. By constructing private tanks, which are utilized for collecting water during served periods and distributing it when public water service isn't available, users attempt to make up for the inconsistent water supply. The demand profile of typical household consumers is altered by private tanks. A proportional float valve is frequently used to fill the tank, which decreases the flow rates that pass through the meter and dampens the instantaneous water demand. The revenue meter does not detect flows that the sluggish closure of the float valve causes that are less than the initial flow. The meter under-registration increases with the roof tank's surface area or the meter's beginning flow (Criminisi et al., 2009).

2.3.5. Water loss assessment methods

(T. AL-Washali et al., 2016) states that water loss can be analyzed in four stages as shown in Figure 2.4-3.

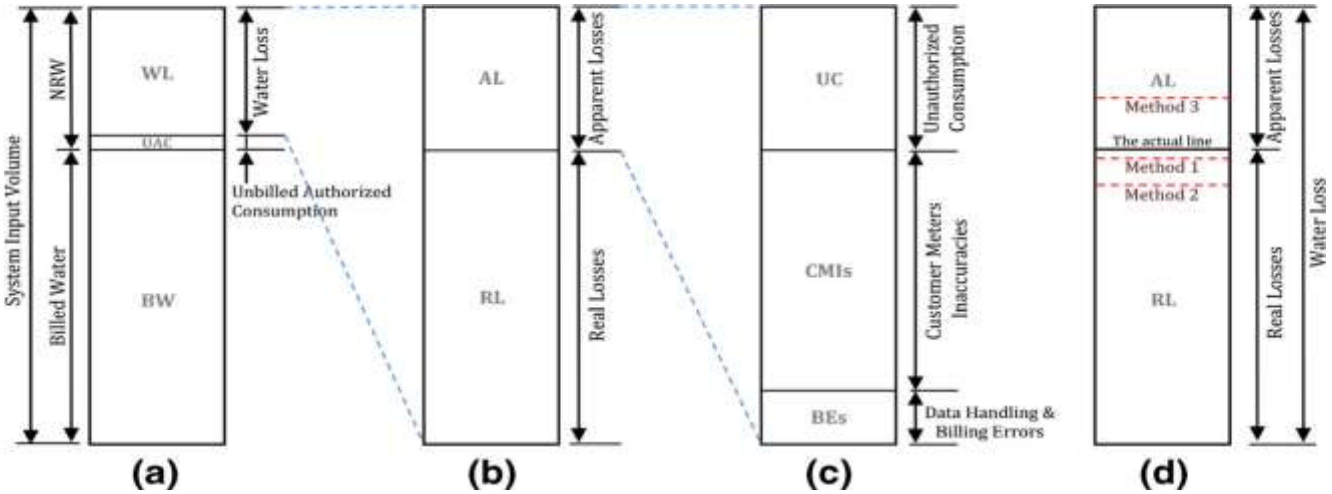


Figure 2.3-2 Water loss assessment stages

Source (T. AL-Washali et al., 2016)

The first stage is water loss assessment is getting all over total water loss. This stage is shown in the figure. a. This stage can easily be analyzed according to Equation 1

$\boldsymbol{NRW = SIV - BW}$……………………………………………Equation 1

Where: -

NRW- Non-revenue water

SIV- System input volume

BW- Billed water

WL- Water loss

UAC- Unbilled Authorized Consumption, which is usually a small component that can be estimated from records of the water utility.

Subdividing the whole volume of WL into apparent losses and real losses is the second step (Fig. 2.4-3b). Sub-component analysis for both apparent and real losses is often done in the third stage (Fig. 2.4-34c). When more than one WLA method may be used or integrated, an advanced stage is then doing an accuracy assessment and/or comparative study of the two primary components of WL.

According to (T. AL-Washali et al., 2016, 2020) there are four ways to estimate water loss. These include component analysis of leakage, minimum night flow (MNF) analysis, top-down water balance, and water and wastewater balance method. Different techniques and scales are employed in these methods to evaluate the components of leakage loss (WL).

2.3.5.1. Component analysis of the leakage

Burst and Background Estimates (BABE), another name for the component analysis of leakage, was initially developed as an empirical model. An analysis of a portion of the RL is done using the BABE concept. The examination of RL subcomponents is a more common application of this technique than the evaluation of WL components. Utilizing this approach, the RL is made up of several leakage events, each with a loss volume determined by the flow rate and average duration for various leakage kinds. Multiplying the average flow rate by the leak or burst's duration yields the volume of each incident. According to this theory, some leakage can be avoidable, but some cannot (T. AL-Washali et al., 2020). The unavoidable leakage can be calculated as stated in (T. AL-Washali et al., 2020; Lambert et al., 1999). Also, it is clearly stated in this paper in section 2.2.4.

$$\boldsymbol{UARL\left\{\frac{l}{day}/service\ connection\right\} = \left[18\ \frac{Lm}{Nc} + 0.8 + 25\frac{Lp}{Nc}\right]P} \text{……….Equation 2}$$

Where:-

UARL- unavoidable annual real loss

Lm(Km)- is the length of the mains pipes (without service pipes).

Lp (Km) -is the total length of service connections (distance between property line and customer water meter)

Nc -is the number of service connections.

P (m) -is the average operating pressure (AOP).

It should be noted that this approach is distinct since it is the only one that can separate actual losses into smaller parts, comprehend the nature of leakage, and design a case-specific plan for reducing it. Nonetheless, a number of the model's presumptions—such as the policy for leak detection and the quality of the pipework and construction—do not apply to other distribution systems. As such, there is a chance that the leakage volume will be significantly underestimated using this method (T. AL-Washali et al., 2020).

2.3.5.2. Minimum night flow

The network's RL can be analyzed in one or more discrete, tiny sections based on MNF analysis. From the WL volume, the AL can then be computed (T. AL-Washali et al., 2020). After the creation of a district-metered area (DMA). With measured supply input flow, it usually includes 500–3000 customer service connections. DMAs may be temporally established to do MNF analysis, or they may already be established in the distribution system (T. AL-Washali et al., 2016). As seen in Fig. 2.4-4, the MNF is the lowest flow into the DMA over 24 hours.

By examining 24-hour zone readings to identify MNF which typically happens between 2:00 and 04:00 AM, when most users are either inactive or don't consume water real losses are estimated by MNF analysis. As a result, leaks account for the majority of the water flow during this time of day.

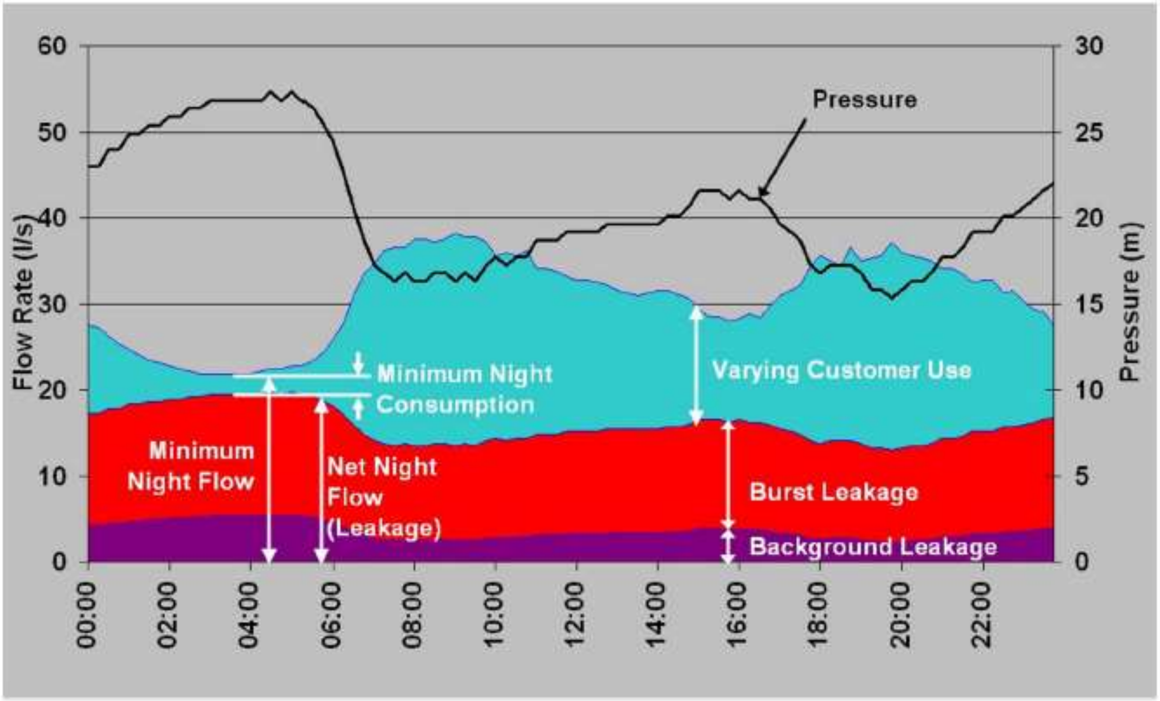


Figure 2.3-4 Variation of flow (indicating MNF), pressure, and leakage in a DMA source (T. AL-Washali et al., 2016).

For intermittent supply, however, the scenario is different; water should be supplied to the DMA until all consumers are saturated and the network's elevated and ground tanks are filled. Although the MNF in this instance may happen at any time during the day, it is usually expected in the early morning. This is because the system becomes continuous during the experiment, regardless of the method of water use direct from the tank or by pumping to another elevated tank. Using Eq.3, the potential lawful nighttime consumption in the DMA is subtracted to estimate the leaks during the MNF hour (T. AL-Washali et al., 2020).

However, because of the pressure-leakage relationship, Eq. 3 shows the leakage rate of the MNF hour, which is larger than the leakage rate during the other hours of the day. The leakage rate is corrected using a pressure correction known as the night-day factor (NDF), which may be computed using Eq. (4), to determine the rate of the true losses during the day. The pressures in the NDF should be representative of the typical real scenario in the DMA and should include the pressure throughout the entire day. The AL may then be determined from the WL volume, and the RL rate can be computed using Eq. (5) (T. AL-Washali et al., 2020).

$\boldsymbol{Q_{NNF} = Q_{MNF} - Q_{LNF}}$……………………………………………….………Equation 3

$\boldsymbol{NDF = \sum_{t=0}^{23} (\frac{P_1}{P_{min}})^{N1}}$…………………………………………………….………Equation 4

$\boldsymbol{Q_{RL} = Q_{NNF} * NDF}$……………………………………………………...Equation 5

Where: -

Q_{NNF} is the net night flow (m^3/h),

Q_{MNF} is the minimum night flow (m^3/h),

Q_{LNF} is the legitimate night flow (m^3/h),

NDF is the night–day factor,

P_{min} is the average pressure during the minimum night hour,

P_i is the average pressure during the day hours,

N_1 is the leakage exponent that can be assumed to be 1

Q_{RL} is the daily rate of the RL in the DMA (m^3/h).

2.3.5.3. Top-down water balance

This method involves first estimating the components of Apparent Losses (AL) and then using the Water Loss (WL) volume to calculate the Real Losses (RL) volume. Once the system input volume and billed consumption (BC) are established, the Non-Revenue Water (NRW) volume can be computed using Equation (6). The Unaccounted-for Water (UAC) is then subtracted from the NRW volume to determine the WL volume Eq. (7). The components of the AL, which include meter inaccuracies, data handling mistakes, and unauthorized consumption, are then assumed or investigated to determine the Unavoidable Annual Real Losses (UC). The estimation of client meter inaccuracies should be based on meter tests conducted at varying flow rates, which correspond to typical customer water consumption and meter guidance manuals (T. AL-Washali et al., 2020).

Using verified data and the utility's experience, the unauthorized use should be estimated. However, estimating each of the UC's parts is a laborious process that takes time and resources. Assuming the UC volume is hence standard procedure (T. AL-Washali et al., 2020).

As indicated (H. E. Mutikanga et al., 2011), 10% of the billed water or 10% of NRW should be assumed for developing countries. While these assumptions are more in line with real-world scenarios in underdeveloped nations, they nevertheless amount to little more than speculation and are not particularly helpful for tracking the UC or enhancing RL estimation in these regions.

Equation (7) can be used to compute the RL volume once the subcomponents of the AL have been computed and combined (T. AL-Washali et al., 2020).

$$\boldsymbol{NRW = SIV - BW} \quad \text{Equation 6}$$

$$\boldsymbol{WL = NRW - UAC = AL + RL} \quad \text{Equation 7}$$

Where: -

NRW -is the non-revenue water (m^3/year),

SIV- is the system input volume (m^3/year),

BC- is the billed consumption,

WL- is the Water Loss volume (m^3/year),

UAC- is the unbilled authorized consumption (m^3/year),

AL is the apparent loss, and RL is the real loss.

2.3.5.4. Water and wastewater balance method

The Apparent Loss Estimation (ALE) equation 8 was proposed by (T. M. AL-Washali et al., 2018) as a method for evaluating the NRW components. By creating a water and wastewater mass balance, the AL is calculated under the assumption that the real water consumed by users finally finds its way into the sewer system and the wastewater treatment plant (WWTP). Customer meter inaccuracies or improper data handling do not impact or decrease the flows in the sewers, in contrast to the billing system and BC. The consumption through illegal connections and bypasses is included in the actual consumption, which is represented by the sewer flow. Therefore, by analyzing the WWTP inflow, the AL volume can be found and the RL may be computed.

Consequently, it is possible to compute the RL and determine the AL volume by examining the WWTP inflow. This approach estimates the AL using the ALE equation Eq. (8).

$$\boldsymbol{Q_{AL} = (\alpha + 1)Q_{WW} - (\beta - \gamma + 1)Q_{bc}} \quad \text{Equation 8}$$

Where: -

Q_{AL}- is the apparent loss (m^3/year) if the assessment period is one year;

Q_{ww} -is the inflow to the WWTP (m^3/year);

Q_{bc} is the billed consumption (m^3/year);

α, β, and ɤ are case-specific factors; α is the exfiltration infiltration factor (3%–10%), β is the unbilled authorized consumption factor (0.5%–1.5%); and ɤ is the outdoor water use factor (4%–40%).

The ALE equation can be used to estimate the AL quantity after the factors α, and β, and have been estimated, assumed, or optimized. (T. M. AL-Washali et al., 2018) analyze these factors' sensitivities and uncertainties. The exfiltration and infiltration to the sewers can be computed using the billing data and the measured per capita consumption by assuming the factor and then verifying it using Eq. (9):

$$\boldsymbol{\alpha = Q_{ex} - Q_{inf} = N_P * q_{cap}\left(1 - \frac{\gamma}{100}\right) + Q_{ind} - Q_{ww}} \ldots\ldots\ldots\ldots\ldots\text{..Equation 9}$$

Where: -

Q_{ex} is the exfiltration volume,

Q_{inf} is the infiltration/inflow volume,

Np is the population with wastewater service,

q_{cap} is the per capita water consumption,

α is the outdoor use percentage of the water consumption,

Q_{ind} is the industrial and commercial wastewater discharge, and

Q_{ww} is the WWTP inflow.

The UAC volume (e.g., firefighting, pipe flushing), that is, factor, can be estimated based on water utility data or using 0.5% of the billed water or 1.25% of the SIV. The volume of the outdoor water use, factor, can be calculated using Eq. (10) and monthly billing data:

$$\gamma = \boldsymbol{\frac{Q_{bc} - 12 * q_{bc.min.month}}{Q_{bc}} * 100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{..Equation 10}$$

where: -

γ is the outdoor water use percentage,

Q_{bc} is the annual volume of the BC and

$q_{bc.\ min.\ month}$ is the volume of the BC in the minimum consumption month of the year.

Lastly, to apply this method, as stated in (T. AL-Washali et al., 2020) the volumes of the two main variables, Q_{ww} and Q_{bc}, should be adjusted to represent only customers with wastewater and water services, i.e., excluding those with only water or only wastewater services. The average dry weather inflow should be used to replace the volume of wet weather days that occur throughout the year in the WWTP inflow. The ALE equation can then be used to determine the AL rate per customer, which can then be applied to all water customers. From the total WL volume, the RL volume can then be computed.

A drawback of this approach is the requirement for accurate WWTP inflow measurements. Furthermore, it can only be used in situations where all or a portion of the customer base has access to a centralized sewer system. Since sewer networks require more funding and resources than water supply networks, many cities in developing nations lack access to them.

The limitations and approaches for each of the four methods are summarized in the table below

Table 2.3-1Methods for water loss component assessment
Source: (T. AL-Washali et al., 2020)

Methods	Scale	Approach	Limitations
Component analysis of leakage	System-wide	-Pressure dependent -Analyses field data and volumes of bursts and the rates of small background leaks -The only method that breaks down RL into subcomponents -Cost-effective	-Many assumptions -Applicable only for utilities that have active leakage control (ALC) - Underestimates RL - Further calibrations are useful
Minimum night flow	District metered area (DMA)	- estimate leakage in a part of the network - both assessment and reduction process - actual measurements	-Intensive fieldwork, zoning -Requires trained manpower and sophisticated equipment -estimates leakage in a part of the network during a time of the year
Top-down water balance	System-wide	-Assume and estimate the AL component and then calculate the RL -Desk method -Pressure independent -Cost-effective	-Focus on RL, not AL -Generic assumptions of AL -No methodology to estimate unauthorized consumption -Likely overestimates RL

Water and wastewater balance method	System-wide	-Estimate AL using WWTP inflow measurements and then calculate RL -Desk method - Pressure-independent - Cost-effective	-Requires centralized sewers for all or part of the network. -Needs measurements of WWTP inflows

2.4. Water Distribution System

2.4.1. Introduction

One of the main societal infrastructure assets is the water distribution system (WDS), which is always being expanded and modernized as a result of rising water needs and ongoing population increase. The process of designing cost-effective WDSs is challenging because it entails simultaneously solving a large number of nonlinear network equations and optimizing the sizes, locations, and operating states of many network elements, including pipes, pumps, tanks, and valves. (Gupta & Bhave, n.d.) This task becomes even more difficult when the optimization problem involves a greater number of specifications that the designed system must meet (for example, water quality) when it includes goals other than the least-cost economic measure (for example, potential fire damage), and when it incorporates more real-world elements (for example, uncertainty, construction staging).

2.4.2. Components of A Water Supply System

(Strafaci et al., 2004) A municipal water supply system is made up of pipelines, pumps, water storage facilities, and other distribution accessories. The main components include:

- Water source: The sources of drinking water can come from groundwater, lakes, reservoirs, rivers, canals, rainwater, and saltwater.
- Water purification and treatment facilities: Different treatment systems are used depending on the source of the water.
- Transmission and distribution systems: The treated water is transported from the source via water mains and sub-mains to the end-users.
- Storage systems: these may include water tanks, reservoirs, and water towers. In smaller systems, pressure vessels and cisterns may be used.
- Pumping stations: to maintain optimal water pressure, additional pressurizing components, called pumping stations, are often used.
- Accessories: these may include support components such as valves, service lines, generators, meters, fire hydrants, and other accessories needed to ensure a smoothly running system.

2.4.3. Types of water distribution system

The water distributed via municipal water supply systems should reach the end-user with sufficient pressure and flow rates. To achieve this, four main water distribution system types are used:

2.4.3.1. Gridiron systems

In gridiron systems, the main water supply line goes through the central part of the area, while the sub-mains branch out perpendicular to the main line. This system has no dead-ends, as all of the individual pipes are interconnected. This type of water supply system is great for cities that have a rectangular layout that resembles a gridiron.

2.4.3.2. Ring systems

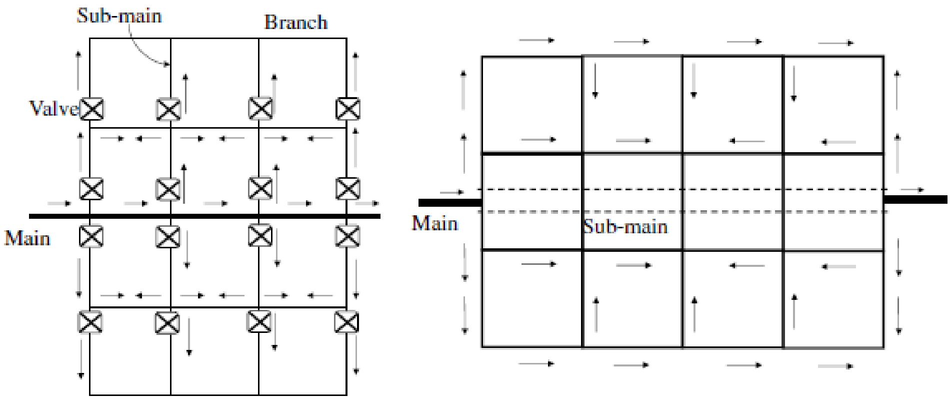
Circular or ring systems feature a supply main that forms a circle or ring around the area of distribution. In this system, the branches are cross-connected to the supply mains and each other. This type of system has similar advantages and disadvantages to gridiron systems and is suitable for towns and cities with well-planned roads and streets.

2.4.3.3. Radial systems

In radial systems, the distribution area is divided into different distribution districts or zones. Each zone has an elevated distribution reservoir in the middle from which supply lines run in a radial pattern towards the distribution district periphery. Radial systems offer swift distribution and allow for simpler design calculations.

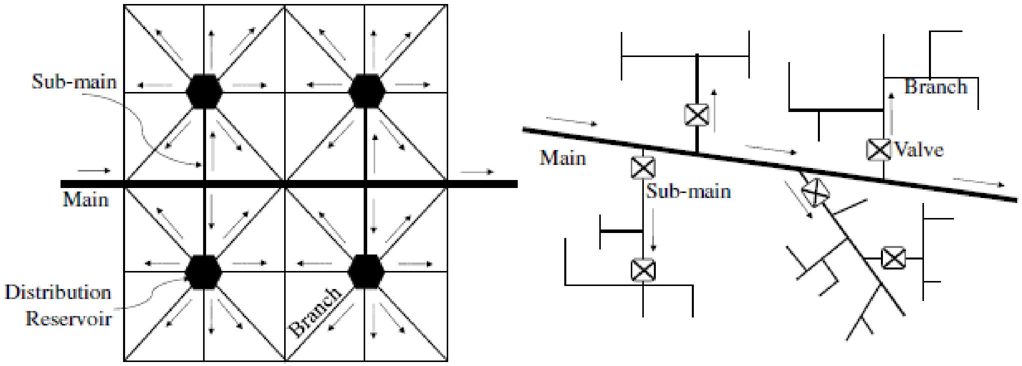
2.4.3.4. Dead-end systems

Dead-end water supply systems are the best choice for cities and towns without definite road patterns. In this type of system, there is one main line that runs through the town or city with sub-mains branching off from left and right. These sub-mains then divide into several branch lines that provide service connections.



Grid Iron

Ring System



Radial System

Dead End

Figure 2.4-1Types of water distribution systems

Source (Mazumder et al., 2018)

2.4.4. Hydraulic Models

Water distribution network (WDN) hydraulic models are effective decision support tools for creating various management scenarios to increase the effectiveness and dependability of current networks and to build new ones. In hydraulic models, well-known hydraulic equations are solved to compute key hydraulic parameters at various places for the stated WDN, such as flow rate, velocity, and water pressure, and the resulting data is displayed in tabular and graphical representations for user evaluation. Accurate determination or estimation of the input parameters, as well as model calibration and verification investigations, are necessary for successful hydraulic model predictions (Kara et al., 2016).

2.4.5. Types of Hydraulic Model Software and their features

There are numerous software's that simulate and analyze WDSs. We have open-source software that anyone can download and use for free, while some are practically off-limits to the public and others are commercially available to anyone who might need them for research, analyzing the development of new water distribution systems, or managing existing WDSs (Awe et al., 2019).

2.4.5.1. Water GEMS

With improvements in system optimization, platform compatibility, and model construction, Water GEMS is a strong, complete, and simple-to-use water modeling and analysis software. A super-set of Water CAD is called Water GEMS. Water GEMS is a powerful and adaptable modeling tool that enhances system behavior understanding, system response to operational strategies, and system capacity to meet future demands. Its adaptable multi-platform workspace enables modeling of fire flow and water quality as well as analyses of pipe flow, pressure, and energy costs. Intelligent system management and planning for system reliability, system efficiency (pumping strategies, system shutdowns, and preventive maintenance to minimize disruptions), and asset renewal or renovation support for sustainability are all capabilities of the water GEMS. Prefixed model construction, platform integration, design, and other activities are some of its capabilities. The most appealing and understandable data presentation format is what makes Water GEMS special. Due to its adaptability, presentations using other graphics tools are also possible. Water GEMS is a commercially offered but closed-source piece of software. To address the requirements for precision in modeling, analysis, and design of WDSs, the Water GEMS program was constructed with a robust design methodology.

2.4.5.2. Water CAD

A subset of Water GEMS is called Water CAD. A variety of features in this user-friendly WDS modeling management and analysis software help to increase design productivity. These features include the creation of prefixed models, data archiving, custom graphic data presentation, evaluation of water demand, WDS configuration, design and operational scenarios, and, last but not least, CAD interoperability, or the capacity to model on any well-known platform of choice. The design of Water CAD sets it apart from other modeling software through a variety of features and functionalities.

2.4.5.3. EPANET

A free hydraulic analysis program for WDSs is called EPANET. Within pressurized WDSs, it extensively simulates hydraulic and water dynamics. It was created to help us better understand how water moves through WDSs. EPANET is a robust and adaptable program that offers a workspace for hydraulic analysis of systems of any scale by modifying system input data, performing hydraulic and water quality simulations, and visualizing the results on several platforms of your choice. Although its primary function is as a research tool, it may also be used to design new WDSs and restore old ones. The United States Environmental Protection Agency invented EPANET.

2.4.5.4. HydrauliCAD

HydrauliCAD is an industry-standard EPANET simulation and modeling engine-based water system design, hydraulic analysis, and water modeling program integrated into AutoCAD. It is open-source software that supports an endless number of applications and is exceedingly simple to use. It functions with the benefits of AutoCAD, including familiarity and versatility, as it was designed as an AutoCAD extension product. To compute pipe pressure, flow, pressure loss, and other variables in WDSs, HydrauliCAD was created. This software features a built-in pipe elements repository that offers comprehensive details about the materials, types, and sizes of pipes that are used to simulate WDSs and also to analyze fire flows. HydrauliCAD is made to be strong, quick, and simple.

2.4.5.5. H2Onet and H2Omap

Both H2Onet and H2Omap are commercially available programs with essentially the same functions and enough integration flexibility to be used with GIS and CAD workspaces. For the modeling, analysis, design, and optimization of WDSs, they are employed. Leakage detection evaluation, fire flow analysis, cost optimization, etc. are some of their distinctive qualities. The main characteristic that sets apart both products is the preprogrammed and user-friendly online SCADA interface. A standalone GIS application is H20Map.

2.4.6. Applications of Water Distribution Models

Based on (Strafaci et al., 2004) The majority of water distribution models (WDMs) can be used for the analysis of a wide range of other pressure piping systems, including industrial cooling systems, oil pipelines, and any network conveying an incompressible, single-phase, Newtonian fluid in full pipes. The most widespread use of these models, however, is in municipal water utilities. Due to its complicated architecture, continual development and change, and immense size, WDSs require models more than any other type of system.

Water distribution network simulations are used for a variety of purposes, such as

- Long-range master planning, including both new development and rehabilitation
- Fire protection studies

- Water quality investigations
- Energy management
- System design
- Daily operational uses including operator training, emergency response, and
- Troubleshooting

2.4.6.1. Long-range master planning, including both new development and rehabilitation

Planning professionals thoroughly investigate every component of a water distribution system to identify which significant capital improvement projects are required to guarantee the level of service in the future. Master planning, also known as capital improvement planning or comprehensive planning, is a method that can be used to forecast system expansion and water demand for the next five, ten, or twenty years. Population growth, annexation, acquisition, or wholesale deals amongst water supply utilities are some of the factors that might lead to system growth. Every time a system expansion is projected, the hydraulic network's capacity to serve its users effectively must be assessed.

A model can be used to not only pinpoint possible problem areas (such as future low-pressure zones or regions with water quality issues), but also to size and site new transmission mains, pumping stations, and storage facilities to make sure the forecasted issues never happen. It is preferable to keep a system operating at a satisfactory level than to have to repair one that has developed issues.

2.4.6.2. Fire protection studies

Water distribution systems are frequently necessary to supply water for fighting fires.

It is crucial to build the system to meet the requirements for fire protection, and doing so typically has a significant impact on how the network is designed as a whole. An engineering model is used to verify whether the system can meet the fire protection criteria after the engineer has determined what those needs are. The model may also be used to size hydraulic components (pipes, pumps, etc.) to fix the issue if the system is unable to sustain acceptable pressures and supply specific flows.

2.4.6.3. Water quality investigations

Some models also can simulate hydraulics and water quality. A user can simulate water age, source tracking, and constituent concentration assessments throughout a network by using a water quality model. For instance, it is possible to research and plan more efficiently for chlorine residual maintenance, analyze disinfection by-product production (DBP) in a network, or assess the influence of storage tanks on water quality. Models of water quality are also used to examine how to change hydraulic processes to enhance water quality.

2.4.6.4. Energy management

Energy consumption for pumping is the second-largest operational expense of many water utilities, after maintenance and repair costs of the infrastructure. The behavior of the system as well as the operating parameters and energy consumption of pumps can be studied using hydraulic simulations. The effects on energy usage can be assessed and the utility can take informed action to reduce energy costs by developing and testing various pumping strategies.

2.4.6.5. Daily Operations

Water distribution system operators often ensure that system-wide pressures, flows, and tank water levels are within acceptable bounds. These indicators must be watched by the operator, who must respond when a value deviates from the permissible range. The operator can modify the system to perform at the proper level of service, for example, by activating a pump or changing a valve. A hydraulic simulation can be used in daily operations to assess the effects of various potential actions, giving the operator better information for making decisions.

2.4.7. Model calibration and validation

During the model-building process, calibration of computer models for water distribution system (WDS) analysis is a crucial and frequently carried out stage. A system's physical and operational features must be identified to calibrate pipe network systems. This is accomplished by choosing several parameters that, when entered into a hydraulic simulation model, would produce a satisfactory match between measured and expected pressures and flows in the network, or, in other words, will produce the "best" values for the unknown model parameters (Savic et al., 2009; Strafaci et al., 2004).

(Ormsbee, 1989) lists the following seven steps for a general calibration procedure:

(1) determining the model's intended purpose
(2) figuring out initial parameter estimates
(3) gathering calibration data
(4) assessing model outputs
(5) macro-level calibration
(6) sensitivity analysis; and

(7) micro-level calibration.

According to (Ayala, 2018) the calibration standards are shown in the below table 2.4-1.

Table 2.4-1Model calibration standard

Intended use	**Level of detail**	**Type of time simulation**	**Number of pressures reading**	**Accuracy of pressure reading**	**Number of flows reading**	**Accuracy of flow reading**
Long range planning	low	Steady-state or EPS	10% of nodes	±5%psi(3.5m)for 100% reading	1% of pipes	±10%
Design	Moderate to high	Steady-state or EPS	5%-2% of nodes	±2 psi (1.4m) for 90% of reading	3% of pipes	±5%
Operations	Low to High	Steady-state or EPS	10%-2% of nodes	±2 psi (1.4m) for 90% of reading	2% of pipes	±5%
Water quality	High	EPS	2% of nodes	±3 psi (2.07m) for 70% reading	5% of pipes	±2%

Source: (Ayala, 2018)

2.5. Infrastructure asset management (IAM)

2.5.1. Introduction

The processes utilities must put in place to make sure that infrastructure performance eventually matches service targets, that risks are appropriately managed, and that the associated costs are as low as possible from a lifetime cost perspective are collectively known as infrastructure asset management, or IAM, of urban water infrastructures. IAM techniques are not entirely the same as those used to manage other kinds of assets. One of the causes is that these infrastructures are built to last an infinite amount of time to meet the ongoing demands of a certain public service. Infrastructures can only be replaced partially, not entirely. As a result, every stage of an asset's existence coexists in an established infrastructure (Alegre & T., 2012).

IAM is becoming a more important subject as wastewater and water supply systems advance toward compliance with performance standards. These systems' sustainable management should address the following needs:

- Encouraging appropriate service levels and bolstering long-term service reliability;
- Enhancing the sustainable use of energy and water;
- Managing service risk while considering users' needs and risk tolerance;
- Maintaining and gradually implementing climate change adaptations;
- Increasing investment and operational efficiency within the organization;
- Justifying investment priorities in an understandable, transparent, and accountable manner.

2.5.2. Integrated IAM approach

Integrated IAM techniques are necessary to prevent the drawbacks of these separate viewpoints; this requirement stems from the necessity to deliver appropriate service levels and long-term sustainable service. To put it briefly, the goal of an integrated strategy is to help water utilities find the answers to the following queries:

- Who are we now, and what kind of service do we provide?
- What kind of infrastructure do we own?
- In the long run, where do we want to be?
- What is the route there?

The integrated IAM technique is represented by the cube in Figure 2.6-1. It argues that IAM needs to be addressed at several planning decision-making levels, strategic level: a tactical level, where the intermediate managers in charge of the infrastructures need to choose what the best medium-term intervention solutions are; an operational level, where the short-term actions are planned and carried out; and a strategic level, driven by corporate and long-term views and aimed at establishing and communicating strategic priorities to staff and citizens. It also highlights the requirement for consistent processes to evaluate the performance, risk, and cost of intervention options throughout the investigation. The third important takeaway is that information, engineering, and business management are the three primary pillars of competency required by IAM (Alegre & T., 2012).

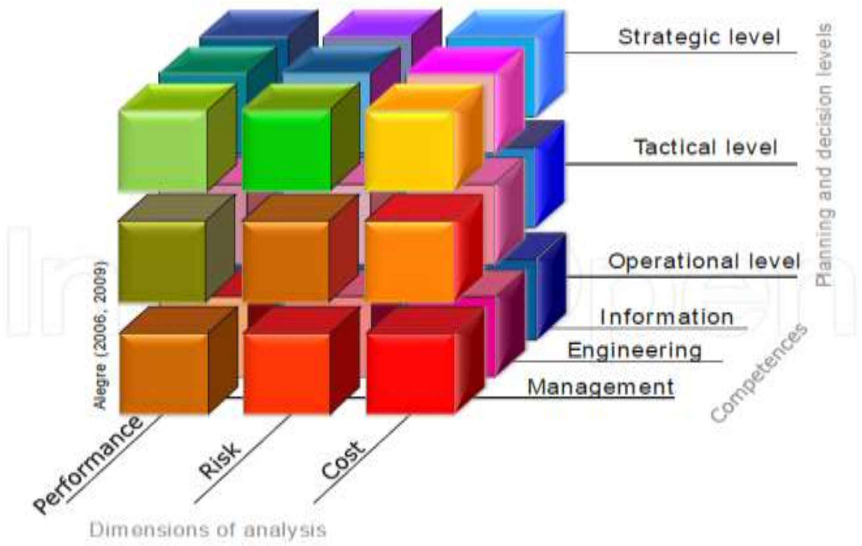


Figure 2.5-1General IAM approach

2.5.3. Water distribution system asset management

WDS are asset-intensive systems that require effective management of asset stock to ensure and sustain the delivery of the required service. According to the USEPA, “asset management is a continuous process that guides the acquisition, use, and disposal of infrastructure assets to optimize service delivery and minimize costs over the asset’s entire life” (USEPA 2002a). This requires utilities to gather information related to assets owned and their worth, the condition of the assets and remaining life, and components that should be fixed first (Marlow et al. 2007; Vanier 2001). The various aspects of WDS asset management focusing on buried pipelines are discussed next.

Water distribution systems (WDS) rely on their assets to provide an uninterrupted service. Efficient management of these assets is crucial to ensure the system delivers the required service over its lifetime while minimizing costs. According to the (USEPA, 2002), utilities must continuously manage their infrastructure assets to optimize service delivery and minimize costs. To achieve this, utilities need to gather information about their assets including their value, condition, and remaining life, and prioritize repairs (Marlow et al., 2015). In the next section, we discussed different aspects of WDS asset management with a focus on underground pipelines.

2.5.3.1. Pipeline Condition Assessment

Condition assessment is a crucial part of asset management for water distribution systems (WDS). It involves evaluating the readiness of WDS components to perform their function and can be used for making decisions about repairing, rehabilitating, or replacing system components. By determining potential failure locations in advance, condition assessment is an effective tool for reducing/mitigating consequences (Liu & Kleiner, 2013). However, it can be a challenging task for WDS because most pipelines run beneath the ground and are difficult to access and assess.

Over the years, various techniques have been developed for the condition assessment of buried water pipelines, which can be broadly divided into direct and indirect methods. Direct methods involve visual inspection (automated/manual) and non-destructive testing (NDT), while indirect methods involve assessing deterioration through soil resistivity tests, water audits, and flow testing. Direct methods provide pipe stress indicators, whereas indirect methods provide inferential indicators that indicate the potential existence of deterioration (Mazumder et al., 2018).

2.5.3.2. Pipeline Failure Prediction Models

Most CA methods are based on non-destructive testing (NDT) methods, which are frequently too costly, time-consuming, and labor-intensive to address all the distress signs (Kleiner & Rajani, 2002). To prioritize inspection, rehabilitation, and replacement, utility companies frequently depend on failure prediction models that were created using pipe, soil, and historical failure data. Based on an examination of the physical mechanisms underlying pipe failures, physical models are built. These mechanisms include elements that explain the deteriorating process, the nature of applied loads, and pipe qualities.

The primary cause of these models' limitations is the complexity and difficulty of modeling the physical mechanisms underlying pipe breakdowns. Studies aimed at comprehending these mechanisms—corrosion, for instance—involve assumptions and oversimplifications that impact the precision of the models that are created. Physical models have the benefit of not requiring a significant amount of historical data to be developed (Mazumder et al., 2018).

The pattern in previous failure data is used by statistical failure prediction models to forecast upcoming failures. The quantity of data and several parameters employed in statistical models determines their accuracy and adaptability. A more complete model will result from data that breaks down the pipe properties, environmental conditions, and operational issues. Therefore, the availability of data is the primary disadvantage of statistical models. This can be very restrictive when it comes to water mains with huge diameters and extremely low failure rates. The fact that statistical models are limited to the area where the data required to create them is gathered is another drawback of statistical models (Mazumder et al., 2018).

2.5.3.3. Renewal and Maintenance Planning

Infrastructure, especially that which is susceptible to time-dependent deterioration, requires routine inspection and maintenance to ensure proper operation. Water pipeline deterioration raises the risk of failure, lowers hydraulic capacity, and lowers the quality of the water. Planning for appropriate maintenance and rehabilitation becomes crucial as a result. Usually, two kinds of maintenance are performed: necessary maintenance, also known as corrective or preventive maintenance. According to (Sánchez-Silva et al., 2016), preventive maintenance is performed before a system fails, whereas corrective or essential maintenance is performed after a system failure.

To restore system functionality, asset management of pipeline infrastructure necessitates a renewal process. In the case of structural age, degradation, inadequate hydraulic efficiency, leaks, or expansion, for instance, renewal (repair, rehabilitation, and replacement) is necessary. Pipelines that can support the repair approach and are structurally sound are repaired using repair techniques. Pipeline structural integrity and hydraulic efficiency are enhanced through rehabilitation. When a pipeline experiences significant deterioration and can no longer produce enough hydraulic flow, replacement is necessary (Selvakumar & Tafuri, 2012). Several variables about pipe longevity, safety concerns, reliability, water quality, and expense must be taken into account during the renewal planning process.

3. MATERIALS AND METHODS

3.1. Description of the study area

Ethiopia is the world's 27st largest country, and the population numbers coincide with the overall size of the country. Ethiopia has numerous cities and towns across its diverse regions. Due to urbanization and the rapidly increasing population Water supply is one of the main critical issues in Ethiopia. Also, water leakage in the water supply system is a hot issue in Ethiopia. In order to ensure that the research is more representative and includes the characteristics of Ethiopian towns and cities, one town cannot be used. Therefore, one city (ADAMA) and two towns (BISHOFTU and MOJO) have been selected based on their level of development, population variations, urbanization patterns, and proximity to the capital city, Addis Ababa. Additionally, the study areas have been chosen based on their accessibility, ease of transport, and cost-effectiveness.

ADAMA is a city in central Oromia region, Ethiopia. ADAMA forms a special zone of Oromia and is surrounded by East Shewa Zone. It is located 8.5^0 N 39.27^0 E at an elevation of 1712 meters, 99 km southeast of Oromia's Addis Ababa. The city sits between the base of an escarpment to the west, and the Great Rift Valley to the east. The other selected town is BISHOFTU is located in the East Shewa Zone of the Oromia Region, it sits at an elevation of 1,920 meters (6,300 ft). This is located 47.9 kilometers (29.8 mi) southeast of Addis Ababa along its route 4 highway. The third selected town is MOJO, a town in central Ethiopia named after the nearby Modjo River. Located in the East Shewa Zone of the Oromia Region, it has a latitude and longitude of 8°39′N 39°5′E with an elevation between 1788 and 1825 meters above sea level. The distance from Mojo to Ethiopia's capital Addis Ababa is approximately 64 km.

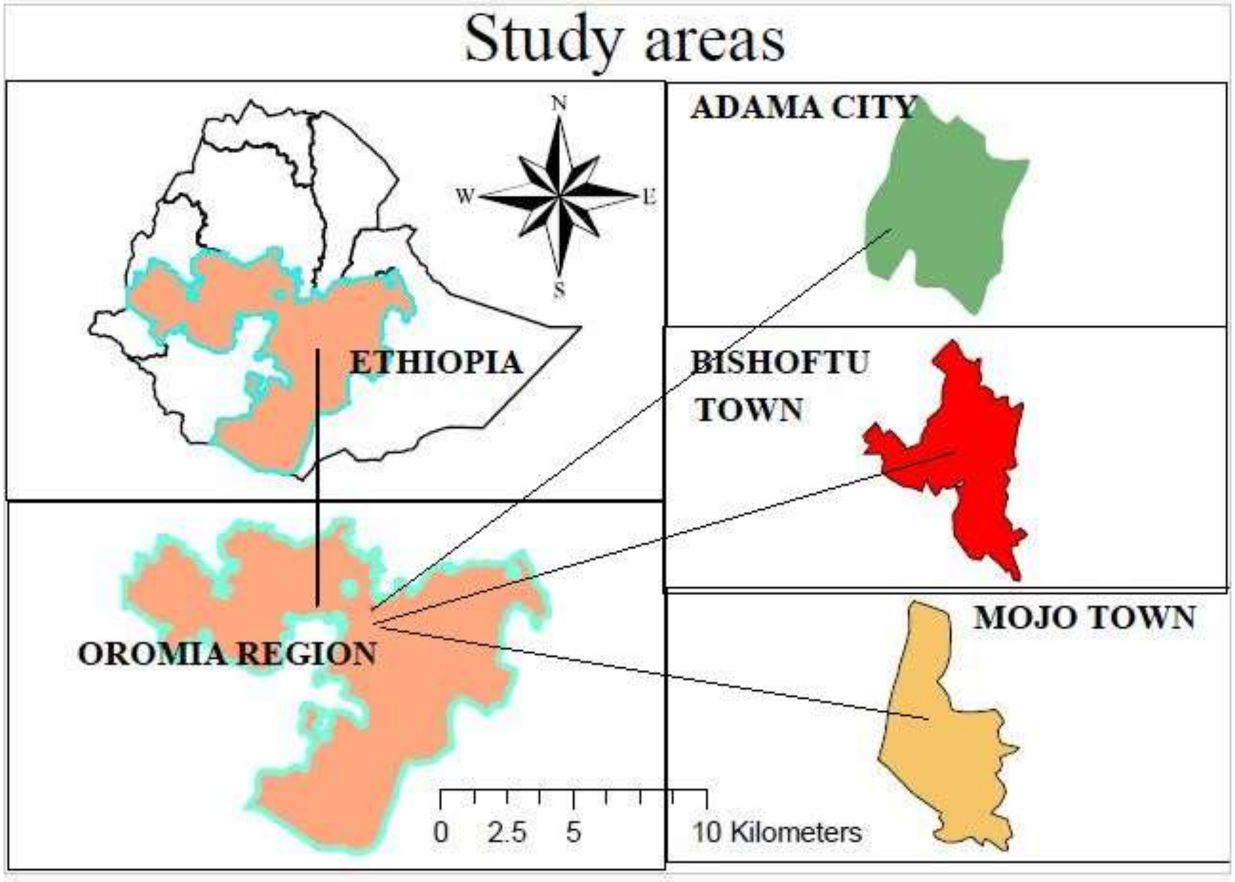


Figure 3.1-1 Selected study areas

3.1.1. Existing water supply system

3.1.1.1. Adama city

River Awash, which is 11 kilometers to the west of the town and the main supply of drinking water for Adama, is the major water source. The pipe materials that are frequently utilized to construct the water distribution systems in Adama are Ductile Cast Iron (DCI), uPVC, GS, and HDPE, according to the (ATWSSE, 2019) report. More than 60% of the length of the distribution pipe in use today is made of uPVC pipes, which dominate the system. The initial installation of Galvanized Steel (GS) pipes in the distribution system was made more than 15 years ago.

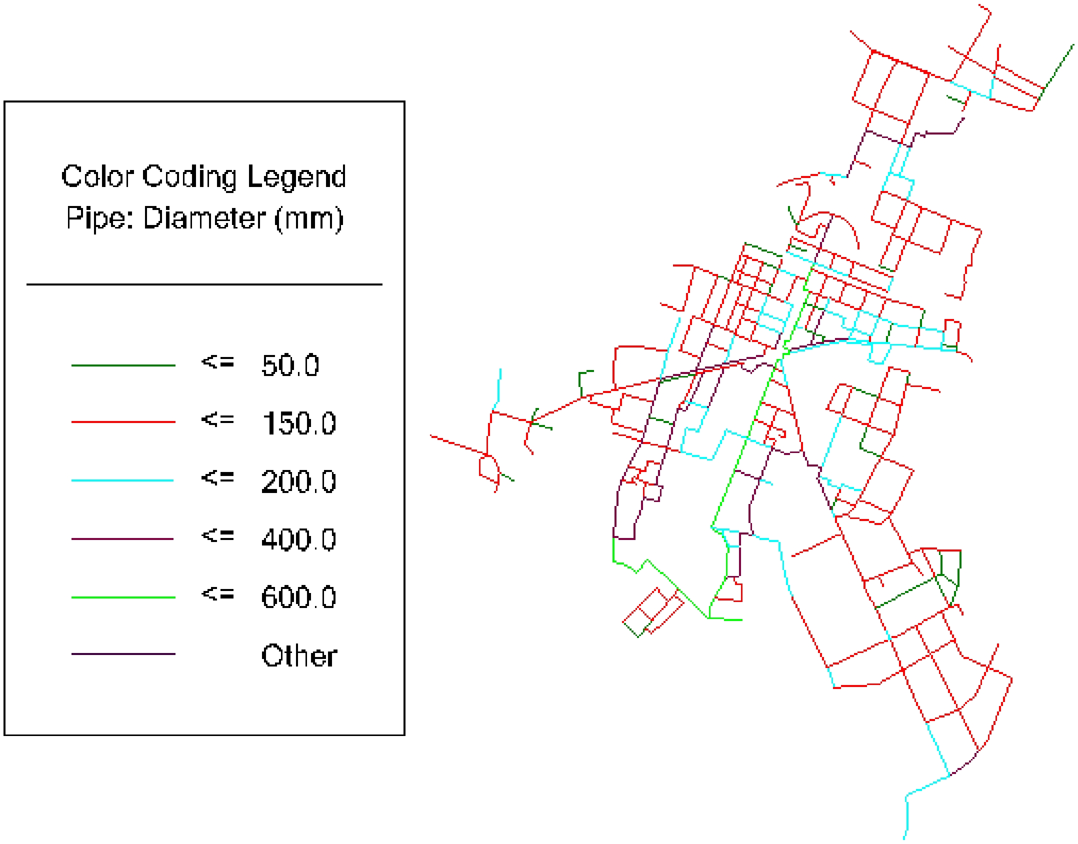


Figure 3.1-2Adama existing water supply system

3.1.1.2. Bishoftu town

The report (BTWSSE, 2017) states that Bishoftu town receives its water supply from 19 existing wells in the Shumbura meda Dembi, Cheleleqa, and Kurkur wellfields. 19 wells produce a combined 18,648 m3 of water per day. For the past 20 years, the Shumbura meda wellfield has been used to extract almost 60% of the water supply. The pipe materials used in the system is 55% uPVC,21% HDPE, 14% DCI, and 11% GS.

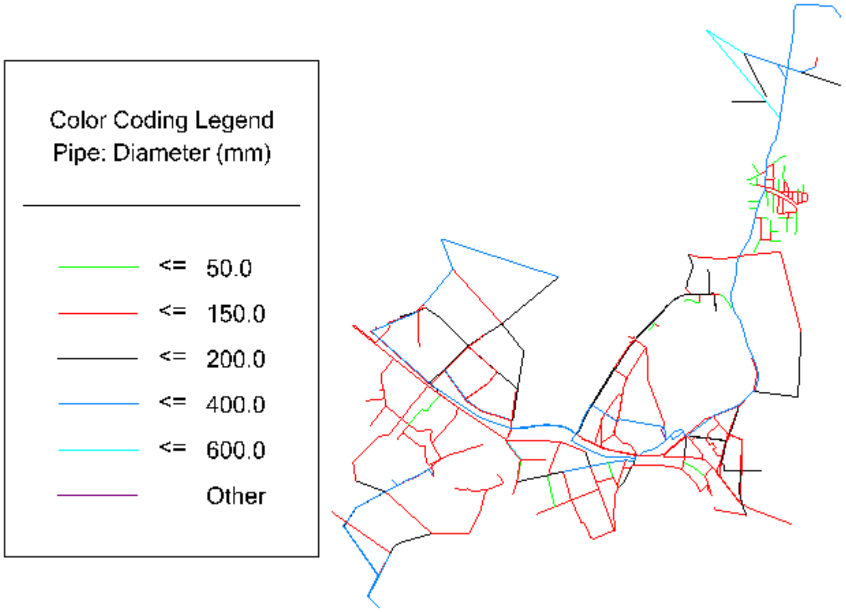


Figure 3.1-3 Bishoftu town existing water supply system

3.1.1.3. Mojo town

The water supply system for Mojo town is supplied from seven boreholes. The current total borehole yield is 141 l/s. Mojo town water supply system was a mix of direct and combined systems. The system has seven different types of water users. those are private, community, governmental, non-governmental, commercial, religious, and industry.

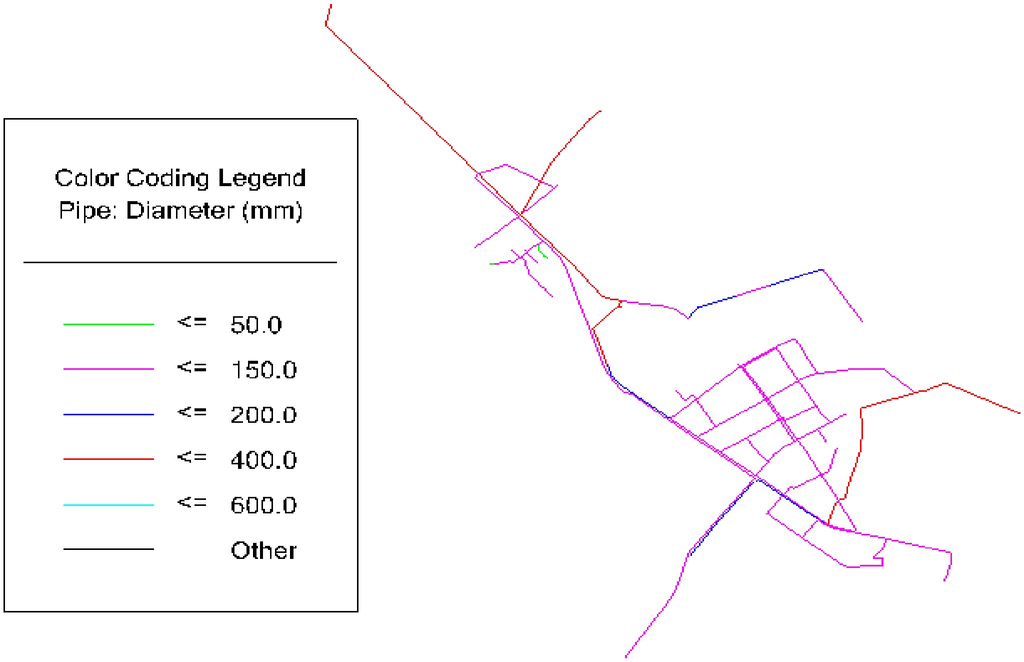


Figure 3.1-4Existing mojo water supply system

3.2. Materials and tools

The section below summarizes the materials and tools used in this study.

3.2.1. Materials used

I. Metrolog –is used to measure field pressure for calibration and validation of the hydraulic model.

II. GPS – used to collect the location of the water source, reservoirs, fire hydrants, location of valves, and junctions used in the design of the water distribution network system of the study area.

3.2.2. Tools used

I. Micro-soft excel

Excel, a product of the Microsoft Corporation, is used to create numerous illustrative tables and figures as well as evaluate various metrics like average, mean, and median. Additionally, it creates database files from data files exported from Water Gems. Excel is also used in this study's calculations of ILI, demand, population forecasts, and other analyses.

II. Auto Cad

A popular piece of commercial software for creating maps is AutoCAD. Additionally, layers from AutoCAD are imported into Water Gems for hydraulic analysis and skeletonization. The other feature is utilized to observe and view the specifics of the network with a map (contour map) drawing that is loaded from Water Gems into AutoCAD.

III. Water Gems

To build and study the hydraulics of the water distribution system, a program called Water Gems is used. Additionally, the hydraulic performance of the distribution network is assessed using Water Gems.

IV. Google Earth

To show the study area for preliminary study and distribution network preparation.

V. Global mapper

Google Earth, Auto CAD, water GEMS, and Arc GIS tools use the global mapper to convert files between their respective file formats.

VI. ArcGIS

Arc GIS is used in this research to prepare the study area location map.

3.3. Data collections

In this research, both primary and secondary data were collected.

3.3.1. Primary data collection

The management personnel and subject matter experts of the Adama Town Water Supply and Sanitation Enterprise, Bishoftu Town Water Supply and Sanitation Enterprise, and Mojo Town Water Supply and Sanitation Enterprise were interviewed and questioned for the primary data. Field pressure measurements were performed at chosen representative locations along the three towns.

Also, a customer water meter inventory was done for the analysis of the type, model/brand, and age of the water meter classification. The following formula determined the sample size of the water meter.

$$\boldsymbol{n} = \frac{\boldsymbol{Z^2 pqN}}{(\boldsymbol{N}-\boldsymbol{1})\boldsymbol{e}^2+\boldsymbol{Z^2 pq}} \text{……………………………………………..Equation 11}$$

Where: -

n - customer meter sample size,

Z – standard variant at given confidence level =1.96,

p=sample proportion, if there is no previous study on the key parameters (P is taken as 50%),

3.3.2. Secondary data collection

Secondary data, such as water production, water consumption, the number of connections available, etc., were gathered from ATWSSE, BTWSSE, and MTWSSE reports as well as various scholarly publications.

3.4. Demand and population analysis

3.4.1. Population projection

Estimates for the future population of the project are based on Growth Rate -Based on the 2007 CSA Analytical Report. Population projections have been made using Oromia water works design and supervision (OWWDSE, 2008) growth rates as shown below in the table and equations respectively.

Table 3.4-1population growth rate

Urban Population Growth Rates by Region	
Year	**Urban Growth Rate %**
1995-2000	5.29%
2000-2005	4.88%
2005-2010	4.74%
2010-2015	4.53%
2015-2020	4.32%
2020-2025	4.08%
2025-2030	3.84%

Source: (OWWDSE, 2008)

Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), Adama City has a total population of 220,212, an increase of 72.25% over the population recorded in the 1994 census, of whom 108,872 are men and 111,340 women. Bishoftu town has a total population of 99,928, of whom 47,860 were men and 52,068 were women. Mojo Town has a total population of 29,547 out of which 14,355 are males and 15,192 are females.

The geometric Increase method of population forecasting has been adopted for this research. Because this, method is mostly applicable to growing towns and cities having vast scope of expansion, like Adama, Bishoftu, and Mojo town.

$$P_n = P_o(1 + 0.01r)^n \text{ ………………………………Equation 12}$$

Where: -

P_n = Design population (after n years)

P_o = Present population (at the start of the design period)

r = Annual population growth rate in %

n = Design period in years.

3.4.2. Water demand

3.4.2.1. General

A fundamental consideration for planning and designing any water supply system or its parts is an estimate of the amount of water expected to be used by the customers on the system.

The total water requirement of a project is normally estimated by its uses for domestic purposes such as drinking, cooking, ablution, washing clothes and utensils, and cleaning houses, and for non-domestic purposes such as public, commercial, industrial, and firefighting institutions, and livestock watering. In addition, unaccounted-for water should be considered while calculating the total water requirement of the system. The following sub-sections outline how to calculate the total water demand of the project.

3.4.2.2. Domestic water demand

Domestic water demand, as mentioned previously, comprises water used for necessities like drinking, cooking, bathing, washing clothes and kitchenware, and cleaning homes. The typical daily water consumption per person varies from nation to nation and from region to region within a nation (OWWDSE, 2008).

The major important factors for these variations are:

I. Level of water supply services

II. Per-capita per day water consumption

III. Climatic conditions

IV. Level of socio-economic development

V. Affordability and willingness of people to pay for water supply services

VI. Water Quality Standards etc.

I. Level of Water Supply Services

As mentioned above the level of a water supply service greatly affects the water demand of the users. If the level of service is excellent like house connection, the water demand is also very high due to its multipurpose such as toilet flushing, laundry machines, and bathing rooms. The water demand of the users decreases as the level of the water supply service decreases and vice versa.

Consequently, the following common three types of service levels have been adopted for designing water supply projects.

- House Connections (HC);

- Yard Connections (YC); And
- Public Fountains.

II. Per capita Water Demand

The amount of water used per person per day for daily life and activity is known as Per capita water demand which is used as a base for estimating the domestic water demand of customers. It is normally a function of the daily basic needs but should be adjusted by socioeconomic development and climatologic factors.

According to (OWWDSE, 2008) urban centers, the design values obtained from the experience of Adama, Bishoftu, and Mojo can be adopted from the following tables.

Table 3.4-2urban per-capita per day water demand in liters (Adama, Bishoftu, and Mojo)

Activity	**The year 2015**			**The year 2025**		
	HC	YC	PF	HC	YC	PF
Drinking	1.5	1.5	1.5	1.5	1.5	1.5
Cooking	5.5	4	4	5.5	4	4
Ablution	12	9	7.5	14	10	9
Washing Dishes	6	5	2.5	8	5	4
Laundry	13	11	7	18	13	9
House cleaning	5	3.5	2.5	6	5	2.5
Bath or shower	20	12		24	14	
Toilet	12	4		12	6	
Other				1	1.5	
Total	75	50	25	90	60	30

Source: (OWWDSE, 2008)

III. Climatic and Socio-Economic Adjustment Factors

As was indicated in the section above, a person's water consumption is typically influenced by the socioeconomic and meteorological factors of their location. This indicates that hotter regions require more water than colder ones. Furthermore, the wealthy use more water than those who are poor do. The adjustment factors are multiplied by the total domestic demand to adjust these.

The following two tables display the climate and socioeconomic condition adjustment factors, respectively.

Table 3.4-3climate adjustment factor based on altitude and mean annual temperature

Mean Annual Temp. (^{0}C)	Description	Altitude	Factor	Examples
<10	Cool	>3,300	0.8	
10 to 15	Cool temperate	2,300-3,300	0.9	Goba
15-20	Temperate	1,500-2,300	1	Addis
20-25	Warm temperate	500-1,500	1.3	Metahara
25 and above	Hot	<500	1.5	Kebridehar

Table 3.4-4socio-economic adjustment factor

Group	Description	Factor
A	Towns enjoying high living standards and with high potential for development	1.1
B	Towns having a very high potential for development, but lower living standards at present	1.05
C	Towns under normal Ethiopian conditions	1
D	Advanced rural towns	0.9

Source: (OWWDSE, 2008)

The altitude and mean annual temperature of Adama town is 1712 meters and 20-25 ^{0}C respectively. This condition is categorized in the 4th group of climate adjustment factors. Also, Adama town has a very high potential for development this is categorized in group B socio-economic adjustment factor. Therefore, the combined climate and socioeconomic adjustment factor for Adama town is 1.365. Mojo town has an altitude range of 1730–1890m above sea level and is characterized by its mean annual temperature of 16−17°C, and mean annual rainfall of 896mm. Mojo town is categorized into 3rd group of climate adjustment factors and group B in socio-economic adjustment factors. Therefore, the combined adjustment factor for Mojo town is

1.05. In the last Bishoftu town altitude, mean annual temperature, and mean annual rainfall are in the range of 1900-1995m,25 ºC - 27ºC, and 746.6 mm respectively. Bishoftu town was categorized in the last climatic factor adjustment group and group B in the socio-economic adjustment factor. The combined adjustment factor for Bishoftu town is 1.575.

3.4.2.3. Non-Domestic Water Demands

(OWWDSE, 2008) non-domestic water demand includes industrial water demand, commercial and public water demand, unaccounted-for water, and water demand for firefighting.

A. Industrial Water Demand

Numerous municipalities' development plans show that certain small- to medium-sized industries are intended to be established. Large companies are typically thought to have their own water supply systems.

If specific industries do not have established water demands, the following numbers may be utilized:

Small industries: 5 m3 /ha /day; major industries: 10 m3 /ha /day

Depending on the scale of the project, it is advised to take 5 to 10% of the household water consumption in cases where there are no specific data available for the project region. For this thesis, about ten percent have been taken (OWWDSE, 2008).

B. Commercial and Public Water Demands

Public demand includes water needed for schools, hospitals, public offices, military camps, public parks, clinics, daycare centers, and so on, whereas commercial demand includes water needed for restaurants, movie theaters, trains, bus stops, retail malls, and local drinks.

Depending on the population size, it is advised to estimate 20–40% of domestic water demand when a thorough assessment of public and commercial institutions is not feasible. An average of 30% has been considered suitable for each of the three study areas in this research because Small-scale industrial businesses should be taken into account when allocating funds for institutional and commercial demand rather than being given their category. Larger enterprises' water needs, however, will be handled differently (OWWDSE, 2008).

C. Unaccounted For Water (UFW)

Unaccounted-for water (UFW) is defined as a percentage of the total amount of water produced for the system, according(OWWDSE, 2008).

System leaks cause UFW, water being stolen by unauthorized connections, inaccurate metering, reservoir overflow, and legal unmetered uses like flushing and firefighting.

The UFW for each of the three research areas is derived from the water balance computation, which distinguishes between physical and commercial loss.

D. Water Demand for Fire Fighting

The amount of water required for combating fires will be determined town by town based on the availability of equipment and the capability of any available fire department. Fire hydrants must be placed in public and municipal spaces, including schools, stores, hospitals, gas stations, and prominent locations within the distribution network. The storage tanks' volume is increased by 10% to meet this need (OWWDSE, 2008).

3.4.2.4. Variation in Demands

Distinct consumers of water supply systems have distinct hourly, daily, and annual usage trends. By keeping track of these differences, standard peak factors for a particular region may be developed, which serves as the foundation for the design of various water supply components. Water supply systems may be over- or under-designed as a result of inaccurate assessment of these parameters. The following design requirements will be taken into account while assessing the various components of a water delivery plan.

- Average day demand

The entire annual (average) water demand spread out over 365 days is the average daily demand. It was calculated by adding together all of the demands—domestic and non-domestic—as well as the unaccounted-for water (UFW). These serve as the foundation for estimating the peak hour and daily demand. It is advised to pump for 20 to 24 hours on an average day's demand.

- Maximum day demand

When calculating the maximum daily water demand, seasonal and weekly variations in water usage are taken into account. It also symbolizes how demand shifts with the seasons and highlights certain noteworthy occasions that take place in a given year. The average day demand is multiplied by the maximum day factor to get the maximum day demand.

- Peak hour demand

This happens, in particular, when there is a rush hour and every water tap is open. These incidents typically take place in the morning when most people use water for cooking and bathing. They may also happen later in the day when people use water for the same purposes after work.

The highest one-hour demand over the maximum day is known as the peak hour demand. It is a representation of the daily fluctuations in water demand brought about by local population behavior patterns. The highest daytime demand is multiplied by the peak hour factor to determine the peak hour demand.

As was already mentioned, the size of the population to be served has a significant impact on both the maximum day and peak hour parameters. Adopting peak factors established from locally recorded consumption data or a water utility with comparable socioeconomic, cultural, and climatic features is always advised.

Without such information, the designer can arbitrarily use the peak factors listed in the following table while taking the local environment into account.

Table 3.4-5Water Demand Peak Factors

Population size	Maximum day factor	Peak hour factor
<2,000	1.3-1.5	2.6
2,000-10,000		2.4-2.2
10,000-50,000		2.2-1.8
50,000-80,000	1.2	1.8-1.7
>80,000		<1.7

3.5. Hydraulic model of the water supply system

Using a Water Gems connect edition update 2 hydraulic model, the current water supply systems in each of the three research locations were examined. The use of the recommended software able to create unlimited number of pipes is appropriate for the development of the skeletal and all mains' models of study areas.

The selected hydraulic model software can be analyzed by steady-state analysis and/or EPS (extended period simulation) also capabilities include graphical editing; image, CAD and GIS background support and can be easily integrated with different software's like auto cad, excel and

GIS. In general, the hydraulic model provides detailed information on the pressure throughout the water supply system. The hydraulic model used in this research is to obtain the Average Operating Pressure (AOP) throughout the water supply distribution system in each study area and for better understanding of the network operation.

3.5.1. Creation of water distribution network system model and data entry

The water distribution networks for Adama, Bishoftu, and Mojo were created by using previously prepared skeleton data from the ATWSSE, MTWSSE, and BTWSSE. This data was based on AutoCAD and GIS software. Additionally, a Google Earth drawing was made of the water distribution system. Once the skeleton of the water distribution network was prepared, the drawing was analyzed using Water Gems software to check for pressure throughout the system. The next step was to input data for elevations and demands at the junctions, as well as pipe data such as pipe material, diameter, length, and roughness. Finally, reservoir, tank, and pump data were added to complete the system.

3.5.1.1. Junction demand allocation

The steps for junction demand allocation for all study areas are stated below.

I. The selection of the demand input method was based on the available water consumption data. There are three different methods for automatic demand inputs using the water GEMS software: point load, area load, and population proportion or land use method. The point load method requires geoinformation-referenced water meter data, while the area load method is applicable when consumption data is not known for the service area. In this case, the area load method was selected for the research area, as there is no population proportion data or land use information available in the selected study areas.

II. Preparing the service area Thiessen polygon on water using the selected nodes and polygon boundary layer prepared by shapefile on ArcGIS ArcMap software.

III. Divide the average daily demand for each Thiessen polygon area and allocate the water demand for each junction based on the results.

3.5.2. Steady-state simulation

steady-state models compute the system's state (flows, pressures, pump characteristics, valve position, etc.) on the assumption that boundary conditions and hydraulic demands don't change over time. However, the mathematical concept of a steady state can be a highly helpful tool for designers since it allows them to anticipate how a particular combination of hydraulic situations (such peak hour demands or a fire at a certain node) will be responded to. This serves as a foundation for the additional simulation analysis as well (Strafaci et al., 2004).

3.5.3. Extended period simulation

The system conditions were calculated using a twenty-four-hour time interval with a one-hour time increment and a 12:00 AM model run time. The software uses the principles of mass and energy conservation to simulate non-steady-state hydraulic calculations

3.6. Calculation of average operating pressure (AOP)

Water pressure field measurements and a mathematically calibrated hydraulic model are two possible bases for determining the average operating water pressure,(Halkijević et al., 2017).

To estimate the average pressure of the zone using a field measurements approach, one must identify the Average Zone Point (AZP), which is typically a hydrant. It is thought that the recorded pressure at this point, when accurate enough, represents the pressure across the zone.

On the other hand, the calibrated hydraulic model is used in the second technique approach. Flow and pressure measurements are among the field data that must be obtained to build such a model. To ascertain the water balance in the system, field measurements are often taken; the same information is then utilized to calibrate the model. The benefit of utilizing a calibrated model is that it makes determining the average pressure easier and faster. It also allows for different types of following pressure analysis to be performed without requiring additional field data (Halkijević et al., 2017).

Thus, the average pressure can be obtained in the same manner by substituting node pressure readings from the model for field measurements. Additionally, the model allows for the quick and easy calculation of weighted pressure values while accounting for all node pressures in the network or at service connections.

In this study, the average operating pressure across the water distribution system is calculated using the hydraulic model.

Weighted node pressure can be used to calculate the average pressure in situations where the node density is not evenly distributed or where a single node does not represent a single service connection. Under such circumstances, the weighted component may consist of the node's water usage and node corresponding length of the water supply network (Halkijević et al., 2017).

It is important to keep in mind that the average pressure of the entire zone will be impacted by the water usage of a single, larger customer, whose consumption is also defined at some node.

In this instance, the average pressure of the zone must be calculated by weighting the average pressures from each node with the corresponding consumption in the following manner:

$$\boldsymbol{\overline{P}} = \frac{\sum \boldsymbol{\overline{P_i}} * (\mathbf{1} + \boldsymbol{d_i})}{\sum (\mathbf{1} + \boldsymbol{d_i})} \text{……………………………………………} \text{Equation 13}$$

Where:

$\dot{P}$- average pressure, (mH2O)

$\dot{P}_i$- average node pressure, (mH2O)

d_i- water consumption (water demand) in the node, (l/s)

3.7. Model calibration and validation

Pressure measurement by Metrolog tool was done to calibrate and validate the hydraulic model. Pressure levels throughout the water distribution system are monitored to ensure proper service and to gather information for use in model calibration. Pressure readings are commonly taken at fire hydrants, hose bibs, and home faucets. In this study, pressure was measured at customers' faucets (Strafaci et al., 2004).

3.7.1. Sampling Design for Calibration and Validation

Sampling design is the process of selecting locations in a water distribution system to collect data for calibration (Strafaci et al., 2004). A typical water network can include hundreds or thousands of links and nodes. During calibration, it is ideal to adjust the model for each link and node. However, due to limited resources, only a small representative sample can be used for calibration. Therefore, it is important to have an efficient methodology and tool to achieve accurate modeling under practical conditions. A total of 10 sample locations were measured in each town (Bishoftu and Mojo) to calibrate and validate the model, but for Adama town there was a measured pressure data in the utility office. Out of the 10 samples collected, 7 were utilized for model calibration, while the remaining 3 were reserved for validation purposes. Figure 3.7-1 and 3.7-2 depict the selected locations for pressure measurement, chosen to represent the town's water supply system.

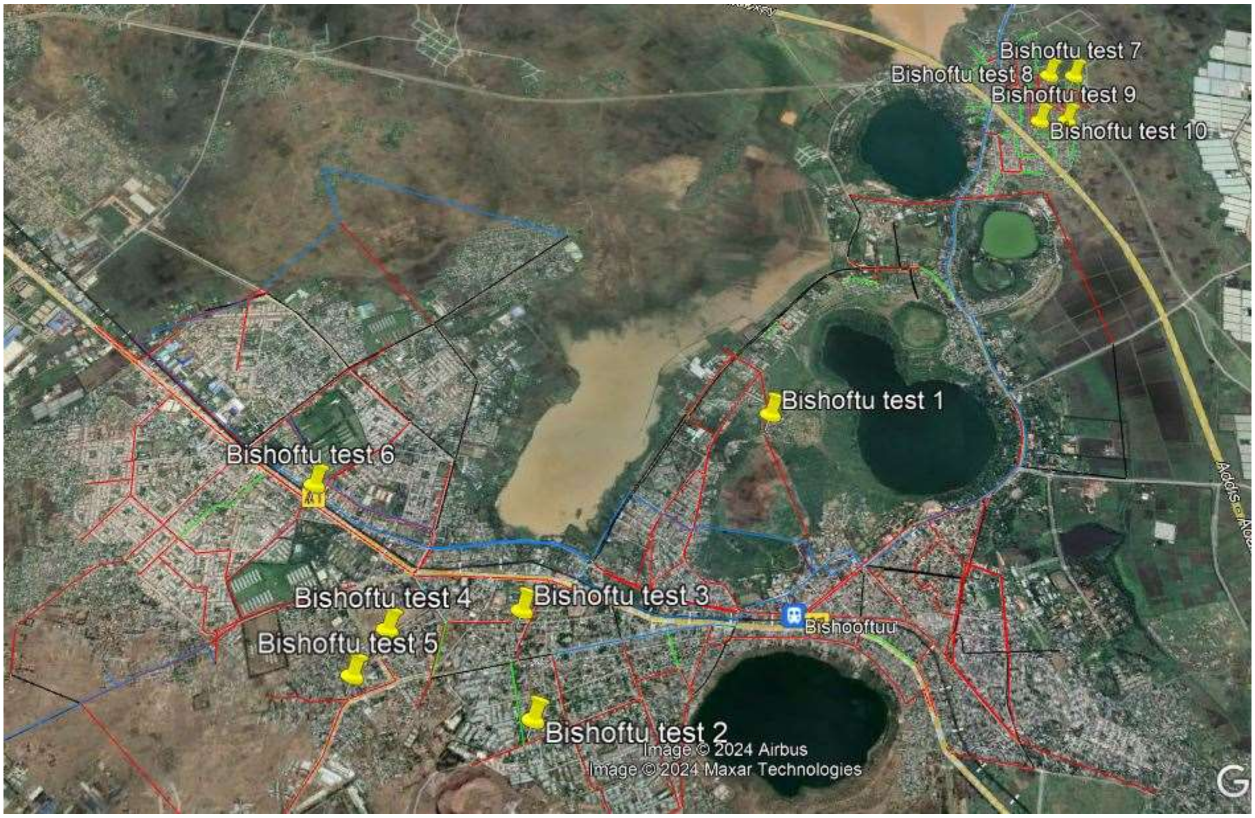


Figure 3.7-1 Locations of pressure test in Bishoftu town

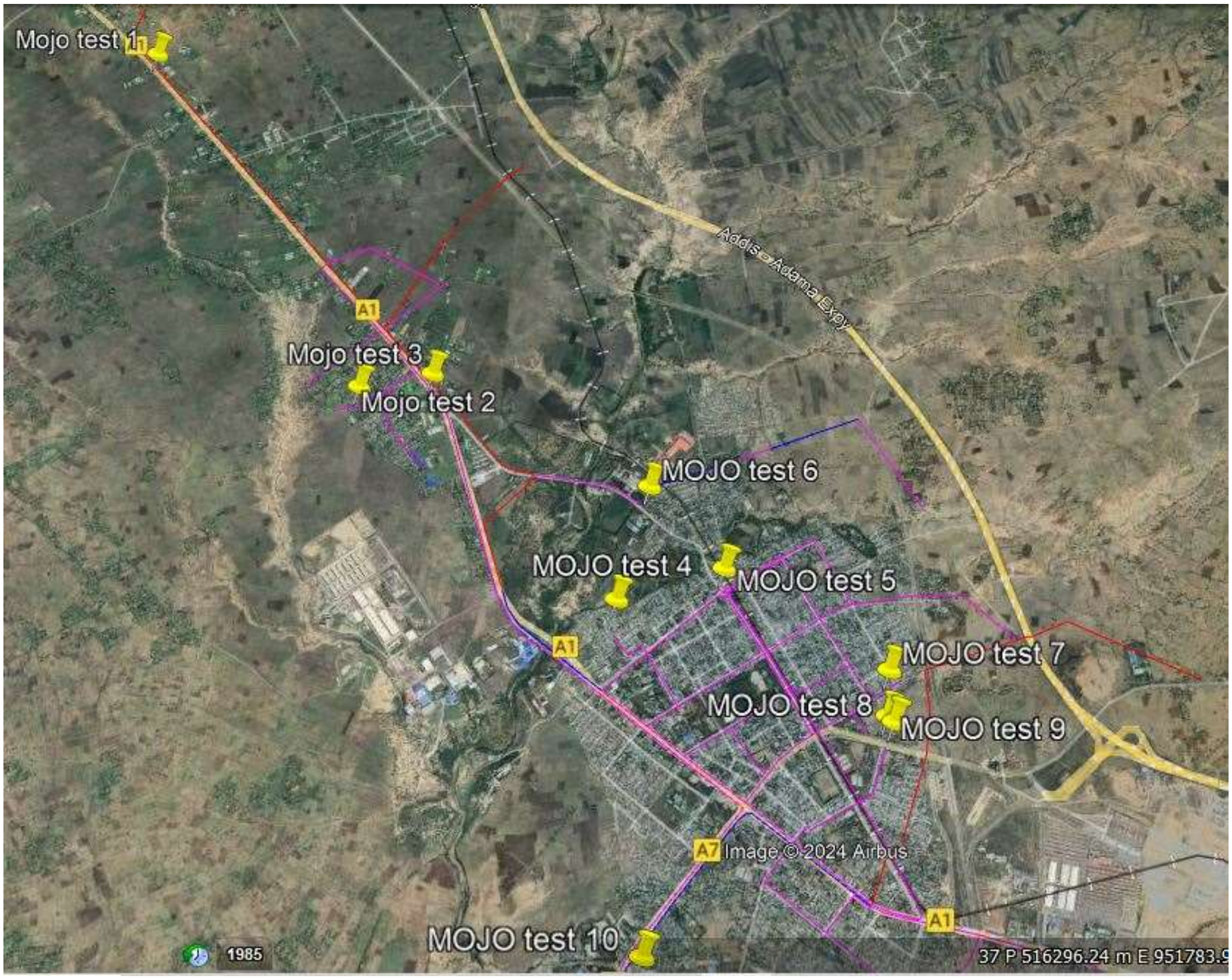


Figure 3.7-2 Location of pressure test in Mojo town

The calibration and validation of the simulated pressure, derived from the on measured pressure, involved assessing the statistical average difference error and correlation coefficient (R^2) using the provided formula.

3.7.1.1. Average difference error

$$average\ difference\ error = \frac{\sum(field\ measured - simulated\ pressure)}{Number\ of\ samples} \text{……….Equation 14}$$

The calibration is validated under which it satisfies average difference error, average ±1.5m pressure head to ±5m pressure head. The acceptable range average difference error is +1.5m pressure head to ±5m pressure head.

3.7.1.2. Correlation coefficient

$$R^2 = \frac{\sum S - Smean * \sum O - Omean}{\sqrt{\sum(S - Smean)^2 * \sum(O - Omean)^2}} \text{…………………..……….Equation 15}$$

Where:

S- the simulated pressure,
O- field measured pressure,
Smean- the sampled average simulated pressure, and
Omean – the average field measured pressure.

3.8. Assessment of water loss

Leakage or real loss (RL) in pipes, storage reservoirs, and customer connections constitutes the WL, whereas apparent loss (AL) results from under-registration of the customer meter, billing, and data handling errors, or unauthorized use. Non-revenue water (NRW) is the total volume of WL plus the volume of unbilled authorized consumption (UAC), which is the authorized use that generates no revenue, such as water used for network cleaning or firefighting (T. AL-Washali et al., 2020). There are four methods used for the assessment of water losses (T. AL-Washali et al., 2020).

3.8.1. Minimum night flow (MNF)

In section 2.2.6, we briefly discussed that MNF is carried out in a district-metered area (DMA). This method allows for an estimation of the actual loss during the night flow, and the apparent loss can be calculated by subtracting the volume of AL from the total volume of water loss (WL).

This method has a few drawbacks. Firstly, it involves fieldwork which can be expensive and time-consuming. Secondly, estimating the real loss value by generalizing the net night flow (NNF) for all hours of the day can lead to overestimation of daily leakage due to lower average operating pressure (AOP) caused by higher flows. Finally, this method requires sophisticated equipment (Taha AL-Washali e. a., 2016). Considering the above-mentioned drawbacks, this approach was not adopted for the analysis of water loss (WL) in this study.

3.8.2. Component analysis of the leakage

The estimation of the volume of leakage can be done through a method called component analysis of the leakages, which is also known as Burst and Background Estimation (BABE). This method involves multiplying Q (leakage flow rate) and T (leak duration) to calculate the volume of leakage. Various factors such as the policies of the water utility, the frequency of leakage detection campaigns, and the reporting of detectable leaks, can affect the duration of the leaks (Taha, 2020). More information on this method can be found in section 2.2.6.

This method of assessing water loss has various limitations. Among these, it relies on several assumptions and is only applicable to utilities with active leakage control (ALC). Due to these reasons, this method cannot be utilized in the current research as the selected study areas lack an ALC system.

3.8.3. Water and wastewater balance method

The water and wastewater balance methods are used to analyze NRW by creating a balance between water and wastewater. More details about this method can be found in section 2.2.6.

This research cannot utilize the water and wastewater balance method due to the requirement of a centralized sewer system for all parts of the network and the need for measurements of wastewater inflows. However, the selected study areas do not have a centralized sewer system.

3.8.4. Top-down water balance

The top-down water balance method is a commonly used approach for assessing water loss. This method involves estimating the components of Apparent Losses (AL) and then calculating the Real Losses (RL) volume using the Water Loss (WL) volume. Once the system input volume and billed consumption (BC) are determined, the Non-Revenue Water (NRW) volume can be computed using Equation (16). The Unaccounted-for Water (UAC) can then be subtracted from the NRW volume to determine the WL volume Eq. (17). The AL components, which include meter inaccuracies, data handling mistakes, and unauthorized consumption, are then investigated to determine the Unavoidable Annual Real Losses (UC) (T. AL-Washali et al., 2020). For more details, refer to section 2.2.6.

$$\boldsymbol{NRW = SIV - BW} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 16}$$

$$\boldsymbol{WL = NRW - UAC = AL + RL} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Equation 14}$$

Where: -

NRW -is the non-revenue water (m^3/year),

SIV- is the system input volume (m^3/year),

BC- is the billed consumption,

WL- is the Water Loss volume (m^3/year),

UAC- is the unbilled authorized consumption (m^3/year),

AL is the apparent loss, and RL is the real loss.

In this study, the top-down water balance method was chosen due to its simplicity and cost-effectiveness. This method doesn't require any advanced equipment, field measurements, or a central wastewater treatment plant (which is not available in the selected study areas). Additionally, it is particularly useful for analyzing water loss in utilities that lack an active leakage control system (which is not available in the selected study areas).

3.8.5. Apparent loss analysis

Apparent losses consist of four primary components: customer meter inaccuracy, meter reading error, unauthorized consumption (theft, meter bypass, illegal connections, misuse of fire hydrants, etc.), data handling, and billing errors (H. E. Mutikanga et al., 2011).

3.8.5.1. Unauthorized Consumption

Unauthorized consumption is the result of domestic illegal connections, illegal connections from organizations and others, meter tampering bypass, etc. at registered customers.

The amounts of unauthorized water consumption in all three study towns were analyzed by conducting questionnaires and interviews with representatives from the water utility offices.

3.8.5.2. Customer meter inaccuracy, meter reading error, data handling and billing errors

Water meter inaccuracies can occur due to various reasons such as customer meter inaccuracy, meter reading error, data handling, and billing errors. To analyze water meter errors, representative samples from customer water meters can be taken and the amount of errors in these water meters can be tested. If a water meter laboratory is not available or there is a shortage of previously tested data, different basic standards on water meter errors can be used for analysis. Additionally, results from different towns and countries can be studied to identify the same character with the selected study areas.

For this study, the second approach was chosen because there is no water meter laboratory available in the selected study areas. Moreover, it cannot be tested in the AWSSA NRW department water meter laboratory because if the customer's water meters are picked up from their houses, they need to be replaced with another water meter. This process requires high manpower and purchasing water meters, which is very costly and impossible to carry out in this study.

This study evaluates water meter inaccuracies by considering the following factors:

- The frequency of customer water meter testing
- The policy for replacing older meters
- The method for identifying and resolving water meter problems
- The average age of the water meter
- The type and brand of the water meter purchased
- The condition of the water supply service, (interruptions of supply will lead to customers using house storage tanks)
- The way data is recorded, transferred, and handled by the water utilities

- The relevant standards and literature on water meter inaccuracies in developing countries.

The calculation of water meter inaccuracies involves categorizing customer water meters based on the age of their service, Brand, size, and condition of service (with storage tank or without storage tank). For Adama town, the water meter inventory was done by the water utility office of the town but for Mojo and Bishoftu towns the inventory was done by gathering primary data as shown in the Appendix 1.

- *Water meter Sampling techniques*

A customer water meter inventory was done for the analysis of the type, model/brand, and age of the water classification. The following formula determined the sample size of the water meter (C.R.Kothari, 2004).

$$\boldsymbol{n = \frac{Z^2pqN}{(N-1)e^2+Z^2pq}} \text{...Equation 15}$$

Where: -

n - customer meter sample size,

Z – standard variant at given confidence level =1.96,

p=sample proportion, if there is no previous study on the key parameters (P is taken as 50%),

N= number of the customer water meter,

q=1-p,

e=the precision (5%).

3.9. Infrastructure leakage index (ILI) analysis

The International Water Association (IWA) water balance helps analyze the ILI (infrastructure leakage index). Water balance is based on measurements or estimations of

I. water produced,
II. water imported and exported,
III. Water consumed, and
IV. Water lost.

The water balance calculation provides a guide to estimate how much is lost as leakage from the network (‘real’ losses), and how much is due to non-physical losses (‘apparent’ losses). This calculation allows the practitioner to answer ‘How much water is being lost?’ (Winarni W, 2009) The water balance is usually computed over 12 months and thus represents the annual average of all components (Alegre et al., 2016). Water balance components should always be calculated as volume before any attempts are made to calculate performance indicators. For Adama town, the analysis of water loss and ILI was conducted over five years; however, due to insufficient data, the analysis was conducted over three years for the Bishoftu and Mojo towns.

(Alegre et al., 2016) Definitions of the principal components of the IWA water balance are as follows:

- *System input volume*: the volume input to the water supply system during the assessment period.
- *Authorized consumption*: the volume of metered and/or non-metered water taken by registered customers, the water supplier, and others who are implicitly or explicitly authorized to do so by the water supplier, for residential, commercial, and industrial purposes, during the assessment period. It includes water exported.
- *Real losses:* physical water losses from the pressurized system, up to the point of measurement of customer use during the assessment period. The volume lost through all types of leaks, bursts, and overflows depends on frequencies, flow rates, and average duration of individual leaks.
- *Apparent losses:* accounts for all types of inaccuracies associated with production and customer metering, plus unauthorized consumption (theft or illegal use).
- *Non-revenue water:* the difference between the volumes of system input and billed authorized consumption. Non-revenue water includes real losses, apparent losses, and unbilled authorized consumption.

The calculation associated with the Water Balance is listed below in Table 3.9-1

Table 3.9-1Components of water balance

A	B	C	D	E
Water balance in m3/year				
System input	Authorized consumption m3/year	Billed authorized m3/year	Billed metered consumption in m3/year	Revenue Water in m3/year

volume m3/year			Billed unmetered consumption in m3/year	
		Unbilled authorized in m3/year	Unbilled metered consumption in m3/year	Non-revenue water in m3/year
			Unbilled unmetered consumption in m3/year	
	Water losses in m3/year	Commercial losses (apparent loss) m3/year	Unauthorized consumption in m3/year	
			Customer meter inaccuracies and data handling errors in m3/year	
		Physical losses (real loss) in m3/year		

Steps for calculating non-revenue water and water losses:

Step 1: Define and enter the system input volume in Column A.

Step 2: Define billed metered consumption and billed unmetered consumption in Column D; enter the total in billed authorized consumption (Column C) and revenue water (Column E).

Step 3: Calculate the volume of non-revenue water (Column E) as system input volume (Column A) minus revenue water (Column E).

Step 4: Define unbilled metered consumption and unbilled unmetered consumption in Column D; transfer the total to unbilled authorized consumption in Column C.

Step 5: Add volumes of billed authorized consumption and unbilled authorized consumption in Column C; enter the sum as authorized consumption (Column B).

Step 6: Calculate water losses (Column B) as the difference between system input volume (Column A) and authorized consumption (Column B).

Step 7: Assess components of unauthorized consumption and metering inaccuracies (Column D) as section 3.8.5, Then calculate the sum of unauthorized consumption and water meter inaccuracies loss, and enter this amount in the apparent loss column (Column C).

Step 8: Calculate real losses (Column C) as water losses (Column B) minus apparent losses (Column C).

3.9.1. Analysis of CARL and UARL

3.9.1.1. Current annual real loss (CARL)

The current annual volume of real losses CARL, as previously described, is the ratio of real losses to the total number of days that the WDN is under pressure during the water balance calculation period.

$$\boldsymbol{CARL}\left(\frac{\boldsymbol{L}}{\boldsymbol{day}}\right) = \frac{\boldsymbol{Real\ losses} * \mathbf{1000}}{\boldsymbol{Tp}} \text{……………………..……………Equation 16}$$

Or CARL can be calculated as per the service of connections

$$\boldsymbol{CARL}(\boldsymbol{l/day/service\ connection}) = \frac{\boldsymbol{Real\ losses} * \mathbf{1000}}{\boldsymbol{Tp} * \boldsymbol{Nc}} \text{………Equation 20}$$

Where: -

CARL- Current annual real loss

Tp - is the number of days in which the WDN is pressurized throughout the water balance calculation

Nc - is the number of service connections

3.9.1.2. Unavoidable annual *real loss (UARL)*

(Helena Alegre, 2017) The Unavoidable Annual Real Losses, or UARL, are the "best estimate" of the technically attainable low-level real losses. This can be calculated as shown below.

$$\boldsymbol{UARL}\left\{\frac{\boldsymbol{L}}{\boldsymbol{day}}\right\} = (\mathbf{18} * \boldsymbol{Lm} + \mathbf{0.8} * \boldsymbol{Nc} + \mathbf{25} * \boldsymbol{Lp}) * \boldsymbol{p} \text{…………Equation 21}$$

UARL also can be calculated as the ratio of service connection

$$\boldsymbol{UARL}\left\{\frac{\boldsymbol{l}}{\boldsymbol{day}}/\boldsymbol{service\ connection}\right\} = \left[\mathbf{18}\,\frac{\boldsymbol{Lm}}{\boldsymbol{Nc}} + \mathbf{0.8} + \mathbf{25}\,\frac{\boldsymbol{Lp}}{\boldsymbol{Nc}}\right]\boldsymbol{P} \text{…...Equation 17}$$

Where:-

UARL- unavoidable annual real loss

Lm(Km)- is the length of the mains pipes (without service pipes).

Lp (Km) -is the total length of service connections (distance between property line and customer water meter)

Nc -is the number of service connections.

P (m) -is the average operating pressure (AOP).

Finally, the ILI (infrastructure leakage index) is calculated as

$$\boldsymbol{ILI = \frac{CARL}{UARL}} \qquad \text{Equation 18}$$

3.10. Infrastructure asset management (IAM) analysis

The IAM analysis was conducted for all selected study areas by gathering primary data from customers and employees of the water utilities and secondary data from water utility reports, journals, and related books. this analysis does not focus on the quality of the water system. Instead, it mainly focuses on asset inventory of water meter inaccuracies, which are necessary to identify apparent losses in the system, customer satisfaction and service interruption. Unfortunately, the asset inventory was not focused on other assets due to a shortage of data.

3.11. Research process

To evaluate the authorized and unauthorized consumption of water in a town, a questionnaire was prepared for the town water utilities. This questionnaire collected information on the amount of water production (system input volume), billed metered consumption, billed unmetered consumption, unbilled consumption, and illegal connections at domestic and organizational levels. Additionally, an estimation of water meter inventory was done to assess water meter inaccuracies in the study areas. After collecting all this data, the water balance was analyzed. The average operating pressure were calculated from the calibrated hydraulic model to help evaluate infrastructure leakage index (ILI).

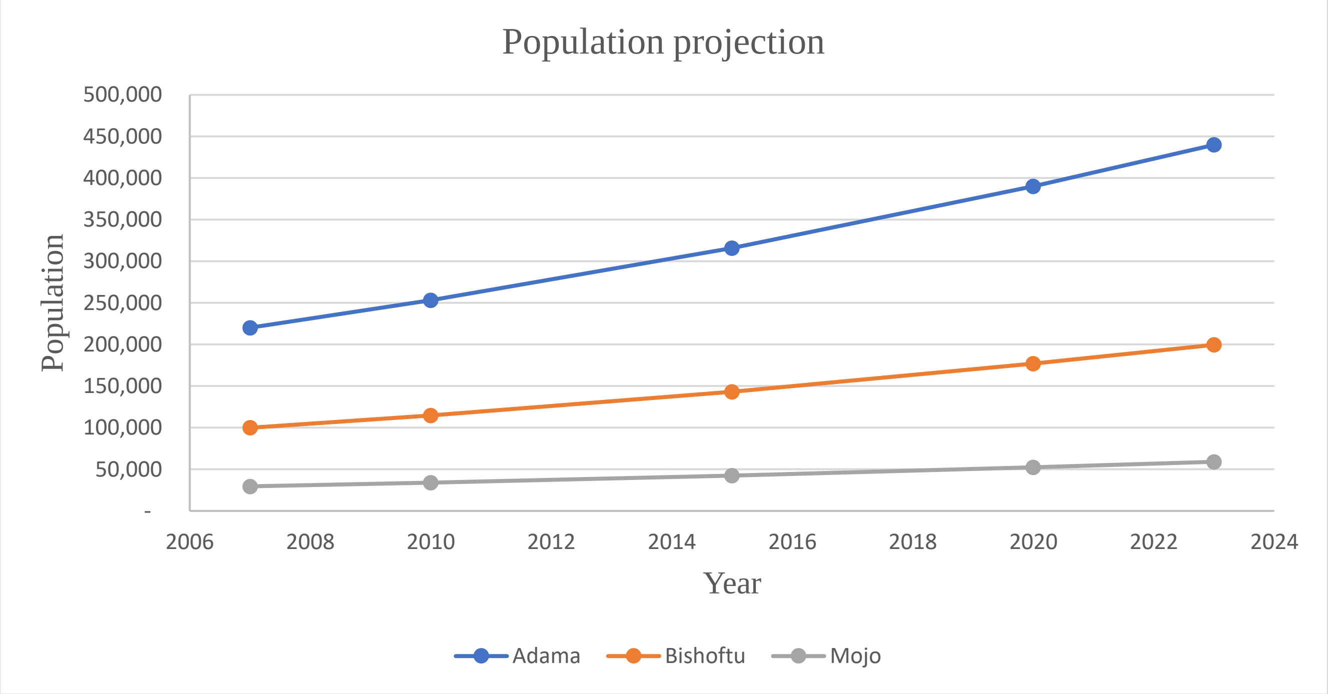
4. RESULT AND DISCUSSION

4.1. Demand and population analysis

4.1.1. Population analysis

According to CSA data, the population of Adama, Bishoftu, and Mojo towns in 2007 was 220,212, 99,928, and 29,547 respectively. By projection to present 2023 the population of Adama, Bishoftu, and Mojo is 43,989, 199,604, and 59,020 respectively. The population forecasted results are shown below.

Table 4.1-1Adama, Bishoftu, and Mojo town population forecast



4.1.2. Water demand

4.1.2.1. Domestic water demand

As stated in the methodology section, the summarized results of domestic water demand for each study area are listed in the appendix 2, 3 and 4.

According to the figure below, in the year 2023, Adama town had a domestic water demand of 28,617.56 m^3/d, while Bishoftu town had a demand of 14,983.97 m^3/d and Mojo town had a demand of 2,953.67 m^3/d. This indicates that Adama town has a higher population density compared to the other towns. On the other hand, Mojo town has a smaller population and thus a lower domestic water demand compared to the other two towns.

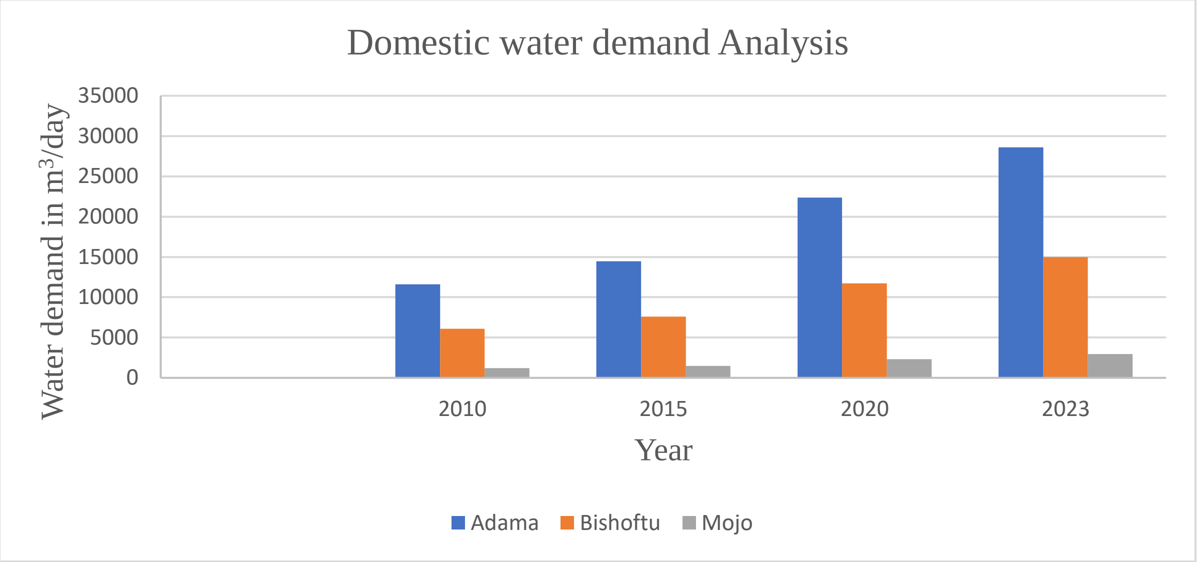


Figure 4.1-1Domestic water demand analysis of Adama, Bishoftu, and Mojo

4.1.2.2. Total water demand evaluation

The total water demand for the study has been determined by adding up all the water demand requirements mentioned in the methodology section above. This includes variations in demand such as the average daily demand, maximum daily demand, and peak hourly demand for the years 2015, 2020, and 2023.

Based on the analysis, the average water demand for the towns of Adama, Bishoftu, and Mojo in 2023 is 48,936.03 m^3/d, 26,821.30 m^3/d, and 5,287.07 m^3/d, respectively. This indicates a significant increase in water demand due to the population growth. Therefore, the town water utility should focus on exploring alternative water sources and improving its water supply and asset management systems. The analysis highlights that Adama town has the highest water demand among the three towns. there is a graph below showing the average water demand in different years for all study areas. Also, there is a full water demand analysis table in the appendix 5, 6 and 7 for each study area.

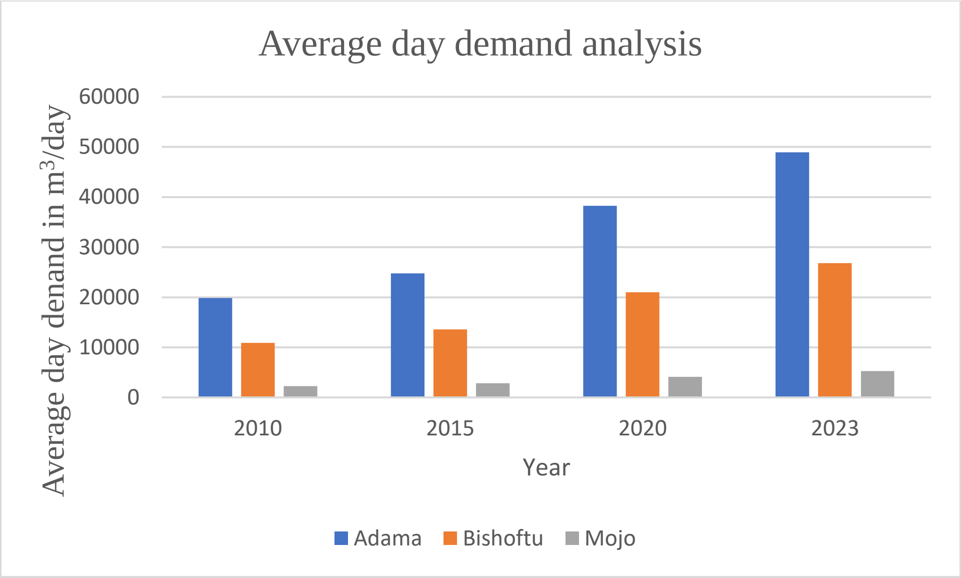


Figure 4.1-2Average Day demand analysis of Adama, Bishoftu, and Mojo

4.2. Junction demand allocations

The allocation of water demand for a water distribution network at junctions was analyzed using the Thiessen polygon areal load method. As shown in the figures below, the demand at each junction is determined based on the area it occupies in the Thiessen polygon. The average daily demand for Adama, Bishoftu, and Mojo is 48,936.03 m^3/day, 26,821.30 m^3/d, and 5,287.07 m^3/d, respectively. These demand values are calculated for the total areas of the Thiessen polygon, which are 4390 ha, 5270 ha, and 2571.95 ha. However, for each junction (514 Adama, 356 Bishoftu, and 129 Mojo), the Thiessen polygon areal load method prepares a separate polygon area and the demand is divided among the junctions according to their respective areas.

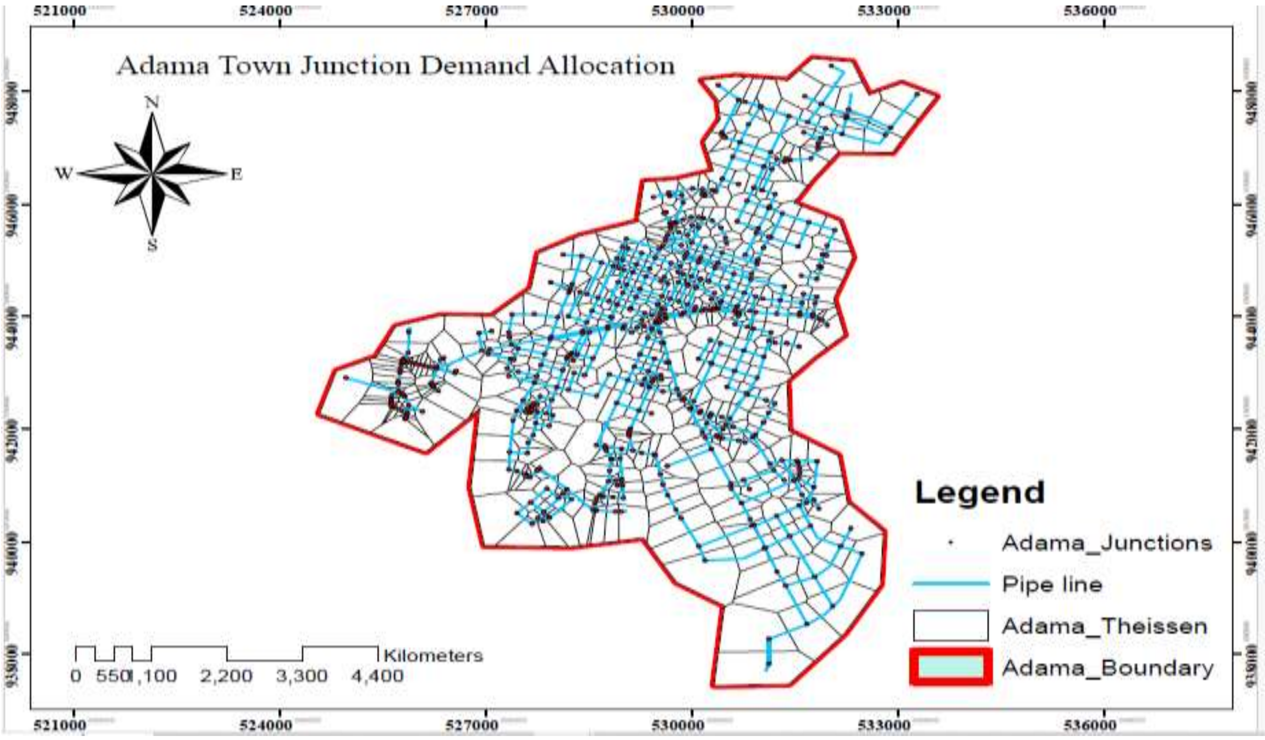


Figure 4.2-1Adama town junction water demand allocation

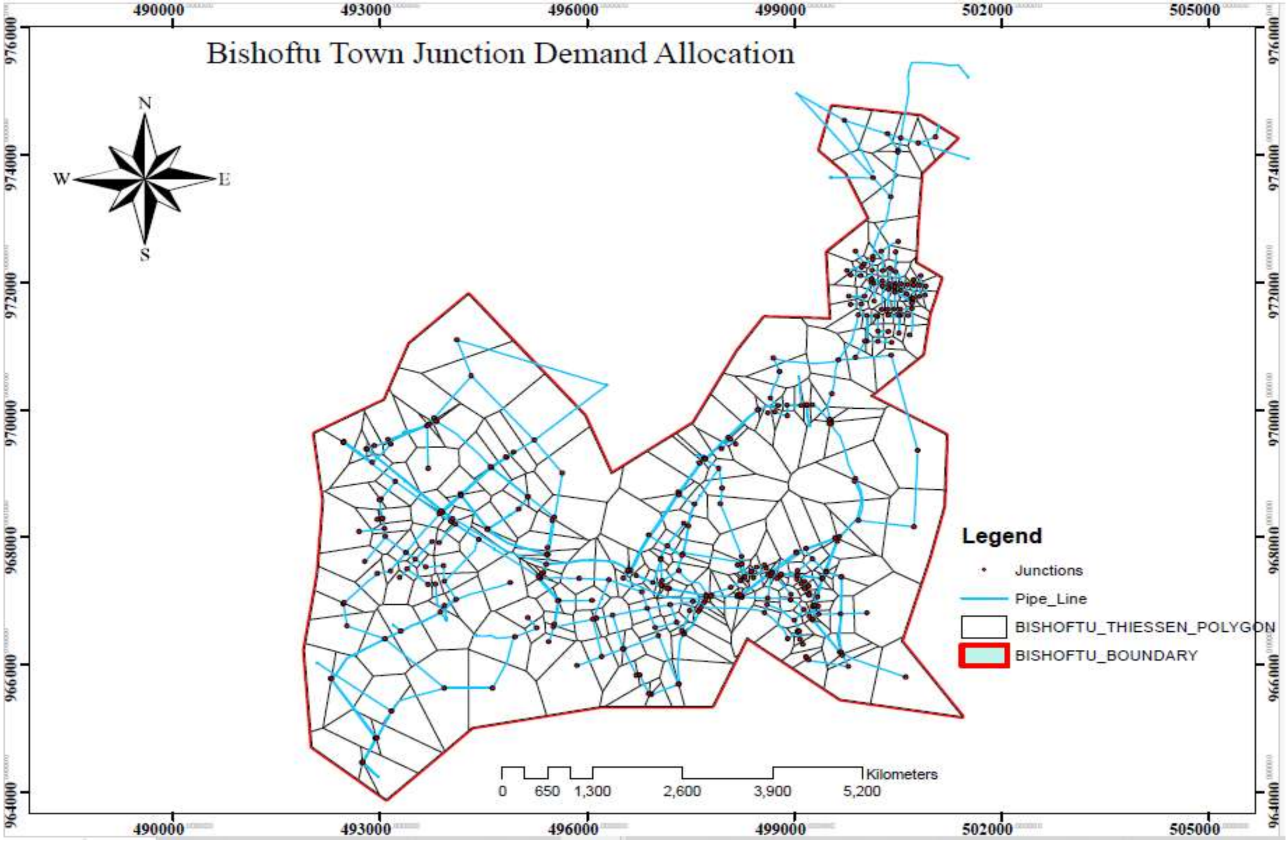


Figure 4.2-2Bishoftu town junction water demand allocation

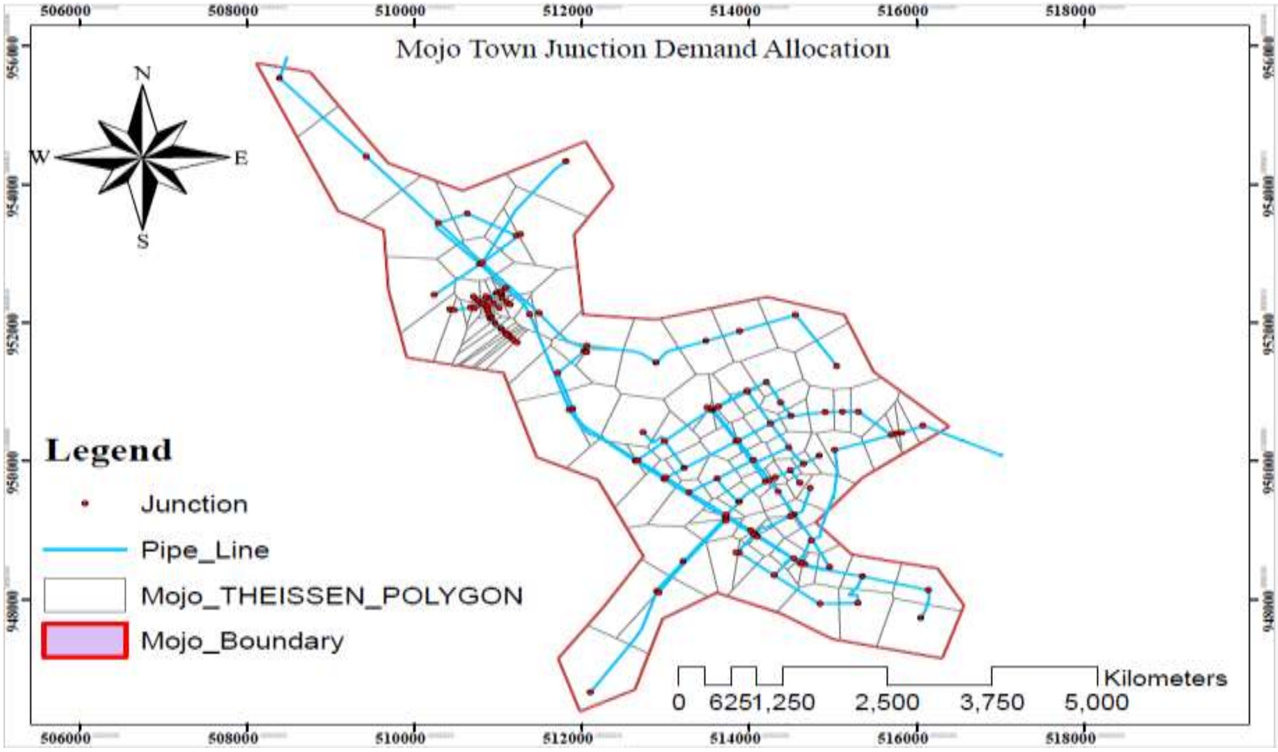


Figure 4.2-3Mojo junction water demand allocation

4.3. Calibration and validation of hydraulic model

As stated in section 3.7 by using a Metrolog tool ten representative pressure measurements were taken in each town for calibration and validation of the water gems hydraulic model. It was difficult to take measurement at a direct connection to the water main nodes, due to size of the pipes. The sample were taken in customers faucets. For the calibration and validation, the head loss between the supply main nodes and the site where pressure is measured had been considered. The head loss included the elevation head and pipe friction loss between two corresponding locations. These head losses and the total head loss are shown in table 4.3-1 up to 6.

Table 4.3-1 Calibration of model result with field measured data for Adama town

S. N	Sample node	Simulated model pressure	Field measured pressure at customer tap (mH2O)	Total head loss between the two locations (m)	The likely Simulated at supply mains node(mH20)	Error (m)	Time from start (hr)	scenario
1	J-81	5.2	4.5	1.60	3.60	0.90	8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early midnight) 2:00-4:00 (early morning)	Base scenario
2	J-96	51.23	46.4	1.19	50.04	-3.64		
3	J-358	65.4	56.7	0.57	64.83	-8.13		
4	J-381	62.7	58.8	0.60	62.10	-3.30		
5	J-431	68.78	54.1	0.64	68.14	-14.04		
6	J-418	42.79	38.6	0.67	42.12	-3.52		
7	J-109	25.67	24.5	0.21	25.46	-0.96		
Average error						-4.67		

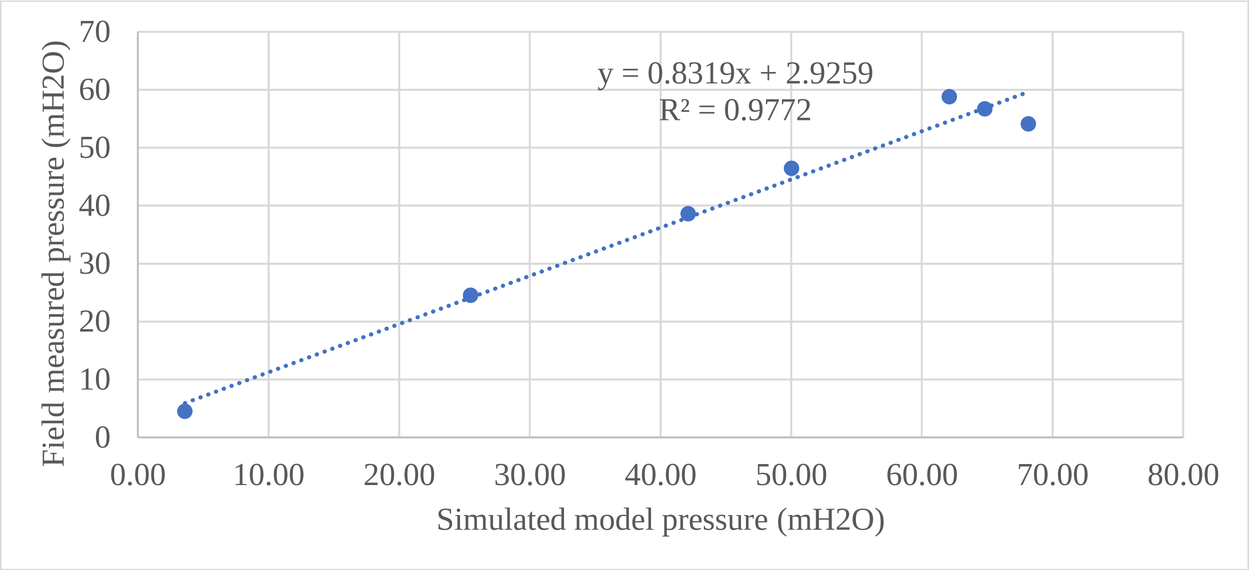


Figure 4.3-1 Calibration correlated plot for Adama

Table 4.3-2 Validation of model result with field measured data for Adama town

S. N	Sample node	Simulated model pressure	Field measured pressure at customer tap (mH2O)	Total head loss between the two locations (m)	The likely Simulated at supply mains node(mH20)	Error (m)	Time from start (hr)	scenario
1	J-17	7.3	6.7	1.80	5.50	1.20	8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early midnight) 2:00-4:00 (early morning)	Base scenario
2	J-468	78.22	70.2	0.08	78.14	-7.94		
3	J-441	71.83	62.5	1.72	70.11	-7.61		
Average error						-4.78		

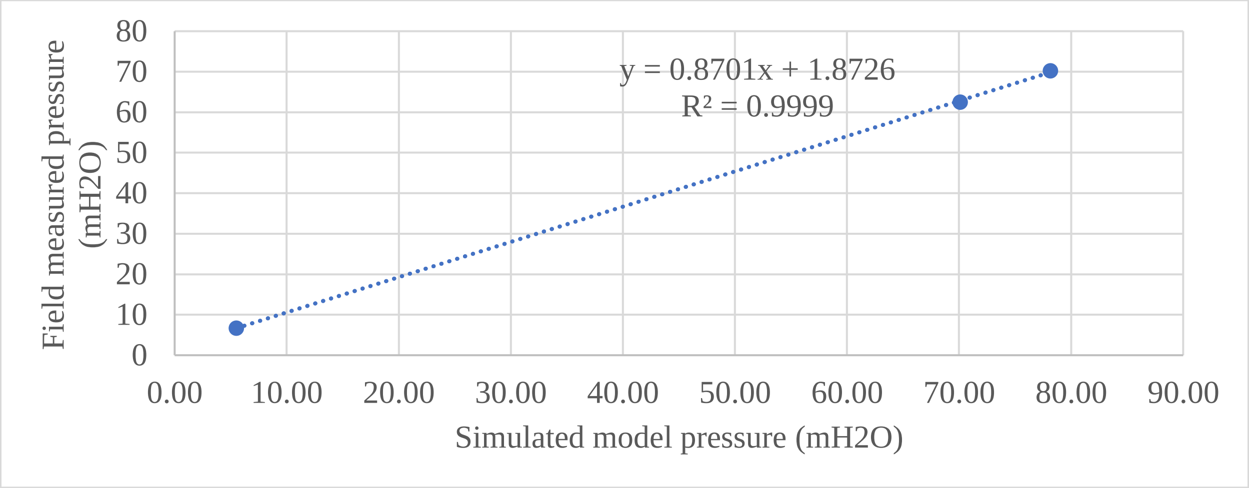


Figure 4.3-2 Validation correlated plot for Adama

Table 4.3-3 Calibration of model result with field measured data for Bishoftu town

S. N	Sample node	Simulated model pressure	Field measured pressure at customer tap (mH2O)	Total head loss between the two locations (m)	The likely Simulated at supply mains node(mH2o)	Error (m)	Time from start (hr)	scenario
1	J-305	101.38	100	1.00	100.380	-0.38	8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early midnight) 2:00-4:00 (early morning)	Base scenario
2	J-301	95.25	92.3	0.50	94.750	-2.45		
3	J-354	95.25	112.3	0.50	94.750	17.55		
4	J-52	47.54	45.8	1.00	46.540	-0.74		
5	J-38	48.56	45.4	1.00	47.560	-2.16		
6	J-69	71.01	68.6	0.50	70.510	-1.91		
7	J-67	69.06	63.8	2.00	67.060	-3.26		
Average error						0.95		

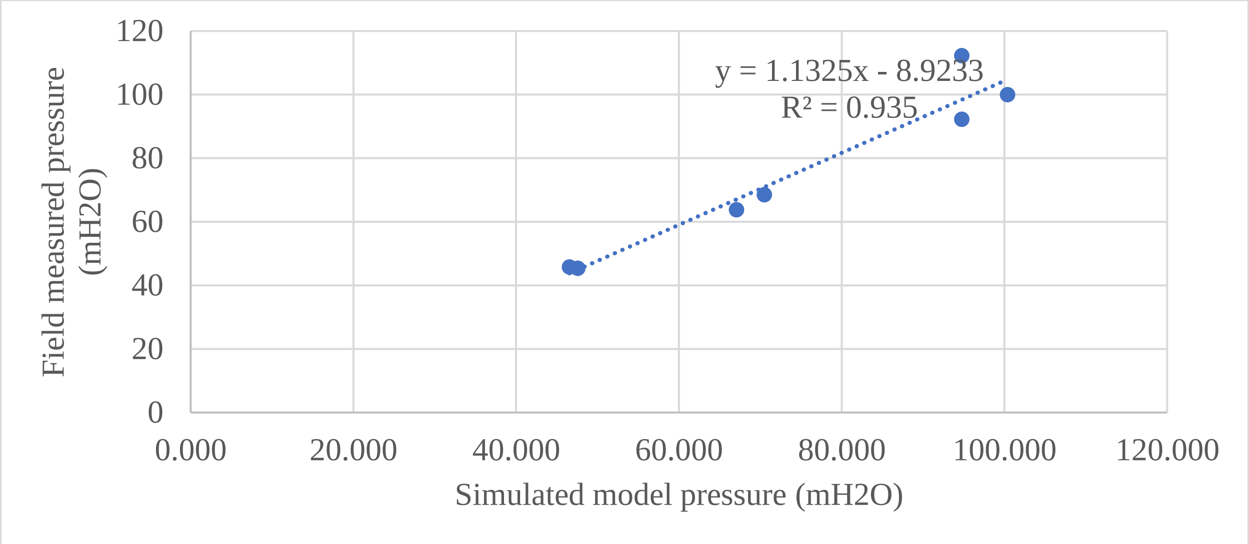


Figure 4.3-3 Calibration correlated plot for Bishoftu

Table 4.3-4 Validation of model result with field measured data for Bishoftu town

S. N	Sample node	Simulated model pressure	Field measured pressure at customer tap (mH2O)	Total head loss between the two locations (m)	The likely Simulated at supply mains node(mH2o)	Error (m)	Time from start (hr)	scenario
1	J-120	15.5	11.5	2.00	13.500	-2.00	8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early midnight) 2:00-4:00 (early morning)	Base scenario
2	J-261	48.11	42.4	1.00	47.110	-4.71		
3	J-275	52.4	48.6	2.00	50.400	-1.80		
Average error						-2.84		

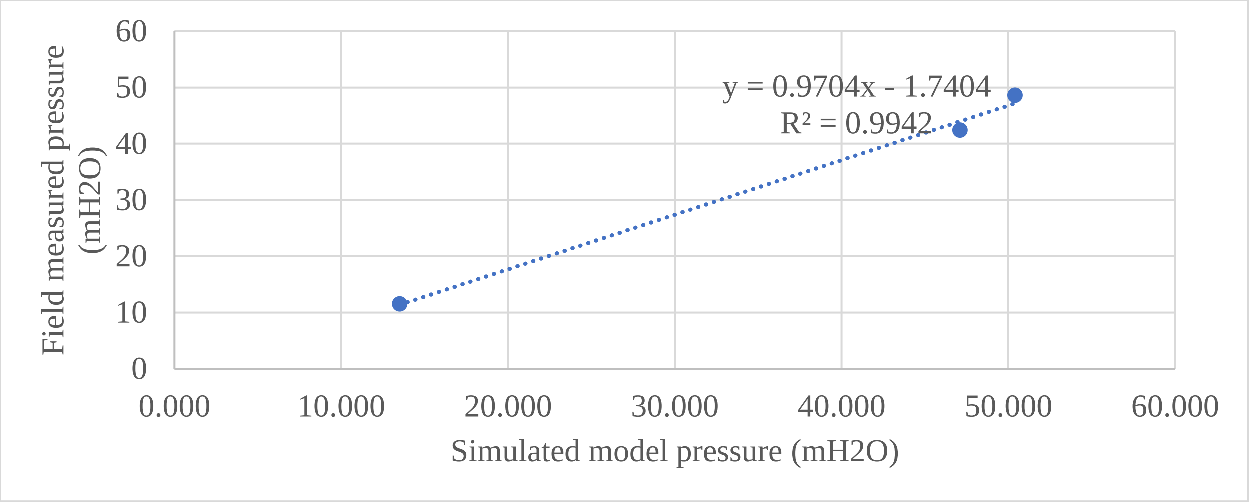


Figure 4.3-4 Validation correlated plot for Bishoftu

Table 4.3-5 Calibration of model result with field measured data for Mojo town

S. N	Sample node	Simulated model pressure	Field measured pressure at customer tap (mH2O)	Total head loss between the two locations (m)	The likely Simulated at supply mains node(mH2O)	Error (m)	Time from start (hr)	scenario
1	J-77	91.32	100	0.00	91.32	8.68	8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early midnight) 2:00-4:00 (early morning)	Base scenario
2	J-11	95.07	92.3	0.51	94.56	-2.26		
3	J-100	94.6	112.3	1.62	92.98	19.32		
4	J-14	54	45.8	0.03	53.97	-8.17		
5	J-65	65.7	45.4	0.50	65.20	-19.80		
6	J-41	77.4	68.6	1.36	76.04	-7.44		
7	J-127	68.72	63.8	0.69	68.03	-4.23		
Average error						-1.99		

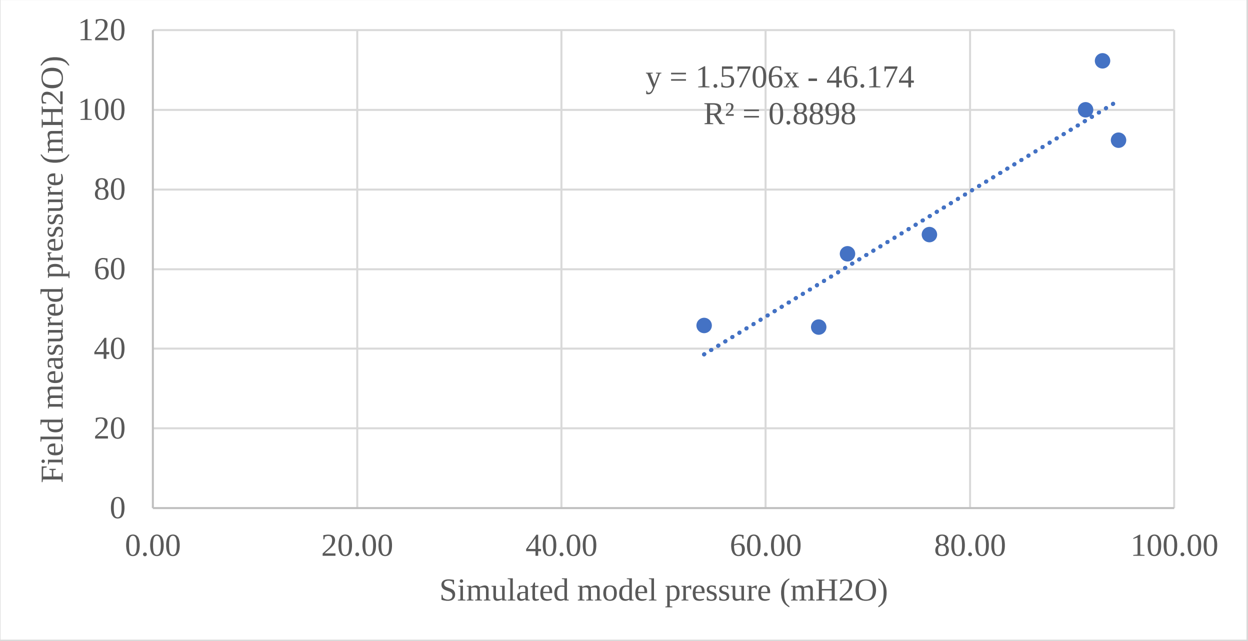


Figure 4.3-5 Calibration correlated plot for Mojo

Table 4.3-6 Validation of model result with field measured data for Mojo town

S. N	Sample node	Simulated model pressure	Field measured pressure at customer tap (mH2O)	Total head loss between the two locations (m)	The likely Simulated at supply mains node(mH2O)	Error (m)	Time from start (hr)	scenario
1	J-10	15.54	11.5	0.41	15.13	-3.63	8:00-12:00 (early mid noon) 2:00-6:00 (afternoon) 8:00-12:00 (early midnight) 2:00-4:00 (early morning)	Base scenario
2	J-13	42.72	42.4	0.50	42.22	0.18		
3	J-38	55.32	48.6	2.00	53.32	-4.72		
Average error						-2.72		

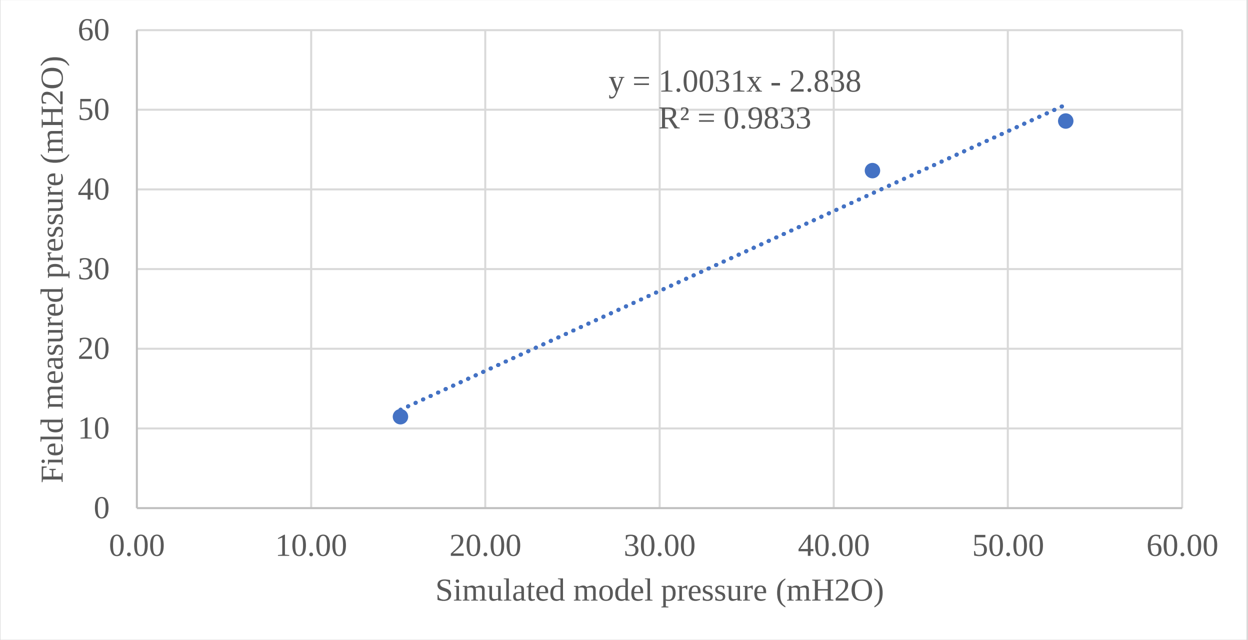


Figure 4.3-6 Validation correlated plot for Mojo

The simulated pressure was validated using validation criteria based on the pressure recorded at the field, and the simulated pressure average difference error exist in the acceptable range between average minimum ±1.5 to average maximum ±5. As shown in the above tables All calibrated pressure values are between with the acceptable range.

Figure 4.3-7 Field pressure measurement

4.4. Hydraulic model of the water supply system

The hydraulic model of Water Gems was used to analyze the water distribution network systems in different study areas during peak hour (PH), average, and minimum hour (MH) variations. In Adama town, the water distribution network is comprised of a total of 140.076 Km, out of which 35% (48.78 Km) is made of uPVC material and the remaining 65% (90.60 Km) is DCI material. Similarly, in Mojo town, the total length of the water distribution network is 57.32 Km, with 59% (33.72 Km) being uPVC and 41% (23.61Km) being HDPE. Also, in Bishoftu town, the total length of the water distribution network is 161.80 Km among this 21.92 Km (13%) is DCI (ductile iron), 17.45 Km (10.78%) is GS, 34.01 Km (21.02%) is HDPE and 88.43 Km (54.65%) is uPVC.

According to the hydraulic model's junction report, in the ADD analysis, Adama, Bishoftu, and Mojo towns have the highest number of junctions with the recommended level of pressure (11-70 m H2O) in the system, which is 58%, 75%, and 52%, respectively. This indicates that the system is functioning satisfactorily. Additionally, Adama, Bishoftu and Mojo have pressure levels exceeding the limit (>100) of 12%, 10% and 4%, respectively. The table below shows all the details about pressure in all the towns.

Table 4.4-1Pressure @ ADD for all study areas

Pressure (m H2O)	**Number of Junction in ADD**		**Percentage (%)**
1-10	Adama	8	2
	Bishoftu	1	0.3
	Mojo	0	0
11-70	Adama	300	58
	Bishoftu	266	75
	Mojo	67	52
71-100	Adama	144	28
	Bishoftu	53	15
	Mojo	57	44
>100	Adama	62	12
	Bishoftu	36	10
	Mojo	5	4

4.5. Analysis of average operating pressure

Adama, Bishoftu, and Mojo's average operating pressure was analyzed by a formula equation 22

$$\boldsymbol{\overline{P}} = \frac{\sum \boldsymbol{\overline{P_i}} * (\boldsymbol{1} + \boldsymbol{d_i})}{\sum (\boldsymbol{1} + \boldsymbol{d_i})} \text{……………………………………………………..Equation 19}$$

Where:

$\dot{P}$- average pressure, (mH2O)

$\dot{P}_i$- average node pressure, (mH2O)

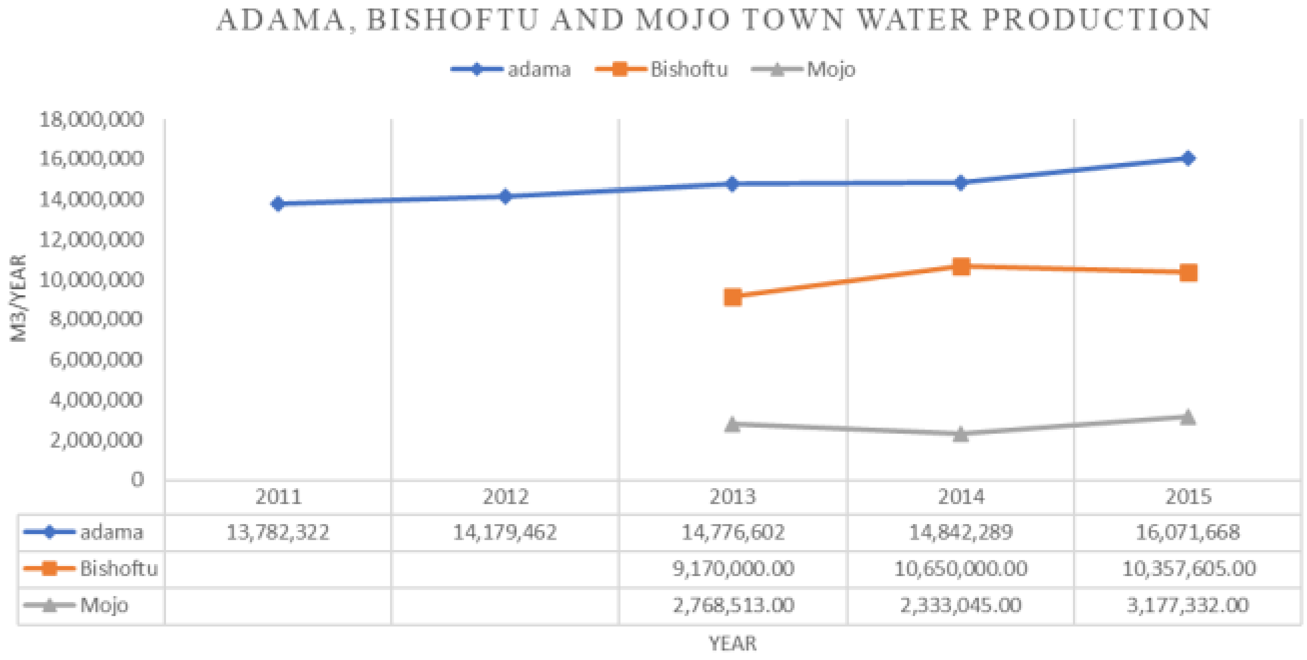
d_i- water consumption (water demand) in the node, (l/s)

On average, the operating pressure of Adama is 39.13 mH2O, Bishoftu is 62.6 mH2O, and Mojo is 55.6 mH2O. This indicates that the pressure in the system during an average day demand is within the recommended range of 10 mH2O and 70 mH2O. The full calculations result for the average operating pressure analysis for each town are included in the appendix 23.

4.6. Assessment of water loss

4.6.1. System input volume (water production)

A report by ATWSSE states that the Awash River, which has a minimum flow rate of approximately 15m^3/s, is regulated by the Koka hydropower reservoir and transported from a distance of around 15km, making it a potential water supply source for Adama Town. To transport raw water to the treatment plant, there are six pumps, each with the capacity to discharge 92 L/s of water using a 1000KW electric generator. The main water source for Mojo Town comes from seven boreholes, and for Bishoftu, the primary source of water is from 29 boreholes along the town, but only 17 of these boreholes are currently functional. The yearly water production for Adama, Bishoftu, and Mojo in 2015 E.C was 16,071,668 m^3/year, 10,357,605.00 m^3/year, and 3,177,332.00 m^3/year, respectively. While there is water production data available for Adama town from 2011 E.C to 2015 E.C, the data for Bishoftu and Mojo is only available from 2013 E.C to 2015 E.C. There are more details in figure 4.6-1 below.



	2011	2012	2013	2014	2015
adama	13,782,322	14,179,462	14,776,602	14,842,289	16,071,668
Bishoftu			9,170,000.00	10,650,000.00	10,357,605.00
Mojo			2,768,513.00	2,333,045.00	3,177,332.00

Figure 4.6-1Adama, Bishoftu, and Mojo town water production

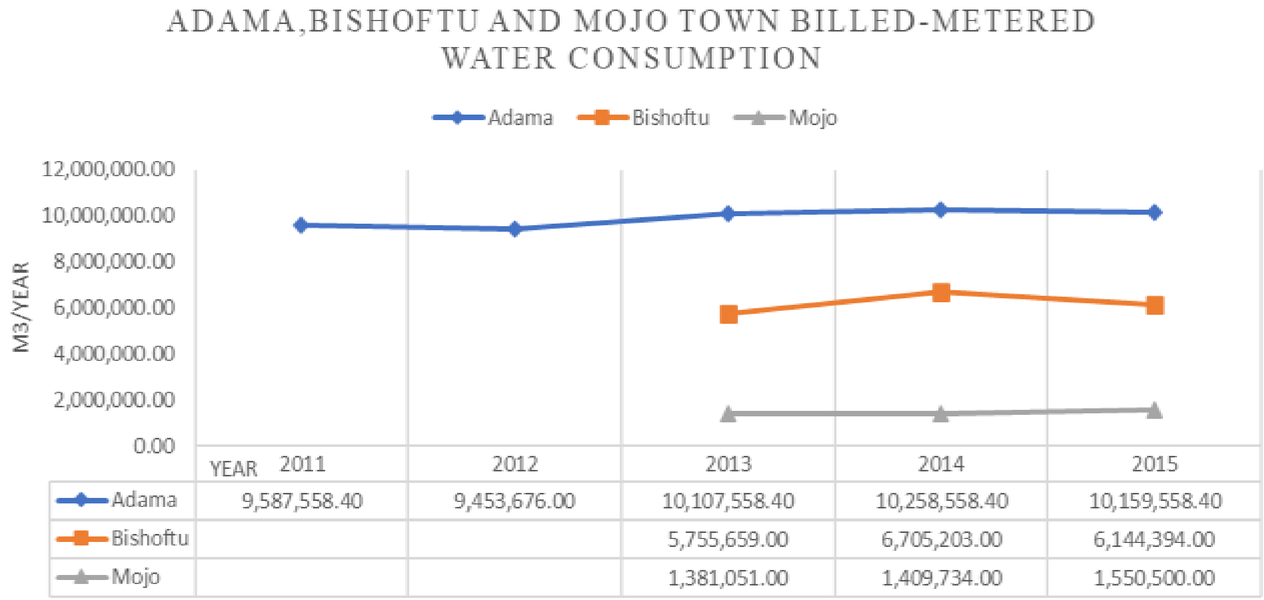
4.6.2. Authorized consumption

Authorized consumption is the volume of Billed-authorized (billed-metered consumption and billed-unmetered consumption) and unbilled authorized consumption (unbilled-metered consumption and unbilled unmetered consumption) during the assessment period.

4.6.2.1. Billed Authorized Consumption

I. Billed metered consumption

The billed-metered consumption is collected from utility monthly billed consumption documents. There is figure 4.6-2 below summarizes the billed metered consumptions for Adama for fiscal years 2011, 2012, 2013, 2014, and 2015 E.C. And for Bishoftu and Mojo towns for fiscal years 2013, 2014, and 2015.



YEAR	2011	2012	2013	2014	2015
Adama	9,587,558.40	9,453,676.00	10,107,558.40	10,258,558.40	10,159,558.40
Bishoftu			5,755,659.00	6,705,203.00	6,144,394.00
Mojo			1,381,051.00	1,409,734.00	1,550,500.00

Figure 4.6-2Adama, Bishoftu, and Mojo town billed metered water consumption

II. Billed Unmetered Consumption

Billed-unmetered consumption includes water lost as a result of damage to town water pipes by contractors or other parties. The responsible party is billed by the town's water utility office for the volume of water lost, which is estimated based on the diameter of the damaged pipe and the duration of the incident. This category also includes water distributed by towns water utilities to consumers by water tankers (trucks). The consumers are billed for this water but they are not metered. For instance, in Bishoftu town, there is an Ethiopian Air Force headquarters that uses water supplied by trucks, and they are billed for it, but it is not metered.

There are summarized tables 4.6-1 below for Adma from 2011 up to the 2015 E.C. fiscal year and for Bishoftu and Mojo from 2013 up to the 2015 E.C. fiscal year.

Table 4.6-1Billed unmetered consumption

Billed unmetered consumption (m3/year)			
Year (E.C)	Adama	Bishoftu	Mojo
2011	1,175	-	-
2012	3,575	-	-
2013	3,865	805.00	600.00
2014	3,980	1,046.50	670.00
2015	4,320	1,207.50	750.0

4.6.2.2. Unbilled Authorized Consumption

I. Unbilled Metered Consumption

This category of consumption includes water used by towns' water utility facilities, where water is metered but bills are not distributed.

The Adama Unbilled Metered Consumption consists of water used at seven reservoir sites and the Koka treatment site location, as well as the water utilized by the utility's employees. The unbilled metered consumption for Bishoftu and Mojo towns includes water used in borehole sites. In areas without access to water supply, the water utility office delivers water by trucks three days a week, with three trucks per day. Eligible staff can use up to 25 m3/month of water without any payment. Additionally, water used at the utility office has a water meter but is not billed and is included in unbilled metered consumption.

Table 4.6-2 below summarizes the unbilled metered consumption for Adama from 2011-2015 E.C. However, data for Bishoftu and Mojo is unavailable from 2011-2012 E.C.

Table 4.6-2Unbilled metered consumption

Unbilled metered consumption (m3/year)			
Year (E.C)	Adama	Bishoftu	Mojo
2011	98,200.00	-	-
2012	99,500.00	-	-
2013	99,100.00	99,657.20	52,701.00
2014	99,200.00	105,657.20	52,601.00
2015	99,400.00	111,957.20	52,201.00

II. Unbilled Unmetered Consumption

Unbilled Unmetered water consumption includes water used by water utilities for mains flushing, reservoir washing, manhole cleaning, etc. Washing reservoirs take water according to their sizes and duration of washing programs. Table 4.6-3 below summarizes the study areas of unbilled unmetered consumption.

Table 4.6-3Unbilled unmetered consumption

Unbilled unmetered consumption (m3/year)			
Year (E.C)	Adama	Bishoftu	Mojo
2011	540	-	-
2012	640	-	-
2013	640	155.00	145.00
2014	640	205.00	150.00
2015	740	255.00	150.00

4.6.3. Water loss analysis

Total Water loss was analyzed by using top-down water loss assessment method. Total Water Loss is the difference between System Input Volume and Authorized Consumption, consisting of Apparent Losses and Real Losses.

4.6.3.1. Total water loss

Total water loss has been evaluated by subtracting authorized consumption in system input volume (water supplied). The value of total water loss for each study areas in different years is stated below table 4.6-4.

Table 4.6-4Total water loss for Adama, Bishoftu and Mojo towns

Total water loss for Adama, Bishoftu and Mojo towns			
Year (E.C)	Adama	Bishoftu	Mojo
2011	4,094,848.60	-	-
2012	4,622,071.00	-	-
2013	4,565,438.60	3,313,723.80	1,334,016.00
2014	4,479,910.60	3,837,888.30	869,890.00
2015	5,807,649.60	4,099,791.30	1,573,731.00

The percentage of total water loss as the system input volume for each study areas in different years is stated in table 4.6-5 below.

Table 4.6-5Average percentage of total water loss as system input volume

Average percentage total water loss as system input volume			
Year (E.C)	Adama	Bishoftu	Mojo
2011	30%	-	-
2012	33%	-	-
2013	31%	36%	48%
2014	30%	36%	37%
2015	36%	40%	50%
Average %	32.0%	37.3%	45.0%

The table (4.6-5) illustrates the average total water loss percentages for Adama, Bishoftu, and Mojo as 32.0%, 37.3%, and 45.0%, respectively. In comparison to the average in developing countries (35%) (Kingdom et al., 2006), Adama's value is lower, while Bishoftu and Mojo's values are higher. Mojo town's percentage (45%) surpasses other Ethiopian towns like Axum (39.1%) (Zewdu, 2014), Debre Birhan (21.5%) (Gebrehiyot, 2015), Mersa (20.28%) (Abebe, 2017), and Debre Markos (39.8%) (Abebaw, 2015). Adama (32%) and Bishoftu (37.3%) have lower values than Debre Markos and Axum but higher than Debre Birhan and Mersa. The main reason higher water loss in the researched areas is attributed to inadequate asset management and insufficient leakage control in the utilities.

4.6.3.2. Apparent Losses

I. Unauthorized Consumption

As stated in the methodology, the unauthorized consumption of all study areas is calculated based on data collected from the questionnaire, including illegal domestic connections, illegal connections made by organizations, meter tampering, bypasses, etc. among registered customers. In general, water utilities have reported that the most common types of water theft are meter reversal and connection before the meter. These types of theft are detected by the meter reader and reported accordingly. Meter reversal may occur by mistake, and sometimes even the water utility staff make such errors. Unauthorized consumption is discovered through anomaly checks on billing data. In some cases, water utility staff follow up on disconnected customers to see how they are getting access to water. The water utility has recorded 75-100 illegal connections in Adama town, 30-40 in Bishoftu town, and 40-55 in Mojo town. However, there may be more illegal connections that haven't been detected yet.

Find below a summary of the unauthorized consumption of Adama, Bishoftu, and Mojo for the years 2011 to 2015. Note that for Bishoftu and Mojo, only data from 2013 to 2015 is available. A detailed calculation report for each town is attached in the appendix 9.

Table 4.6-6Unauthorized consumption

Unauthorized consumption (m^3/year)			
Year (E.C)	Adama	Bishoftu	Mojo
2011	10,275	-	-
2012	12,209	-	-
2013	10,293	3,650.00	4,562.50
2014	12,739	4,179.25	5,931.25
2015	12,830	5,840.00	5,529.75

According to the data, the amount of unauthorized consumption is very low compared to the billed metered consumption. Specifically, for Adama and Bishoftu towns, the percentage of unauthorized consumption is less than 0.1% of the metered billed consumption. Similarly, for Mojo town, it is less than 0.3%. So, the unauthorized consumption contribution in the NRW of the towns is insignificant.

II. Metering Inaccuracies

Metering inaccuracies can occur due to customer meter issues, errors in meter reading, data transfer, and billing. These inaccuracies can lead to overbilling or underbilling.

- *Water meter inventory*

A water meter inventory was conducted for each town to analyze water meter inaccuracies. The inventory was done using random representative samples. As explained in section 3.8.5, the number of samples in the water meter inventory was determined by the equation provided below.

$$\boldsymbol{n = \frac{Z^2 pqN}{(N-1)e^2 + Z^2 pq}} \text{……………………………………………………Equation 20}$$

Where: -

n - customer meter sample size,

Z – standard variant at given confidence level =1.96,

p=sample proportion, if there is no previous study on the key parameters (P is taken as 50%),

N= number of the customer water meter,

q=1-p,

e=the precision (5%).

A water meter inventory was conducted in three towns. In Bishoftu, 37,818 water meters were identified and 380 representative samples were taken across the town. In Mojo, 16,264 water meters were identified and 375 representative samples were taken throughout the town. For Adama, the town's water utility office conducted the inventory and took 2,876 representative samples from a total of 83,039 customers.

As in 3.8.5 briefly discussed the inventory includes age, brand, service type (with storage tank or without storage tank), and locations of the water meters.

According to the inventory report, out of 2,876 Adama water meter samples, 8% of the total water meters are Metron and have age over 30 years. 10% of the E-Series (Badger) water meters have aged over 20 years. 32% of the water meters are Apator PoWo Gaz, PoWo Gaz and their years of service is over 10 years. All the selected water meters are ½ inch size. The remaining water meters and their years of service are listed in the table 4.6-5. Moreover, 65% of the total customers do not have a roof storage tank, while the remaining 35% customers do have a roof water tank (ATWSSE, 2019).

Table 4.6-7Adama town water meter inventory

No	Model/Brand	Years of service	% of total water meters
1	Metron	>30 years	8
2	E-Series (Badger)	>20 years	10
3	Apator PoWo Gaz, PoWo Gaz	>10 years	32
4	LXH	>10 years	8
5	ASTRAL	>10 years	5
6	SH-Meter	About 4 years	7
7	EUROPA (ASM)	About 3 years	25
8	Others (Maddalena, Sino-Italian, Lian Li, ATCO, NB…)	>15	5

Source: (ATWSSE, 2019)

According to the water meter inventory at the Mojo town, 63% of the water meters are of the smart type, 13% are Sabean brand, 6% are Apator type, and the remaining are Kiwa, H.B, B.H, and other brands. In Mojo town, 45% of the water meters are aged between 5-10 years, 33% are aged between 0-5 years, 15% are aged between 10-15 years, 5% are aged between 15-20%, and the rest are aged between 20-25 years. All sample water meter sizes are ½ inch. Furthermore, 76% of the town's customers do not have storage tanks in their houses, while 24% do have storage tanks in their houses.

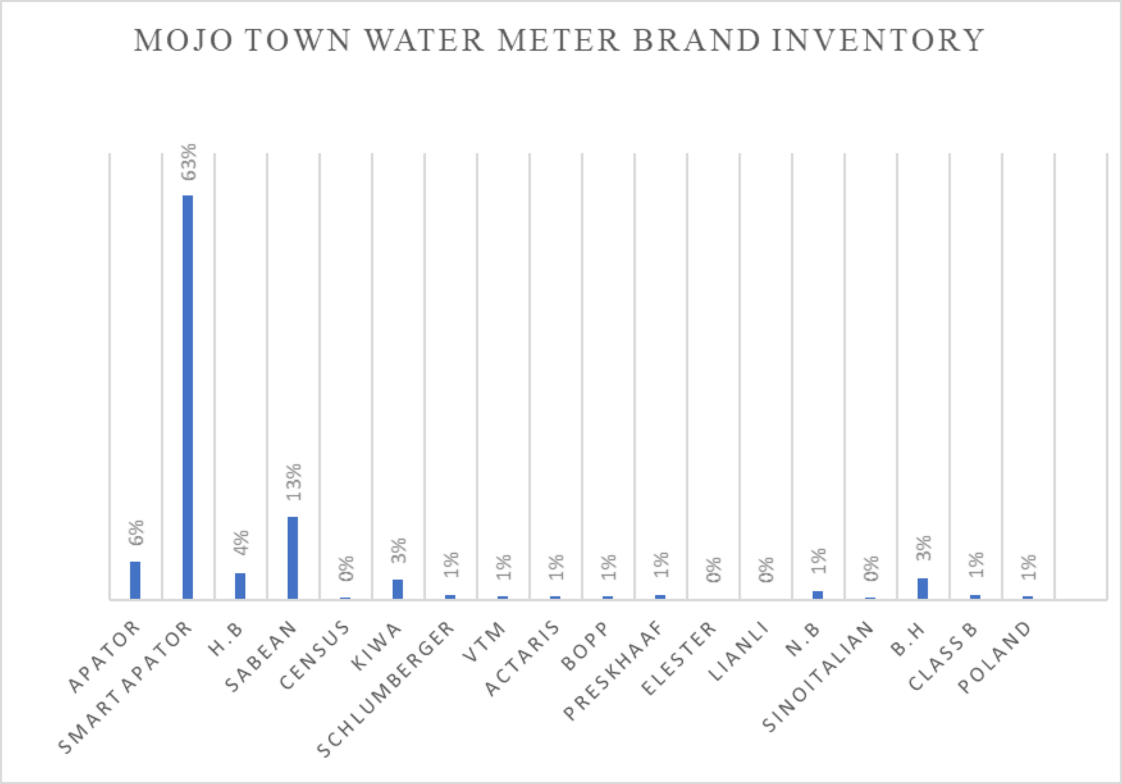


Figure 4.6-3Mojo town water meter brand inventory

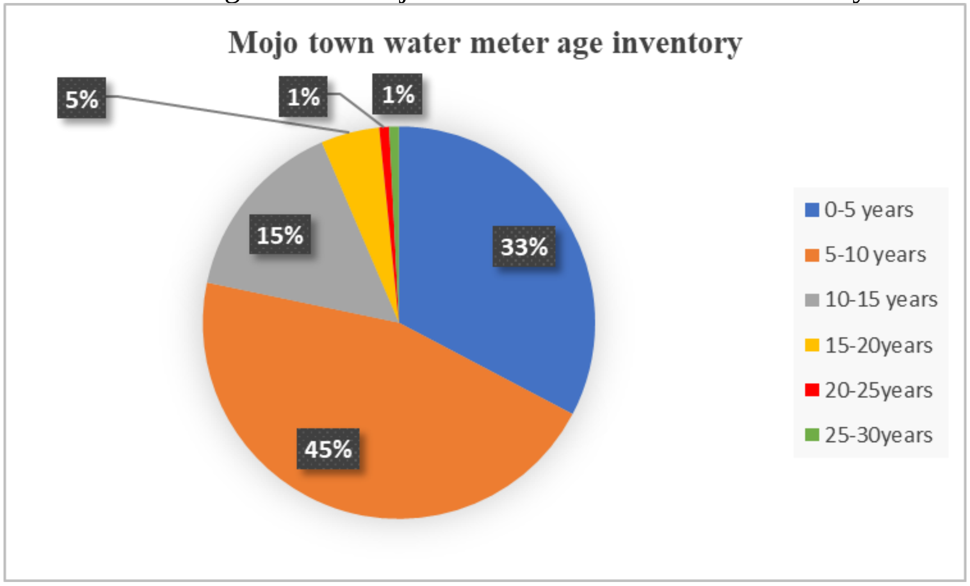


Figure 4.6-4Mojo town water meter age inventory

According to the Bishoftu town water meter inventory data, 61% of the water meters are between 15-20 years old, 30% are between 10-15 years old, and only 8% are less than 10 years old.

Additionally, 45% of the total water meters are N.B, 34% are H.B, and there are other categories as well. Out of all the customers, 73% do not have a roof water tank, while the remaining 27% use a roof water tank in their house. All sample water meters sample sizes are ½ inches. There is detail information below figures for Bishoftu water meter inventory.

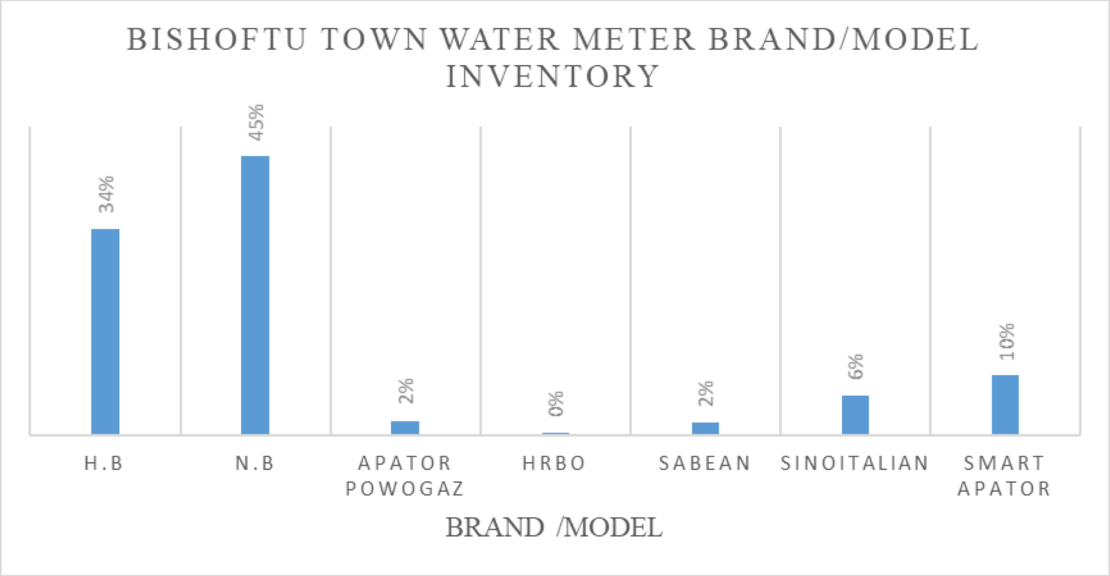


Figure 4.6-5 Bishoftu town water meter brand/model inventory

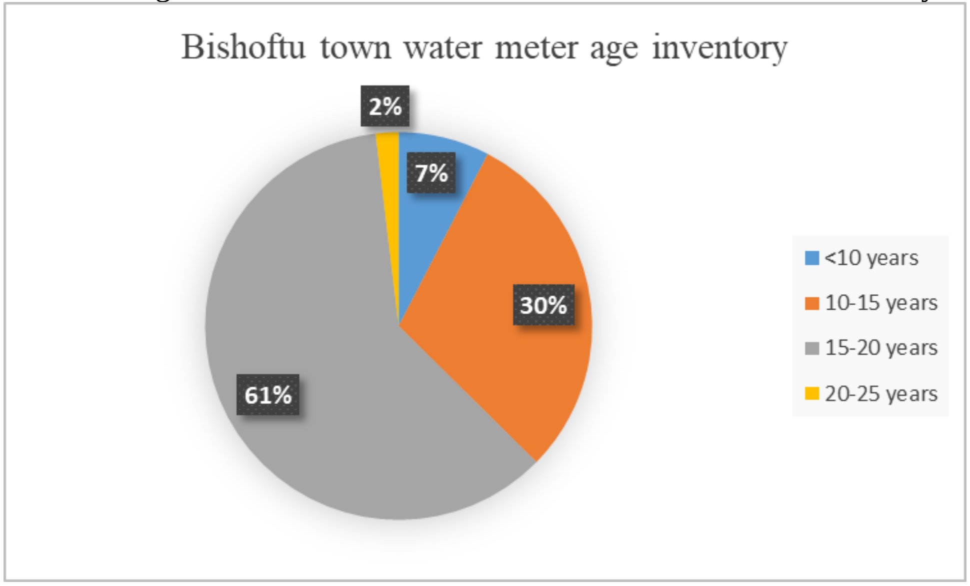


Figure 4.6-6 Bishoftu town water meter age inventory

- *Evaluation* of percentage of water meter inaccuracies errors

In section 3.8.5 discussed that water meter inaccuracies can occur due to data handling and billing errors, as well as meter under or over registration. Unfortunately, the water meter cannot test directly for this study as there is no water meter laboratory available in the study areas. Therefore, the water meter's over or under registration estimate by considering previous similar studies and literature, as well as by considering different conditions such as the town water utility's trend to test customer water meters, policies for replacing old meters, methods for identifying and resolving water meter problems, the average age of the water meter, the condition of the water supply service (interruption of supply), and the way the water utility office's data is recorded. some current conditions of the water utility offices are discussed below.

All selected study areas used a uniform method for collecting and transferring both meter reading and billing data. The water utility offices in these study areas utilize a software application known as water supply information system, designed to streamline the identification of customer water meter locations and the subsequent manual transfer of reading data to the IT and billing departments. However, a notable limitation of this software lies in its inability to automatically retrieve the metered number from the water meter. This drawback can potentially lead to the generation of inaccurate data. For instance, meter readers may input intentionally false data without physically visiting the customer's residence. In scenarios where a customer's house is inaccessible or locked, there is a risk of readers submitting false data to avoid revisiting the location. Additionally, unintentional errors by the reader during data input could also contribute to the creation of inaccurate records.

An additional crucial aspect to consider in evaluating water meter inaccuracies is the examination of customer water meter testing trends, policies governing the replacement of aging meters, and established methods for identifying and resolving water meter issues. In all the selected study areas, the absence of a dedicated water meter testing laboratory poses a significant challenge, potentially resulting in the oversight of dysfunctional water meters within the system. Moreover, these study areas lack clear policies for the proactive replacement of aging meters and systematic procedures for identifying and addressing water meter problems. The existing practice primarily involves checking and replacing customer water meters only when customers report suspected overcharging issues or when utility technicians observe no variance in the meter reading compared to the previous recorded amount, presuming the water meter is completely blocked. In contrast, the Ethiopian national guideline for technical service provision to customers by urban water supply utilities stipulates that water meter functionality should undergo testing at least once every 1-2 years by the utility (FDRE MoWE, 2013).

Another crucial factor to consider in the evaluation of water meter inaccuracies pertains to the average age of the water meters and the nature of the water supply service, specifically the interruptions in supply. According to inventory data for Adama, Bishoftu, and Mojo towns, a notable percentage of water meters have exceeded the recommended service life of 10 years, standing at 68%, 92%, and 22%, respectively. Studies by (Lambert, 2002b; Moahloli et al., 2019) emphasize that water meters with over 10 years of service should be replaced with new ones to ensure accurate measurements.

Additionally, the condition of the water supply service, particularly instances of supply interruptions, constitutes another vital consideration in evaluating water meter inaccuracies. During supply interruptions, customers often resort to installing roof water tanks for usage, a practice highlighted by (Lambert, 2002b) as a factor leading to the under-registration of meters. The inventory reveals that in Adama town, 35% of customers have roof storage tanks, while Bishoftu and Mojo have 27% and 24%, respectively.

Considering all the aforementioned factors, the estimated water meter inaccuracies for Adama town is 6% of the system input volume, while Bishoftu and Mojo towns are estimated 7% and 5% respectively. In comparison with other Ethiopian towns, Bishoftu’s result surpasses Debre Markos (6.62%) (Abebaw, 2015), Debrebirhan (3.95%) (Gebrehiyot, 2015), Axum (3.35%) (Zewdu, 2014), and Mersa (2.37%) (Abebe, 2017). However, for Adama and Mojo towns, the percentage of water meter inaccuracies concerning the system input volume is lower than Debre Markos but higher than Debrebirhan, Axum, and Mersa. This discrepancy can be attributed to the implementation of a more robust water meter testing and replacement program, particularly in response to customer reports of over and under registration of meters.

The summarized values of water meter inaccuracies for all towns in different years are shown below table 4.6-6.

Table 4.6-8Adama, Bishoftu and mojo towns amount of water loss by water meter inaccuracies

Amount of water loss by water meter inaccuracies (m^3/year)			
Year (E.C)	Adama	Bishoftu	Mojo
2011	826,939.32	-	-
2012	850,767.72	-	-
2013	886,596.12	679,000.00	138,425.65
2014	890,537.34	766,500.00	116,652.25
2015	964,300.08	725,032.35	158,866.60

The percentage of apparent loss as the total water loss in each town each year is stated in the following below table 4.6-7.

Table 4.6-9Average percentage of apparent loss as total water loss

Average percentage of apparent loss as total water loss			
Year (E.C)	Adama	Bishoftu	Mojo
2011	20%	-	-
2012	19%	-	-
2013	20%	19%	11%
2014	20%	20%	14%
2015	17%	18%	10%
Average %	19.2%	19%	11.67%

As stated in the above table 4.6-7 the Apparent loss (AL) of Adama, Bishoftu and mojo is 19.2%, 19% and 11.67% as the percentage of total water loss. This implies most of the water loss is real loss which is mainly caused due to deterioration of the existing distribution system infrastructure. When it compares with another Ethiopian towns the value of Adama, and Bishoftu is more close with Debrebirhan 20.4% (Gebrehiyot, 2015) and Debre Markos 18.36% (Abebaw, 2015), but higher than Mersa town 13.31% (Abebe, 2017) and Axum 9.5% (Zewdu, 2014). The average percentage AL of Mojo is much lower than Debrebirhan 20.4% (Gebrehiyot, 2015) and Debre Markos 18.36% (Abebaw, 2015) but nearly close to Mersa town 13.31% (Abebe, 2017), and Axum 9.5% (Zewdu, 2014). The difference in the values is comes from the towns active and proactive leakage control management, the program of water meter replacement and water meter test availability.

4.6.3.3. Real loss

The real loss was calculated by top-down water loss assessment method and IWA water balance analysis. As percentage to system input volume the real loss for Adama, Bishoftu and Mojo in 2015 E.C is 30%, 33%, and 44% respectively.

The detailed calculation top-down water loss assessment and IWA water balance analysis are stated in the following section. The real loss for all three towns in different years is stated below in the Table 4.6-8.

Table 4.6-10Average percentage of real loss as total water loss

Average percentage of real loss as total water loss			
Year (E.C)	Adama	Bishoftu	Mojo
2011	80%	-	-
2012	81%	-	-
2013	80%	81%	89%
2014	80%	80%	86%
2015	83%	82%	90%
Average %	80.8%	81%	88.33%

As indicated by the results, a significant portion of the total water loss is attributed to real losses. This outcome underscores the deterioration of the water supply system, poor asset management in utilities, highlights challenges in water supply management, and emphasizes the crucial need for the implementation of a program to control leaks.

4.6.4. Water balance and non-revenue water analysis

The assessment of the IWA water balance is based on the calculated data and the collected data mentioned above. The IWA water balance effectively illustrates the percentage of non-revenue water within the system. The average percentage of non-revenue water for each year across all study areas is provided in Table 4.6-9. Detailed water balance calculations can be found in the appendix 10 -20.

Table 4.6-11Average percentage of non-revenue water (NRW) as system input volume

Average percentage non-revenue water (NRW) as system input volume			
Year (E.C)	Adama	Bishoftu	Mojo
2011	30%	-	-
2012	33%	-	-
2013	32%	37%	50%
2014	31%	37%	41%
2015	37%	41%	51%
Average %	32.6%	38.33%	47.33%

As highlighted in Table 4.6-9, the non-revenue water (NRW) levels in the towns are notably high, with figures of 32.6% for Adama, 38.33% for Bishoftu, and 47.33% for Mojo. This signifies a substantial amount of water not generating revenue, posing a significant impact on the utility's financial health and the overall water resources of the respective towns.

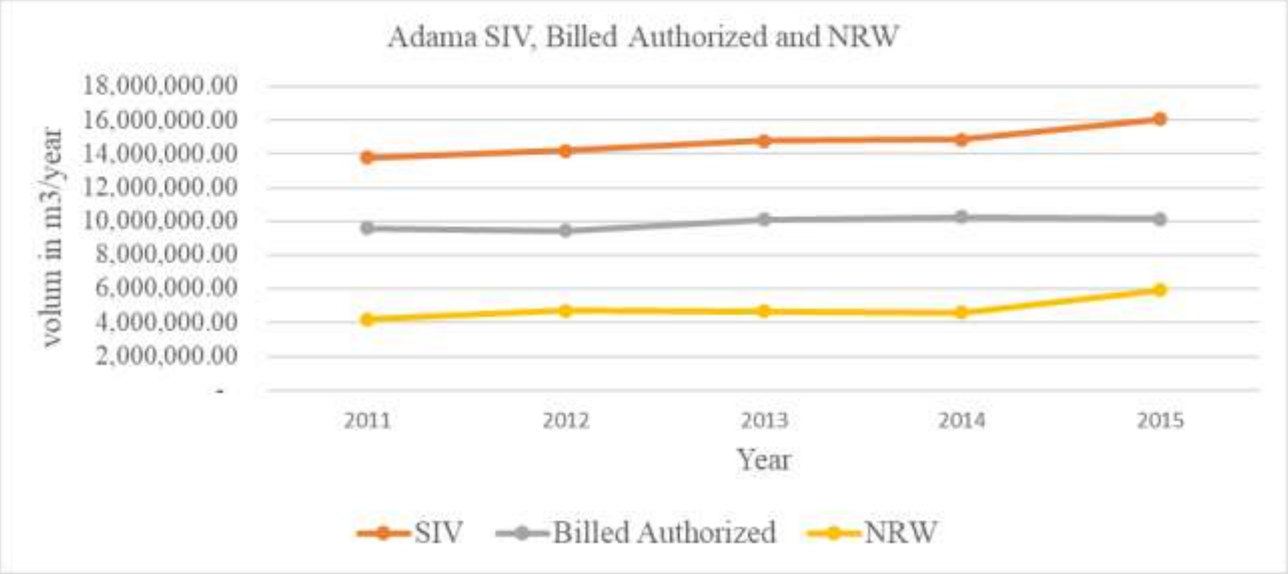


Figure 4.6-7Adama town SIV, Billed Authorized and NRW

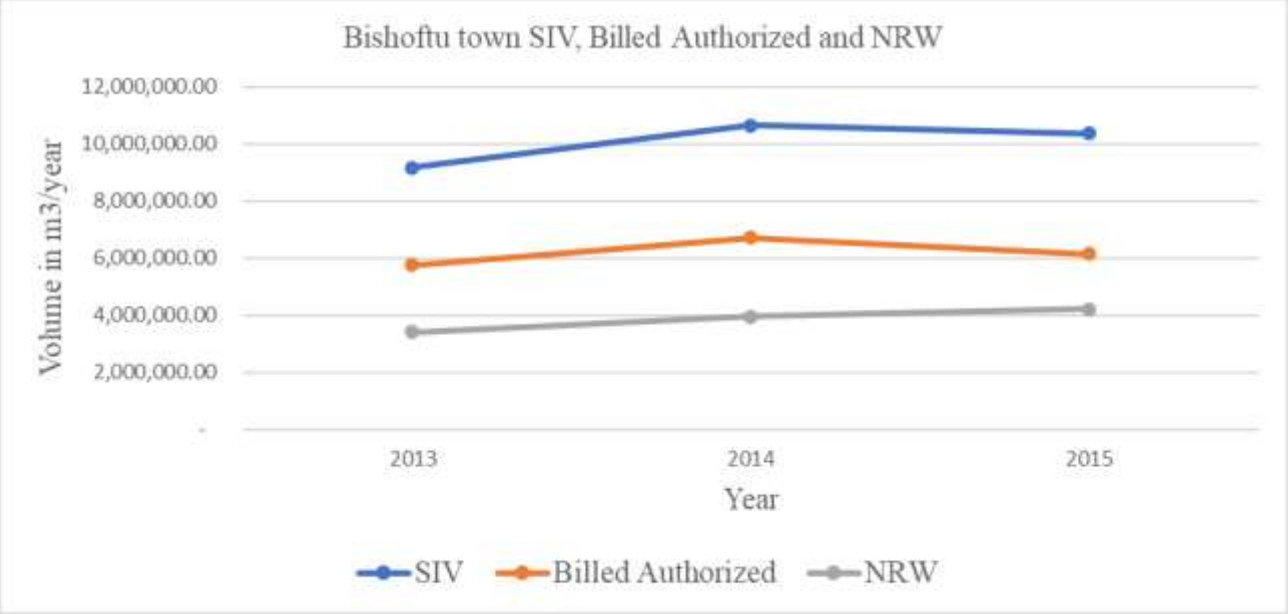


Figure 4.6-8Bishoftu town SIV, Billed Authorized and NRW

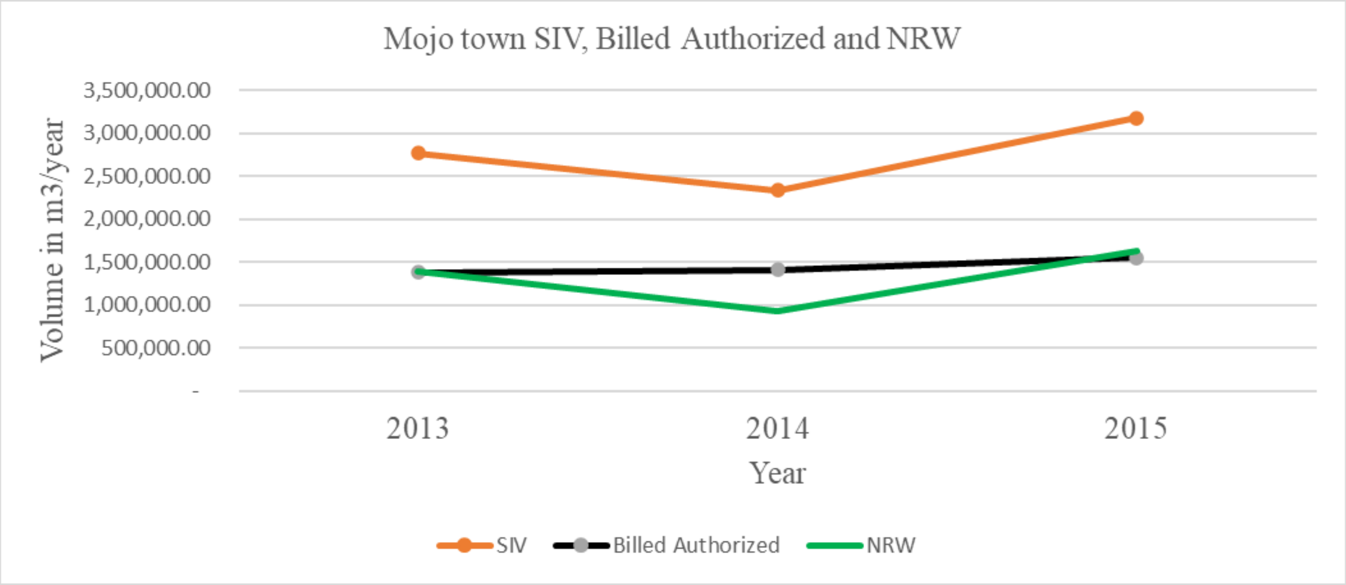


Figure 4.6-9Mojo town SIV, Billed authorized and NRW

4.7. Assessment of Infrastructure Leakage Index (ILI)

4.7.1. Current annual real loss (CARL)

CARL is the ratio of real losses to the total number of days that the WDN is under pressure during the water balance calculation period. Which can be calculated as equation below.

$$\boldsymbol{CARL}\left(\frac{\boldsymbol{L}}{\boldsymbol{day}}\right) = \frac{\boldsymbol{Real\ losses * 1000}}{\boldsymbol{Tp}}$$

Where:

CARL= Current annual real loss (l/day)

Tp= the number of days in which the WDN is pressurized throughout the water balance calculation.

Real losses in m^3/year

For all selected study areas CARL value is stated in the table 4.7-1 below.

Table 4.7-1Adama, Bishoftu and Mojo CARL (current annual real loss)

Current annual real loss (CARL) (l/day)			
Year (E.C)	Adama	Bishoftu	Mojo
2011	13,387,539.16	-	-
2012	15,448,331.63	-	-
2013	15,076,230.74	9,882,125.19	4,633,988.99
2014	14,698,499.01	11,437,811.30	2,907,581.12
2015	19,851,451.11	12,477,477.59	5,483,365.69

4.7.2. Unavoidable Annual Real Losses (UARL)

UARL is the "best estimate" of the technically attainable low-level real losses. This can be calculated as shown below.

$$\boldsymbol{UARL\left\{\frac{L}{day}\right\} = (18 * Lm + 0.8 * Nc + 25 * Lp) * p}$$

UARL- unavoidable annual real loss

Lm(Km)- is the length of the mains pipes (without service pipes).

Lp (Km) -is the total length of service connections (distance between property line and customer water meter)

Nc -is the number of service connections.

P (mH_2O) -is the average operating pressure (AOP).

For all selected study areas UARL value is stated in the table 4.7-2 below.

Table 4.7-2 Adama, Bishoftu and Mojo town Unavoidable annual real losses (UARL)

Unavoidable annual real loss (UARL) (l/day)			
Year (E.C)	Adama	Bishoftu	Mojo
2011	3,940,538.24	-	-
2012	4,096,231.00	-	-
2013	4,179,286.70	2,241,873.21	1,230,689.76
2014	4,352,686.27	2,468,644.08	1,328,112.99
2015	4,531,564.19	2,336,548.92	1,381,309.83

4.7.3. Infrastructure leakage index (ILI)

The infrastructure leakage index (ILI) indicators are defined as a ratio of current annual real losses (CARL) and unavoidable annual real losses (URAL).

$$\boldsymbol{ILI = \frac{CARL}{UARL}}$$

Where:

ILI= Infrastructure leakage index

CARL= Current annual real loss

UARL= Unavoidable annual real loss

The value of ILI for all selected study areas in different years is stated below table 4.7-3.

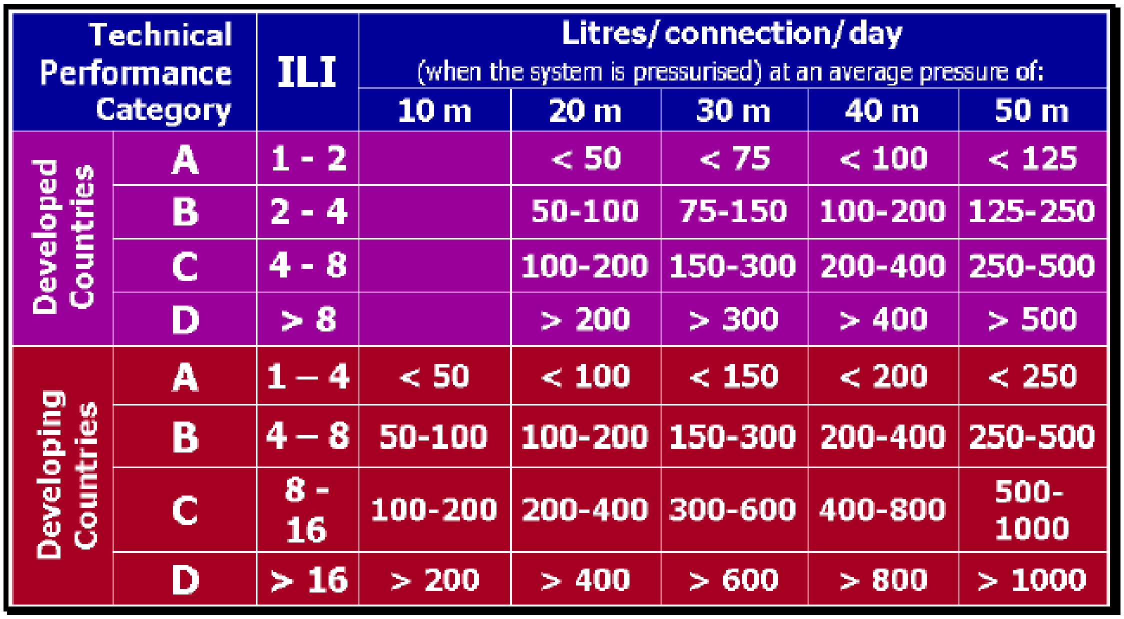
Table 4.7-3Adama, Bishoftu and Mojo towns infrastructure leakage index (ILI)

	Infrastructure leakage index (ILI)		
Year (E.C)	Adama	Bishoftu	Mojo
2011	3.39	-	-
2012	3.77	-	-
2013	3.60	4.22	3.77
2014	3.37	4.63	2.19
2015	4.38	4.40	3.97
Average	3.7	4.41	3.31

The table (4.7-3) indicates that the average Infrastructure Leakage Index (ILI) for Adama, Bishoftu, and Mojo towns is 3.70, 4.41, and 3.31, respectively. Comparatively, other Ethiopian towns like Debre Markos (Abebaw, 2015), Mersa (Abebe, 2017), Debre Birhan (Gebrehiyot, 2015), and Axum (Zewdu, 2014) have ILI values of 3.59, 1.9, 1.37, and 1.47, respectively, which are lower than the selected study areas. These towns fall within the range considered as "Excellent – no specific intervention required" where further loss reduction may be uneconomic unless there are shortages (ILI 1-4) based on studies by (Liemberger, 2010; Liemberger et al., 2007; Liemberger & McKenzie, 2005; Seago et al., 2005).

However, contrasting views from other sources, such as (Schrenk & Verein CORP - Competence Center of Urban and Regional Planning, 2011; Zewdu, 2014), emphasize the challenges faced by Ethiopian towns, including aging water distribution systems, poor infrastructure asset management and a lack of leakage management. The broader issues in Ethiopia, like water pipe breaks, non-functional water supply systems, technical limitations, and weak governance, are noted. Also as (H. Mutikanga et al., 2010) stated that in developing countries due to intermittent supply and fluctuation of pressure systems the applicability of ILI lead to inappropriate result.

In light of these challenges, achieving a lower ILI value in the mentioned towns emphasizes the inapplicability of the Performance Indicator (PI) for the town water utility.



Technical Performance Category		ILI	Litres/connection/day (when the system is pressurised) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Countries	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50-100	75-150	100-200	125-250
	C	4 - 8		100-200	150-300	200-400	250-500
	D	> 8		> 200	> 300	> 400	> 500
Developing Countries	A	1 – 4	< 50	< 100	< 150	< 200	< 250
	B	4 – 8	50-100	100-200	150-300	200-400	250-500
	C	8 - 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

Figure 4.7-1ILI and its indications for developed and developing countries

Source (Seago et al., 2005)

A = Excellent – no specific intervention required.

B = Good – no urgent action required although should be monitored carefully.

C = Poor – requires attention.

D = Very Bad – requires immediate water loss reduction interventions.

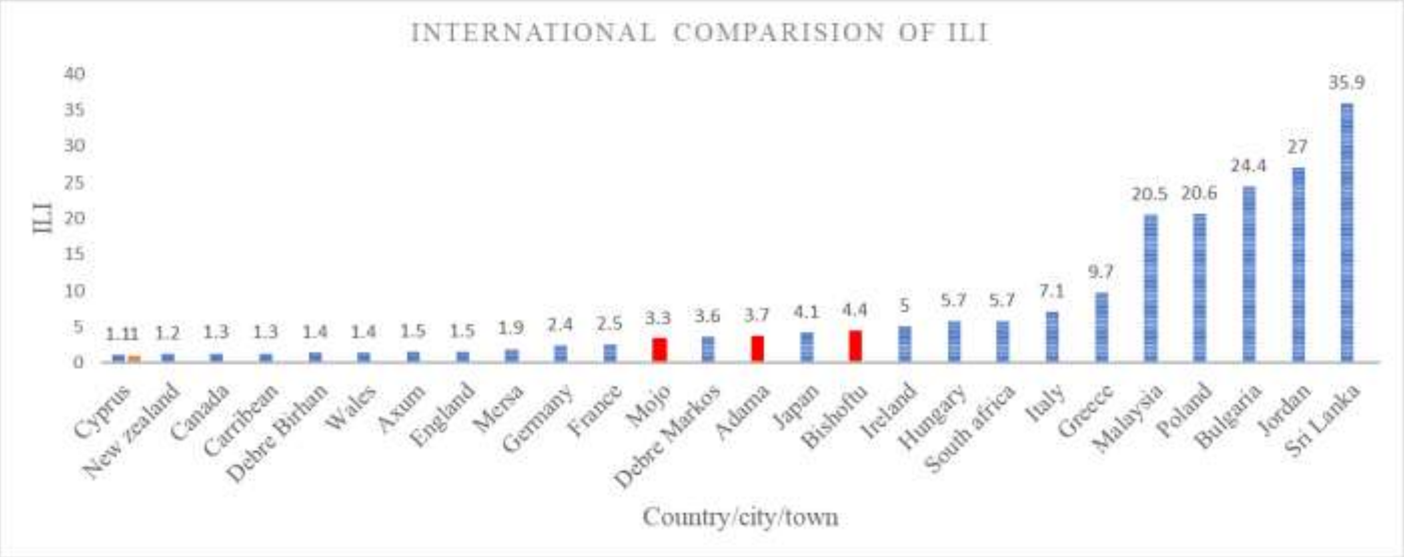


Figure 4.7-2International and local comparison of ILI values

Source: (Abebaw, 2015; Abebe, 2017; Gebrehiyot, 2015; Zewdu, 2014)

4.8. Analysis of infrastructure asset management (IAM)

4.8.1. Product quality

4.8.1.1. Service delivery

I. Drinking water flow and pressure: Based on the data collected, it has been observed that there are fluctuations in water pressure at certain points within the Adama system. Additionally, the hydraulic model indicates that there are 8 junctions with pressure below the recommended 10 mH2O during average day demand scenarios. In the case of Bishoftu and Mojo town, customers have reported experiencing low water pressure, sometimes having to wait until midnight to get enough pressure.

II. Service interruptions: Service interruptions were assessed through community interviews in the selected study areas. In Bishoftu town, certain kebeles experience water interruptions with a three-day on, three-day off schedule. Mojo encounters interruptions in some kebeles, with water delivered only for three days in a week. Adama has no fixed delivery schedule but faces sudden interruptions lasting half a day or a full day. Overall, service interruptions are prevalent in all study areas, often attributed to low pressure, maintenance and repair activities, and water shortages in the system.

4.8.1.2. Customer Satisfaction

I. Customer service delivery: This measure requires the utility, based on internal objectives and customer input, to set desirable customer service levels, then determine an appropriate (target) percentage of time to meet the performance levels. Once established, the utility can track how often it meets the service levels, helping the utility to determine how well customer needs are being satisfied. There are no data base found from all three water utilities regarding Call responsiveness (percent), Error-driven billing adjustment rate and Service start/stop responsiveness (percent).

II. Customer satisfaction: No record data is found from all three water utilities to examine this criteria but from survey data collected from the community it is shown a low overall satisfaction level.

4.8.2. Infrastructure Strategy and Performance

4.8.2.1. Asset (system) renewal/replacement

This measure evaluates the rates of asset renewal and replacement over a period of time. The measure should reflect the utility's targets, which will differ depending on the acceptable risks for various asset classes. Unfortunately, there are no active databases that provide information on the total number of assets replaced per year for each asset class. However, as discussed in section 4.6.3, the water meter asset inventory indicates that 68%, 92%, and 22% of water meters in Adama, Bishoftu, and Mojo respectively have been in service for over 10 years and need to be replaced with new ones. But they have not been replaced yet, indicating that there is no effective renewal and replacement program in all utilities.

4.8.2.2. Water distribution/collection system integrity

Non-revenue water (NRW): Water supplied to the network that does not return revenue to the utility, including unbilled authorized consumption, apparent losses (theft, customer metering inaccuracies, systematic data handling errors), and real losses (leakage from the pipe network and distribution storage). As stated in this research the NRW is high which is 32.6%, 38.33% and 47.33% for Adama, Bishoftu and Mojo respectively.

4.8.2.3. Infrastructure planning and maintenance

this measure addresses planning for future infrastructure needs and ongoing maintenance for existing infrastructure, which is critical to overall infrastructure strategy and performance. and since the SCADA System is malfunctioning there is no active plan on maintaining the asset even ongoing maintenance is takes place whenever they receive notification from the society.

Overall, there is a lack of proper management for assets concerning allocation, life expectancy, age, and location. This deficiency results in unnecessary maintenance and operational costs. The status of certain assets is unknown, and maintenance relies on information gathered from the community. Additionally, the status of asset renewal or replacement remains unknown due to the absence of a proper asset management control technique. Furthermore, the Non-Revenue Water (NRW) analysis indicates a significant portion of water does not generate revenue, resulting in financial losses for the water utilities.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study aimed to assess the applicability of the Infrastructure Leakage Index (ILI) in Ethiopian towns, specifically Adama, Bishoftu, and Mojo. Water losses and Non-Revenue Water (NRW) were estimated for these areas, revealing total water losses of 32%, 37.3%, and 45%, respectively, as a percentage of system input volume. Apparent losses (AL) accounted for 19.2%, 19%, and 11.67% of total water loss, with the remainder being Real losses (RL). Non-revenue water was identified as a significant challenge, constituting 32.6%, 38.33%, and 47.33% of total water production, respectively. The primary contributors to high water losses and NRW were identified as poor asset management, inadequate leakage control, and insufficient operation and maintenance of water assets in the supply systems.

Therefore, while the ILI values suggest that the water supply systems in Adama, Bishoftu, and Mojo are performing well, the high levels of water losses and NRW indicate that achieving lower ILI values is challenging under the current conditions. This suggests that the ILI, as currently applied, does not fully capture the complexities and specific challenges faced by the water utilities in these towns. Further studies and tailored approaches are necessary to adapt the ILI to better suit the local context and improve its effectiveness as a performance indicator for the water utilities in Adama, Bishoftu, and Mojo.

5.2. Recommendations

The research suggests that the Infrastructure Leakage Index (ILI) does not fully capture the specific conditions of the selected study areas of Adama, Bishoftu, and Mojo. Additional factors such as water usage patterns (including intermittency of supply) and the condition of infrastructure asset management should be considered when applying the ILI performance indicator. Water utilities in these towns are encouraged to ensure that the ILI takes these conditions into account before using it as a performance indicator.

Given the significant real losses identified in the study, it is recommended that water utilities enhance their active leakage control management to reduce these losses. Additionally, prompt action should be taken in response to any pipe bursts or system damages. Overall, improving water infrastructure asset management in these towns is essential.

Water utilities should consider establishing a water meter test laboratory to periodically test customer water meters, which will aid in accurately analyzing and reducing apparent loss (AL). Water meters older than 10 years should be replaced with new ones to ensure accuracy.

To improve the efficiency of data collection from customers, water utilities could benefit from adopting an Automated Water Meter Reading (AMR) system. This technology allows for automatic recording and transfer of consumption data, facilitating better data collection and management.

Some data used for analyzing AL in this study were estimated and assumed. Therefore, future efforts should focus on collecting real primary data to achieve more accurate results.

The study indicates that the ILI, as currently applied, does not fully reflect the performance of water utilities in Adama, Bishoftu, and Mojo. To better evaluate the performance of water utilities in these towns, it would be beneficial to enhance the ILI by incorporating other critical parameters such as asset management and water supply service. Additionally, expanding the scope to include more towns and cities within the region could provide a more comprehensive assessment.

Furthermore, the research analyzed water meter inaccuracies under various conditions in the system. For more precise results regarding water meter inaccuracies and apparent loss, it is recommended to analyze water meters in a laboratory setting. These recommendations aim to provide valuable insights and information for future studies, enhancing the understanding and management of water utilities in Adama, Bishoftu, and Mojo.

REFERENCES

Abebaw, M. (2015). *Assessment of Water Loss in Water Supply Networks (A Case of Debre Markos Town)*. Addis Ababa University.

Abebe, S. Y. (2017). *ASSESSMENT OF WATER LOSSES FROM INTERMITTENT WATER SUPPLY SYSTEM: CASE STUDY OF MERSA TOWN, EASTERN AMHARA REGIONAL STATE*. Arba Minch University.

Alegre, H., Baptista, J. M., Cabrera, E., Cubillo, F., Duarte, P., Hirner, W., Merkel, W., & Parena, R. (2016). Performance Indicators for Water Supply Services: Third Edition. *Water Intelligence Online*, *15*(0), 9781780406336–9781780406336. https://doi.org/10.2166/9781780406336

Alegre, H., & T., S. (2012). Infrastructure Asset Management of Urban Water Systems. In A. Ostfeld (Ed.), *Water Supply System Analysis—Selected Topics*. InTech. https://doi.org/10.5772/52377

AL-Washali, T. M., Sharma, S. K., & Kennedy, M. D. (2018). Alternative Method for Nonrevenue Water Component Assessment. *Journal of Water Resources Planning and Management*, *144*(5), 04018017. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000925

AL-Washali, T., Sharma, S., & Kennedy, M. (2016). Methods of Assessment of Water Losses in Water Supply Systems: A Review. *Water Resources Management*, *30*(14), 4985–5001. https://doi.org/10.1007/s11269-016-1503-7

AL-Washali, T., Sharma, S., Lupoja, R., AL-Nozaily, F., Haidera, M., & Kennedy, M. (2020). Assessment of water losses in distribution networks: Methods, applications, uncertainties, and implications in intermittent supply. *Resources, Conservation and Recycling*, *152*, 104515. https://doi.org/10.1016/j.resconrec.2019.104515

ATWSSE. (2019). *Detail investigation of NRW and pressure zone problems of adama town water supply distribution systems*.

Awe, O. M., Okolie, S. T. A., & Fayomi, O. S. I. (2019). Review of Water Distribution Systems Modelling and Performance Analysis Softwares. *Journal of Physics: Conference Series*, *1378*(2), 022067. https://doi.org/10.1088/1742-6596/1378/2/022067

Ayala, R. F. (2018). *URBAN WATER SUPPLY SYSTEM PERFORMANCE ASSESSMENT (THE CASE OF HOLETA TOWN, ETHIOPIA)*.

Bhagat, Tiyasha, Welde, Tesfaye, Tung, Al-Ansari, Salih, & Yaseen. (2019). Evaluating Physical and Fiscal Water Leakage in Water Distribution System. *Water*, *11*(10), 2091. https://doi.org/10.3390/w11102091

BTWSSE. (2017). *Bishoftu Town Water supply Improvement Project Source Development.pdf*.

Criminisi, A., Fontanazza, C. M., Freni, G., & Loggia, G. L. (2009). Evaluation of the apparent losses caused by water meter under-registration in intermittent water supply. *Water Science and Technology*, *60*(9), 2373–2382. https://doi.org/10.2166/wst.2009.423

C.R.Kothari. (2004). *Research-Methodology* (second). New Age International (P) Ltd.

Desalegn, W. (2005). *Water Supply Coverage and Water Loss in Distribution Systems The case of Addis Ababa*. INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION.

Farouk, A. M., Rahman, R. A., & Romali, N. S. (2023). Non-revenue water reduction strategies: A systematic review. *Smart and Sustainable Built Environment*, *12*(1), 181–199. https://doi.org/10.1108/SASBE-04-2021-0071

FDRE MoWE. (2013). *National guideline for technical service provision to customers by urban water supply utilities*. MoWE.

Gebrehiyot, T. (2015). *Assessing Water Supply Coverage and Water Losses in Distribution System: A Case Study of Debre Birhan Town, Ethiopia*. Arba Minch University.

Gupta, R., & Bhave, P. (n.d.). *Reliability Analysis of Water-Distribution Systems*.

Halkijević, I., Vouk, D., & Posavčić, H. (2017). *AVERAGE PRESSURE IN A WATER SUPPLY SYSTEM*.

Hussein, M., Yoneda, K., Othman, N., Mohd Zaki, Z., & Mohd Yusof, M. H. (2017). EFFECTS OF NUMBER OF CONNECTIONS AND PIPE LENGTH TO THE WATER LOSSES IN MELAKA. *Jurnal Teknologi*, *79*(3). https://doi.org/10.11113/jt.v79.9874

Kara, S., Karadirek, I. E., Muhammetoglu, A., & Muhammetoglu, H. (2016). Hydraulic Modeling of a Water Distribution Network in a Tourism Area with Highly Varying Characteristics. *Procedia Engineering*, *162*, 521–529. https://doi.org/10.1016/j.proeng.2016.11.096

Kingdom, B., Liemberger, R., & Marin, P. (2006). *The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries How the Private Sector Can Help: A Look at Performance-Based Service Contracting*.

Kleiner, Y., & Rajani, B. (2002). Forecasting Variations and Trends in Water-Main Breaks. *Journal of Infrastructure Systems*, *8*(4), 122–131. https://doi.org/10.1061/(ASCE)1076-0342(2002)8:4(122)

Lambert, A. O. (2002a). International Report: Water losses management and techniques. *Water Supply*, *2*(4), 1–20. https://doi.org/10.2166/ws.2002.0115

Lambert, A. O. (2002b). International Report: Water losses management and techniques. *Water Supply*, *2*(4), 1–20. https://doi.org/10.2166/ws.2002.0115

Lambert, A. O., Brown, T. G., Takizawa, M., & Weimer, D. (1999). A review of performance indicators for real losses from water supply systems. *Journal of Water Supply: Research and Technology—AQUA*, *48*(6), 227–237. https://doi.org/10.2166/aqua.1999.0025

Liemberger, R. (2010). *Recommendations for Initial Non-Revenue Water Assessment*.

Liemberger, R., Brothers, K., Lambert, A., McKenzie, R., Rizzo, A., & Waldron, T. (2007). *Water Loss Performance Indicators*.

Liemberger, R., & McKenzie, R. (2005). Accuracy Limitations of the ILI - Is it an Appropriate Indicator for Developing Countries? *Conference Proceedings*.

Liemberger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. *Water Supply*, *19*(3), 831–837. https://doi.org/10.2166/ws.2018.129

Liu, Z., & Kleiner, Y. (2013). State of the art review of inspection technologies for condition assessment of water pipes. *Measurement*, *46*(1), 1–15. https://doi.org/10.1016/j.measurement.2012.05.032

Macharia, P., Kreuzinger, N., & Kitaka, N. (2020). Applying the Water-Energy Nexus for Water Supply—A Diagnostic Review on Energy Use for Water Provision in Africa. *Water, 12*(9), 2560. https://doi.org/10.3390/w12092560

Marlow, D., Gould, S., Beale, D., & Lane, B. (2015). Rehabilitation of Small-Diameter Cast-Iron Pipe: US, UK, and Australian Perspectives. *Journal AWWA*, *107*(1). https://doi.org/10.5942/jawwa.2015.107.0003

Mazumder, R. K., Salman, A. M., Li, Y., & Yu, X. (2018). Performance Evaluation of Water Distribution Systems and Asset Management. *Journal of Infrastructure Systems*, *24*(3), 03118001. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000426

Moahloli, A., Marnewick, A., & Pretorius, J. (2019). Domestic water meter optimal replacement period to minimize water revenue loss. *Water SA*, *45*(2 April). https://doi.org/10.4314/wsa.v45i2.02

Mutikanga, H. E., Sharma, S. K., & Vairavamoorthy, K. (2011). Assessment of apparent losses in urban water systems. *Water and Environment Journal*, *25*(3), 327–335. https://doi.org/10.1111/j.1747-6593.2010.00225.x

Mutikanga, H., Sharma, S., Vairavamoorthy, K., & Jr, E. C. (2010). *Using performance indicators as a water ioss management tooi in developing countries*.

Ormsbee, L. E. (1989). Implicit Network Calibration. *Journal of Water Resources Planning and Management*, *115*(2), 243–257. https://doi.org/10.1061/(ASCE)0733-9496(1989)115:2(243)

OWWDSE. (2008). *Design guideline for water supply projects*.

Rizzo, A., & Cilia, J. (2005). Quantifying Meter Under-Registration Caused by the Ball Valves of Roof Tanks (for Indirect Plumbing Systems). *Conference Proceedings*.

Sánchez-Silva, M., Frangopol, D. M., Padgett, J., & Soliman, M. (2016). Maintenance and Operation of Infrastructure Systems: Review. *Journal of Structural Engineering*, *142*(9), F4016004. https://doi.org/10.1061/(ASCE)ST.1943-541X.0001543

Savic, D. A., Kapelan, Z. S., & Jonkergouw, P. M. R. (2009). Quo vadis water distribution model calibration? *Urban Water Journal*, *6*(1), 3–22. https://doi.org/10.1080/15730620802613380

Schrenk, M., & Verein CORP - Competence Center of Urban and Regional Planning (Eds.). (2011). *A ‘CUT’ Perspective on ‘New’ Technologies for Improved Municipal Asset Management in Urban Ethiopia*.

Seago, C., Mckenzie, R., & Liemberger, R. (2005). *International Benchmarking of Leakage from Water Reticulation Systems*.

Selvakumar, A., & Tafuri, A. N. (2012). Rehabilitation of Aging Water Infrastructure Systems: Key Challenges and Issues. *Journal of Infrastructure Systems*, *18*(3), 202–209. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000091

Strafaci, A., Walski, T. M., & Haestad Methods, Inc (Eds.). (2004). *Advanced water distribution modeling and management* (1. ed., 2. print). Haestad Press.

Taylor, R. (n.d.). *WHAT IS THE INFRASTRUCTURE LEAKAGE INDEX (ILI) AND HOW DID WAITAKERE CITY COUNCIL MANAGE TO ACHIEVE AN ILI OF 1.0?*

USEPA, U. S. E. P. A. (2002). *Fact Sheet: Asset Management for Sewer Collection Systems*.

Winarni W. (2009). *Infrastructure Leakage Index (ILI) as Water Losses Indicator*. Civil Engineering Dimension.

Zewdu, A. (2014). Assessing Water Supply Coverage and Water Losses from Distribution System for Planning Water Loss Reduction Strategies (Case Study on Axum town, North Ethiopia). *Civil and Environmental Research*.

APPENDIX

Appendix 1 questionary for all water utility offices and water meter inventory questionary

Request for information from the ------- water utility branch office

Dear Sir/ Madam

As part of the Master's research being conducted by Zelalem Tamyalew at the Addis Ababa Institute of Technology's School of Civil and Environmental Engineering under the title "Applicability of Infrastructure Leakage Index (ILI) in Ethiopia in case of Adama, Bishoftu, and Mojo Towns." This study aims to determine whether the ILI (Infrastructure Leakage Index) is applicable in Ethiopia and to make some recommendations on the performance indicators in the chosen study areas. The data collected is kept anonymous and will be treated with utmost confidentiality. It will only be utilized to carry out the research. The data gathered will only be accessible to the researcher.

I would be happy to talk with your good office about the prepared questions below.

Thank you in advance for your time!

1. What is the total main length of the town water supply network distribution? Which means the pipe length without a service connection?

2. How many service connections are available in the town? Which means the total number of service connections (total number of customer water meters)?

3. What is the amount of water **billed but unmetered consumption**? Which means the volume of ***authorized consumption that is billed but not metered***.

Example

A. Water used for firefighting
B. Flushing and street cleaning
C. Other

4. What is the amount of **water unbilled but metered**? It means that the amount of ***water used is metered but not billed.***

For example

A. The amount of water used at the water utility office.
B. Organizations that are using water meters but are not billed
C. Others if any?

5. Amount of water ***unmetered and unbilled*** **but they are authorized**.

Example

A. Water used for firefighting
B. Water used for flushing and firefighting
C. Water used at different organizations like water utility offices etc.
D. Water used for flushing town sewer lines
E. Amount of water used for washing reservoirs
F. Others if any?

6. **Unauthorized consumption**

A. Amount of water that is considered illegal connection (average amount of illegal connections in m^3)
B. Water Theft

7. How much water is lost by water meter inaccuracies?

Customer water meter inventory based on Type, age, and model.

TOWN------------------------------KEBELE----------------------

no	location			Brand/manufacturer	size	age	With storage tank	Without storage tank
	X-coordinate	Y-coordinate	Z-coordinate					
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								

Appendix 2 Adama town Domestic water demand

No	Town: Adama Description	Unit	2010	2015	2020	2023
1	Total population	No	253,033.89	315,779.14	390,140.77	439,868.83
	Coverage by Service Level					
	HC (house connection)		5.1%	5.1%	10.1%	15.1%
	YC (yard connection)		71.1%	71.1%	65.8%	60.6%
	PF (public fountain)		10.5%	10.5%	24.1%	24.4%
	Population served by					
	HC	No	12,904.73	16,104.74	39,326.19	66,200.26
	YC	No	179,907.09	224,518.97	256,829.67	266,340.57
	PF	No	26,568.56	33,156.81	94,023.92	107,327.99
2	Demand					
2.1	Domestic					
	Per capita demand					
	HC	l/c/d	60.00	60.00	68.00	75.00
	YC	l/c/d	40.00	40.00	45.00	50.00
	PF	l/c/d	20.00	20.00	23.00	25.00
	Consumption (daily)					
	HC	m^3/d	774.28	966.28	2,674.18	4,965.02
	YC	m^3/d	7,196.28	8,980.76	11,557.34	13,317.03
	PF	m^3/d	531.37	663.14	2,162.55	2,683.20
	Sub Total		8,501.94	10,610.18	16,394.07	20,965.25
	Climatic and Socio-Economic factors	combined	1.37	1.37	1.37	1.37

	Total Domestic Demand	m^3/d	11,605.15	14,482.89	22,377.90	28,617.56

Appendix 3 Bishoftu town Domestic water demand

No	Town: Bishoftu Description	Unit	2010	2015	2020	2023
1	Total population	No	114,821.95	143,294.54	177,038.43	199,604.07
	Coverage by Service Level					
	HC (house connection)		5.1%	5.1%	10.1%	15.1%
	YC (yard connection)		71.1%	71.1%	65.8%	60.6%
	PF (public fountain)		10.5%	10.5%	24.1%	24.4%
	Population served by					
	HC	No	5,855.92	7,308.02	17,845.47	30,040.41
	YC	No	81,638.40	101,882.42	116,544.40	120,860.27
	PF	No	12,056.30	15,045.93	42,666.26	48,703.39
2	Demand					
2.1	Domestic					
	Per capita demand					
	HC	l/c/d	60.00	60.00	68.00	75.00
	YC	l/c/d	40.00	40.00	45.00	50.00
	PF	l/c/d	20.00	20.00	23.00	25.00
	Consumption (daily)					
	HC	m^3/d	351.36	438.48	1,213.49	2,253.03
	YC	m^3/d	3,265.54	4,075.30	5,244.50	6,043.01
	PF	m^3/d	241.13	300.92	981.32	1,217.58

	Sub Total		3,858.02	4,814.70	7,439.31	9,513.63
	Climatic and Socio-Economic factors	combined	1.58	1.58	1.58	1.58
	Total Domestic Demand	m^3/d	6,076.38	7,583.15	11,716.92	14,983.97

Appendix 4 Mojo town Domestic water demand

No	Town: Mojo	Unit	2010	2015	2020	2023
	Description					
1	Total population	No	33,950.89	42,369.75	52,347.23	59,019.51
	Coverage by Service Level					
	HC (house connection)		5.1%	5.1%	10.1%	15.1%
	YC (yard connection)		71.1%	71.1%	65.8%	60.6%
	PF (public fountain)		10.5%	10.5%	24.1%	24.4%
	Population served by					
	HC	No	1,731.50	2,160.86	5,276.60	8,882.44
	YC	No	24,139.08	30,124.89	34,460.18	35,736.31
	PF	No	3,564.84	4,448.82	12,615.68	14,400.76
2	Demand					
2.1	Domestic					
	Per capita demand					
	HC	l/c/d	60.00	60.00	68.00	75.00
	YC	l/c/d	40.00	40.00	45.00	50.00
	PF	l/c/d	20.00	20.00	23.00	25.00
	Consumption (daily)					
	HC	m^3/d	103.89	129.65	358.81	666.18

	YC	m^3/d	965.56	1,205.00	1,550.71	1,786.82
	PF	m^3/d	71.30	88.98	290.16	360.02
	Sub Total		1,140.75	1,423.62	2,199.68	2,813.02
	Climatic and Socio-Economic factors	combined	1.05	1.05	1.05	1.05
	Total Domestic Demand	m^3/d	1,197.79	1,494.80	2,309.66	2,953.67

Appendix 5 Total water demand analysis for Adama town

No	Town: Adama Description	Unit	2010	2015	2020	2023
1	Total population	No	253,033.89	315,779.14	390,140.77	439,868.83
	Coverage by Service Level					
	HC (house connection)		5.1%	5.1%	10.1%	15.1%
	YC (yard connection)		71.1%	71.1%	65.8%	60.6%
	PF (public fountain)		10.5%	10.5%	24.1%	24.4%
	Population served by					
	HC	No	12,904.73	16,104.74	39,326.19	66,200.26
	YC	No	179,907.09	224,518.97	256,829.67	266,340.57
	PF	No	26,568.56	33,156.81	94,023.92	107,327.99
2	Demand					
2.1	Domestic					
	Per capita demand					
	HC	l/c/d	60.00	60.00	68.00	75.00
	YC	l/c/d	40.00	40.00	45.00	50.00
	PF	l/c/d	20.00	20.00	23.00	25.00

Consumption (daily)					
HC	m^3/d	774.28	966.28	2,674.18	4,965.02
YC	m^3/d	7,196.28	8,980.76	11,557.34	13,317.03
PF	m^3/d	531.37	663.14	2,162.55	2,683.20
Sub Total		8,501.94	10,610.18	16,394.07	20,965.25
Climatic and Socio-Economic factors	combined	1.37	1.37	1.37	1.37
Total Domestic Demand	m^3/d	11,605.15	14,482.89	22,377.90	28,617.56
industrial demand 10%	m^3/d	1,160.51	1,448.29	2,237.79	2,861.76
commercial and public demand (30%)	m^3/d	3,481.54	4,344.87	6,713.37	8,585.27
unaccounted for water (31%)	m^3/d	3,597.60	4,489.70	6,937.15	8,871.44
Average day demand	m^3/d	19,844.80	24,765.75	38,266.21	48,936.03
Maximum day factor		1.2	1.2	1.2	1.2
Maximum day water demand	m^3/d	23,813.76	29,718.90	45,919.45	58,723.24
Maximum day water demand	L/s	275.62	343.97	531.48	679.67
peak hour demand factor		1.70	1.70	1.70	1.70
peak hour demand	m^3/d	33,736.16	42,101.77	65,052.56	83,191.26
peak hour demand	L/s	390.46	487.29	752.92	962.86

Appendix 6 Total water demand for Bishoftu town

No	Town: Bishoftu Description	Unit	2010	2015	2020	2023
1	Total population	No	114,821.95	143,294.54	177,038.43	199,604.07
	Coverage by Service Level					
	HC (house connection)		5.1%	5.1%	10.1%	15.1%
	YC (yard connection)		71.1%	71.1%	65.8%	60.6%
	PF (public fountain)		10.5%	10.5%	24.1%	24.4%
	Population served by					
	HC	No	5,855.92	7,308.02	17,845.47	30,040.41
	YC	No	81,638.40	101,882.42	116,544.40	120,860.27
	PF	No	12,056.30	15,045.93	42,666.26	48,703.39
2	Demand					
2.1	Domestic					
	Per capita demand					
	HC	l/c/d	60.00	60.00	68.00	75.00
	YC	l/c/d	40.00	40.00	45.00	50.00
	PF	l/c/d	20.00	20.00	23.00	25.00
	Consumption (daily)					
	HC	m^3/d	351.36	438.48	1,213.49	2,253.03
	YC	m^3/d	3,265.54	4,075.30	5,244.50	6,043.01
	PF	m^3/d	241.13	300.92	981.32	1,217.58
	Sub Total		3,858.02	4,814.70	7,439.31	9,513.63
	Climatic and Socio-Economic factors	combined	1.58	1.58	1.58	1.58

Total Domestic Demand	m^3/d	6,076.38	7,583.15	11,716.92	14,983.97
industrial demand 10%	m^3/d	607.64	758.31	1,171.69	1,498.40
commercial and public demand (30%)	m^3/d	1,822.91	2,274.94	3,515.08	4,495.19
unaccounted for water (39%)	m^3/d	2,369.79	2,957.43	4,569.60	5,843.75
Average day demand	m^3/d	10,876.72	13,573.83	20,973.29	26,821.30
Maximum day factor		1.2	1.2	1.2	1.2
Maximum day water demand	m^3/d	13,052.06	16,288.60	25,167.94	32,185.56
Maximum day water demand	L/s	151.07	188.53	291.30	372.52
peak hour demand factor		1.70	1.70	1.70	1.70
peak hour demand	m^3/d	18,490.42	23,075.52	35,654.59	45,596.21
peak hour demand	L/s	214.01	267.08	412.67	527.73

Appendix 7 Total water demand for Mojo town

No	Town: Mojo Description	Unit	2010	2015	2020	2023
1	Total population	No	33,950.89	42,369.75	52,347.23	59,019.51
	Coverage by Service Level					
	HC (house connection)		5.1%	5.1%	10.1%	15.1%
	YC(yard connection)		71.1%	71.1%	65.8%	60.6%
	PF(public fountain)		10.5%	10.5%	24.1%	24.4%
	Population served by					
	HC	No	1,731.50	2,160.86	5,276.60	8,882.44
	YC	No	24,139.08	30,124.89	34,460.18	35,736.31
	PF	No	3,564.84	4,448.82	12,615.68	14,400.76
2	Demand					
2.1	Domestic					
	Per capita demand					
	HC	l/c/d	60.00	60.00	68.00	75.00
	YC	l/c/d	40.00	40.00	45.00	50.00
	PF	l/c/d	20.00	20.00	23.00	25.00
	Consumption (daily)					
	HC	m^3/d	103.89	129.65	358.81	666.18
	YC	m^3/d	965.56	1,205.00	1,550.71	1,786.82
	PF	m^3/d	71.30	88.98	290.16	360.02
	Sub Total		1,140.75	1,423.62	2,199.68	2,813.02
	Climatic and Socio-Economic factors	combined	1.05	1.05	1.05	1.05
	Total Domestic Demand	m^3/d	1,197.79	1,494.80	2,309.66	2,953.67

industrial demand 10%	m^3/d	119.78	149.48	230.97	295.37
commercial and public demand(30%)	m^3/d	359.34	448.44	692.90	886.10
unaccounted for water (49%)	m^3/d	586.92	732.45	900.77	1,151.93
Average day demand	m^3/d	2,263.82	2,825.18	4,134.29	5,287.07
Maximum day factor		1.2	1.2	1.2	1.2
Maximum day water demand	m^3/d	2,716.58	3,390.22	4,961.15	6,344.48
Maximum day water demand	L/s	31.44	39.24	57.42	73.43
peak hour demand factor		1.70	1.70	1.70	1.70
peak hour demand	m^3/d	3,848.49	4,802.81	7,028.30	8,988.01
peak hour demand	L/s	44.54	55.59	81.35	104.03

Appendix 9 unauthorized consumption for all study areas

Town	**Descriptions**	**Number of customers**		**Persons per house**	**Consumption per person in lit/day**	**Total consumption [lit/pers/day]**	**Total in M^3/day**	**Total in M^3/year**
Adama	Domestic Illegal connection	Years (E.C)	no	5	50.00	amount	amount	amount
		2011	37			9250	9.25	3376.25
		2012	45			11250	11.25	4106.25
		2013	34			8500	8.5	3102.5
		2014	43			10750	10.75	3923.75
		2015	55			13750	13.75	5018.75
	Organizations and other illegal connections	2011	24	10	60	14400	14.4	5256
		2012	32			19200	19.2	7008
		2013	27			16200	16.2	5913
		2014	29			17400	17.4	6351
		2015	29			17400	17.4	6351
	Meter tampering bypass etc.	2011	18	5	50	4500	4.5	1642.5
		2012	12			3000	3	1095
		2013	14			3500	3.5	1277.5
		2014	27			6750	6.75	2463.75
		2015	16			4000	4	1460
		2013	15	5	50	3750	3.75	1368.75
		2014	23			5750	5.75	2098.75

Bishoftu	Domestic Illegal connection	2015	18			4500	4.5	1642.5
	Organizations and other illegal connections	2013	5	10	60	3000	3	1095
		2014	7			4200	4.2	1533
		2015	15			9000	9	3285
	Meter tampering bypass etc.	2013	13	5	50	3250	3.25	1186.25
		2014	6			1500	1.5	547.5
		2015	10			2500	2.5	912.5
Mojo	Domestic Illegal connection	2013	34	5	50	8500	8.5	3102.5
		2014	50			12500	12.5	4562.5
		2015	46			11500	11.5	4197.5
	Organizations and other illegal connections	2013	5	10	60	3000	3	1095
		2014	5			3000	3	1095
		2015	4			2400	2.4	876
	Meter tampering bypass etc.	2013	2	5	50	1000	1	365
		2014	3			750	0.75	273.75
		2015	5			1250	1.25	456.25

Appendix 10 Mojo town 2013 E.C water balance

Mojo town Water balance in m3/year (2013E.C)				
System input volume m3/year 2,768,513.00 (100%)	Authorized consumption m3/year 1,434,497 (52%)	Billed authorized m3/year 1,381,651.00 (50%)	Billed metered consumption in m3/year 1,381,051.00 (50%)	Revenue Water in m3/year 1,381,651.00 (50%)
			Billed unmetered consumption in m3/year 600.00 (0.02%)	
		Unbilled authorized in m3/year 52,846.00 (2%)	Unbilled metered consumption in m3/year 52,701.00 (2%)	Non-revenue water in m3/year 1,386,862.00 (50%)
			Unbilled unmetered consumption in m3/year 145.00 (0.01%)	
	Water losses in m3/year 1,334,016.00 (48%)	Commercial losses (apparent loss) m3/year 142,988.15 (5%)	Unauthorized consumption in m3/year 4,562.50 (0.16%)	
			Customer meter inaccuracies and data handling errors in m3/year 138,425.65 (5%)	
		Physical losses (real loss) in m3/year 1,191,027.85 (43%)		

Appendix 11 Mojo town 2014 E.C water balance

Mojo town Water balance in m3/year (2014 E.C)				
System input volume m3/year 2,333,045.00 (100%)	Authorized consumption m3/year 1,463,155.00 (63%)	Billed authorized m3/year 1,410,404.00 (60%)	Billed metered consumption in m3/year 1,409,734.00 (60%)	Revenue Water in m3/year 1,410,404.00 (60%)
			Billed unmetered consumption in m3/year 670.00 (0.03%)	
		Unbilled authorized in m3/year 52,751.00 (2%)	Unbilled metered consumption in m3/year 52,601.00 (2%)	Non revenue water in m3/year 922,641.00 (40%)
			Unbilled unmetered consumption in m3/year 150.00 (0.01%)	
	Water losses in m3/year 869,890.00 (37%)	Commercial losses (apparent loss) m3/year 122,583.50 (5%)	Unauthorized consumption in m3/year 5,931.25 (0.25%)	
			Customer meter inaccuracies and data handling errors in m3/year 116,652.25 (5%)	
		Physical losses(real loss) in m3/year 747,306.50 (32%)		

Appendix 12 Mojo town 2015 E.C water balance

Mojo town Water balance in m3/year (2015 E.C)				
System input volume m3/year 3,177,332.00 (100%)	Authorized consumption m3/year 1,603,601 (50%)	Billed authorized m3/year 1,551,250 (49%)	Billed metered consumption in m3/year 1,550,500.00 (49%)	Revenue Water in m3/year 1,551,250 (49%)
			Billed unmetered consumption in m3/year 750 (0.02%)	
		Unbilled authorized in m3/year 52,351 (2%)	Unbilled metered consumption in m3/year 52,201 (2%)	Non revenue water in m3/year 1,626,082 (51%)
			Unbilled unmetered consumption in m3/year 150 (0.005%)	
	Water losses in m3/year 1,573,731.00 (50%)	Commercial losses (apparent loss) m3/year 164,396.35 (5%)	Unauthorized consumption in m3/year 5,529.75 (0.2%)	
			Customer meter inaccuracies and data handling errors in m3/year 158,866.60 (5%)	
		Physical losses(real loss) in m3/year 1,409,334.65 (44%)		

Appendix 13 Bishoftu town 2013 E.C water balance

Bishoftu town Water balance in m3/year (2013E.C)				
System input volume m3/year 9,170,000.00 (100%)	Authorized consumption m3/year 5,856,276.20 (64%)	Billed authorized m3/year 5,756,464.00 (63%)	Billed metered consumption in m3/year 5,755,659.00 (63%)	Revenue Water in m3/year 5,756,464.00 (63%)
			Billed unmetered consumption in m3/year 805.00 (0.01%)	
		Unbilled authorized in m3/year 99,812.20 (1%)	Unbilled metered consumption in m3/year 99,657.20 (1%)	Non-revenue water in m3/year 3,413,536.00 (37%)
			Unbilled unmetered consumption in m3/year 155.00 (0.002%)	
	Water losses in m3/year 3,313,723.80 (36%)	Commercial losses (apparent loss) m3/year 645,550.00 (7%)	Unauthorized consumption in m3/year 3,650.00 (0.04%)	
			Customer meter inaccuracies and data handling errors in m3/year 641,900.00 (7%)	
		Physical losses (real loss) in m3/year 2,668,173.80 (29%)		

Appendix 14 Bishoftu town 2014 E.C water balance

<table>
<tr><th colspan="5">Bishoftu town Water balance in m3/year (2014E.C)</th></tr>
<tr><td rowspan="7">System input volume m3/year 10,650,000 (100%)</td><td rowspan="4">Authorized consumption m3/year 6,812,111.7 (64%)</td><td rowspan="2">Billed authorized m3/year 6,706,249.5 (63%)</td><td>Billed metered consumption in m3/year 6,705,203 (63%)</td><td rowspan="2">Revenue Water in m3/year 6,706,249.5 (63%)</td></tr>
<tr><td>Billed unmetered consumption in m3/year 1,046.5 (0.01%)</td></tr>
<tr><td rowspan="2">Unbilled authorized in m3/year 105,862.2 (1%)</td><td>Unbilled metered consumption in m3/year 105,657.2 (1%)</td><td rowspan="5">Non-revenue water in m3/year 3,943,750.5 (37%)</td></tr>
<tr><td>Unbilled unmetered consumption in m3/year 205 (0.002%)</td></tr>
<tr><td rowspan="3">Water losses in m3/year 3,837,888.3 (36%)</td><td rowspan="2">Commercial losses (apparent loss) m3/year 749,679.25 (7%)</td><td>Unauthorized consumption in m3/year 4,179.25 (0.04%)</td></tr>
<tr><td>Customer meter inaccuracies and data handling errors in m3/year 745,500.00 (7%)</td></tr>
<tr><td colspan="2">Physical losses (real loss) in m3/year 3,088,209.05 (29%)</td></tr>
</table>

Appendix 15 Bishoftu town 2015 E.C water balance

Bishoftu town Water balance in m^3/year (2015 E.C)				
System input volume m^3/year 10,357,605 (100%)	Authorized consumption m^3/year 6,257,813.7 (60%)	Billed authorized m^3/year 6,145,601.5 (59%)	Billed metered consumption in m^3/year 6,144,394 (59%)	Revenue Water in m^3/year 6,145,601.5 (59%)
			Billed unmetered consumption in m^3/year 1,207.5 (0.01%)	
		Unbilled authorized in m^3/year 112,212.2 (1%)	Unbilled metered consumption in m^3/year 111,957.2 (1%)	Non-revenue water in m^3/year 4,212,003.5 (41%)
			Unbilled unmetered consumption in m^3/year 255 (0.002%)	
	Water losses in m^3/year 4,099,791.3 (39.6%)	Commercial losses (apparent loss) m^3/year 730,872.35 (7%)	Unauthorized consumption in m^3/year 5,840 (0.1%)	
			Customer meter inaccuracies and data handling errors in m^3/year 725,032.35 (7%)	
		Physical losses (real loss) in m^3/year 3,368,918.95 (33%)		

Appendix 16 Adama town 2011 E.C water balance

Adama town Water balance in m3/year (2011 E.C)				
System input volume m3/year 13,782,322.00 (100%)	Authorized consumption m3/year 9,687,473.4 (70%)	Billed authorized m3/year 9,588,733.4 (70%)	Billed metered consumption in m3/year 9,587,558.4 (70%)	Revenue Water in m3/year 9,588,733 .40 (70%)
			Billed unmetered consumption in m3/year 1,175 (0.01%)	
		Unbilled authorized in m3/year 98,740 (1%)	Unbilled metered consumption in m3/year 98,200 (1%)	Non-revenue water in m3/year 4,193,588 .60 (30%)
			Unbilled unmetered consumption in m3/year 540 (0.004%)	
	Water losses in m3/year 4,094,848.60 (30%)	Commercial losses (apparent loss) m3/year 837,214.07 (6%)	Unauthorized consumption in m3/year 10,274.75 (0.1%)	
			Customer meter inaccuracies and data handling errors in m3/year 826,939.32 (6%)	
		Physical losses (real loss) in m3/year 3,257,634.53 (24%)		

Appendix 17 Adama town 2012 E.C water balance

Adama town Water balance in m3/year (2012 E.C)				
System input volume m3/year 14,179,462.00 (100%)	Authorized consumption m3/year 9,557,391 (67%)	Billed authorized m3/year 9,457,251 (67%)	Billed metered consumption in m3/year 9,453,676 (67%)	Revenue Water in m3/year 9,457,251.00 (67%)
			Billed unmetered consumption in m3/year 3,575 (0.03%)	
		Unbilled authorized in m3/year 100,140 (1%)	Unbilled metered consumption in m3/year 99,500 (1%)	Non-revenue water in m3/year 4,722,211.00 (33%)
			Unbilled unmetered consumption in m3/year 640 (0.005%)	
	Water losses in m3/year 4,622,071.00 (33%)	Commercial losses (apparent loss) m3/year 862,976.97 (6%)	Unauthorized consumption in m3/year 12,209.25 (0.1%)	
			Customer meter inaccuracies and data handling errors in m3/year 850,767.72 (6%)	
		Physical losses (real loss) in m3/year 3,759,094.03 (27%)		

Appendix 18 Adama town 2013 E.C water balance

Adama town Water balance in m3/year (2013 E.C)

System input volume m3/year 14,776,602 (100%)	Authorized consumption m3/year 10,211,163.4 (69%)	Billed authorized m3/year 10,111,423.4 (68%)	Billed metered consumption in m3/year 10,107,558.4 (68%)	Revenue Water in m3/year 10,111,423.40 (68%)
			Billed unmetered consumption in m3/year 3,865 (0.03%)	
		Unbilled authorized in m3/year 99,740 (1%)	Unbilled metered consumption in m3/year 99,100 (1%)	Non-revenue water in m3/year 4,665,178.60 (32%)
			Unbilled unmetered consumption in m3/year 640 (0.004%)	
	Water losses in m3/year 4,565,438.60 (31%)	Commercial losses (apparent loss) m3/year 896,889.12 (6%)	Unauthorized consumption in m3/year 10,293 (0.1%)	
			Customer meter inaccuracies and data handling errors in m3/year 886,596.12 (6%)	
		Physical losses (real loss) in m3/year (25%) 3,668,549.48		

Appendix 19 Adama town 2014 E.C water balance

Adama town Water balance in m3/year (2014 E.C)				
System input volume m3/year 14,842,289.00 (100%)	Authorized consumption m3/year 10,362,378.4 (70%)	Billed authorized m3/year 10,262,538.4 (69%)	Billed metered consumption in m3/year 10258558.4	Revenue Water in m3/year 10,262,538.40 (69%)
			Billed unmetered consumption in m3/year 3,980 (0.03%)	
		Unbilled authorized in m3/year 99,840 (1%)	Unbilled metered consumption in m3/year 99,200 (1%)	Non-revenue water in m3/year 4,579,750.60 (31%)
			Unbilled unmetered consumption in m3/year 640 (0.004%)	
	Water losses in m3/year 4,479,910.60 (30%)	Commercial losses (apparent loss) m3/year 903,275.84 (6%)	Unauthorized consumption in m3/year 12,738.5 (0.1%)	
			Customer meter inaccuracies and data handling errors in m3/year 890,537.34 (6%)	
		Physical losses (real loss) in m3/year 3,576,634.76 (24%)		

Appendix 20 Adama town 2015 E.C water balance

Adama town Water balance in m3/year (2015 E.C)				
System input volume m3/year 16,071,668.00 (100%)	Authorized consumption m3/year 10,264,018.4 (64%)	Billed authorized m3/year 10,163,878.4 (63%)	Billed metered consumption in m3/year 10,159,558.4 (63%)	Revenue Water in m3/year 10,163,878.40 (63%)
			Billed unmetered consumption in m3/year 4,320 (0.03%)	
		Unbilled authorized in m3/year 100,140 (1%)	Unbilled metered consumption in m3/year 99,400 (1%)	Non-revenue water in m3/year 5,907,789.60 (37%)
			Unbilled unmetered consumption in m3/year 740 (0.005%)	
	Water losses in m3/year 5,807,649.60 (36%)	Commercial losses (apparent loss) m3/year 977,129.83 (6%)	Unauthorized consumption in m3/year 12,829.75 (0.1%)	
			Customer meter inaccuracies and data handling errors in m3/year 964,300.08 (6%)	
		Physical losses (real loss) in m3/year 4,830,519.779 (30%)		

Appendix 21 calculation of average operating pressure for Adama

Label	Demand (L/s)	Pressure (m H2O)	pi*(1+di)	(1+di)
J-77	3.3	1.11	4.773	4.3
J-78	0.46	2.1	3.066	1.46
J-1	3.47	2.82	12.6054	4.47
J-79	1.65	3.5	9.275	2.65
J-22	9.64	3.94	41.9216	10.64
J-3	6.31	6.68	48.8308	7.31
J-17	1.03	7.3	14.819	2.03
J-83	1.33	9.03	21.0399	2.33
J-89	1.5	13.25	33.125	2.5
J-90	0.31	13.46	17.6326	1.31
J-25	0.47	14.15	20.8005	1.47
J-92	1.87	14.89	42.7343	2.87
J-93	0.29	15.75	20.3175	1.29
J-94	0.36	16.17	21.9912	1.36
J-19	0.59	17.37	27.6183	1.59
J-95	0.36	17.74	24.1264	1.36
J-48	2.03	18.85	57.1155	3.03
J-99	0.68	20.33	34.1544	1.68
J-2	1.49	21.18	52.7382	2.49
J-49	2.38	21.35	72.163	3.38
J-68	9.74	24.28	260.767	10.74
J-55	1.55	25.37	64.6935	2.55
J-109	0.27	25.67	32.6009	1.27
J-6	3.64	26.5	122.96	4.64
J-111	0.74	26.77	46.5798	1.74
J-13	0.98	27.28	54.0144	1.98
J-18	2.19	28.15	89.7985	3.19
J-115	0.87	29.06	54.3422	1.87
J-4	0.7	29.18	49.606	1.7
J-26	3.63	29.59	137.002	4.63
J-11	2.7	30.84	114.108	3.7
J-12	3.64	30.84	143.098	4.64
J-32	4.07	30.92	156.764	5.07
J-14	3.4	31.7	139.48	4.4
J-15	0.58	31.88	50.3704	1.58
J-123	0.37	32.28	44.2236	1.37

J-16	1.05	32.35	66.3175	2.05
J-71	1.1	32.65	68.565	2.1
J-72	0.53	33.3	50.949	1.53
J-9	0.51	33.55	50.6605	1.51
J-35	2.15	33.7	106.155	3.15
J-5	0.37	33.91	46.4567	1.37
J-75	1.42	34.51	83.5142	2.42
J-70	2.29	34.55	113.67	3.29
J-126	0.5	34.73	52.095	1.5
J-8	0.46	34.78	50.7788	1.46
J-127	0.19	34.92	41.5548	1.19
J-76	0.58	35	55.3	1.58
J-129	0.9	35.19	66.861	1.9
J-147	0.49	35.54	52.9546	1.49
J-7	0.04	35.64	37.0656	1.04
J-131	0.43	35.71	51.0653	1.43
J-130	0.44	35.84	51.6096	1.44
J-150	1.26	36.12	81.6312	2.26
J-132	0.94	36.2	70.228	1.94
J-20	0.33	36.28	48.2524	1.33
J-64	2.27	36.47	119.257	3.27
J-65	0.62	36.56	59.2272	1.62
J-10	0.39	36.62	50.9018	1.39
J-33	2.42	36.9	126.198	3.42
J-81	6.67	5.2	283.407	7.67
J-66	1.72	37.17	101.102	2.72
J-23	0.16	37.39	43.3724	1.16
J-136	0.37	37.93	51.9641	1.37
J-30	3.56	38.12	173.827	4.56
J-137	0.77	38.44	68.0388	1.77
J-80	0.35	38.5	51.975	1.35
J-43	0.7	38.76	65.892	1.7
J-52	1.08	39.39	81.9312	2.08
J-138	0.3	39.85	51.805	1.3
J-140	0.6	40.08	64.128	1.6
J-73	2.12	40.32	125.798	3.12
J-143	1.32	40.83	94.7256	2.32
J-144	0.73	40.88	70.7224	1.73
J-82	1.97	41.6	123.552	2.97

J-181	2.78	41.76	157.853	3.78
J-21	0.57	41.78	65.5946	1.57
J-154	0.4	42.25	59.15	1.4
J-151	0.38	42.33	58.4154	1.38
J-38	3.08	42.5	173.4	4.08
J-24	0.07	42.52	45.4964	1.07
J-74	1.46	42.59	104.771	2.46
J-84	2.28	42.61	139.761	3.28
J-34	3.34	42.86	186.012	4.34
J-202	0.23	42.89	52.7547	1.23
J-39	0.23	42.92	52.7916	1.23
J-203	2.18	43.14	137.185	3.18
J-153	0.73	43.32	74.9436	1.73
J-160	1.22	43.44	96.4368	2.22
J-139	1.17	43.49	94.3733	2.17
J-27	0.12	43.59	48.8208	1.12
J-28	0.85	44.08	81.548	1.85
J-37	0.17	44.11	51.6087	1.17
J-29	0.53	44.22	67.6566	1.53
J-159	0.37	44.72	61.2664	1.37
J-87	1.02	44.76	90.4152	2.02
J-85	1.03	45.05	91.4515	2.03
J-164	0.66	45.23	75.0818	1.66
J-31	0.19	45.33	53.9427	1.19
J-227	1.44	45.34	110.63	2.44
J-163	0.35	45.44	61.344	1.35
J-86	0.73	45.79	79.2167	1.73
J-42	4.06	46.21	233.823	5.06
J-88	0.77	46.28	81.9156	1.77
J-166	0.17	46.33	54.2061	1.17
J-91	1.28	46.81	106.727	2.28
J-44	0.44	46.83	67.4352	1.44
J-169	0.5	47.07	70.605	1.5
J-168	0.13	47.13	53.2569	1.13
J-170	0.22	47.25	57.645	1.22
J-54	0.19	47.32	56.3108	1.19
J-171	0.62	47.58	77.0796	1.62
J-172	0.2	47.61	57.132	1.2
J-36	0.87	47.78	89.3486	1.87

J-174	0.07	47.87	51.2209	1.07
J-40	0.29	47.88	61.7652	1.29
J-58	0.16	47.91	55.5756	1.16
J-50	0.41	48.4	68.244	1.41
J-53	0.22	48.5	59.17	1.22
J-298	2.8	48.73	185.174	3.8
J-222	0.58	48.73	76.9934	1.58
J-41	0.47	48.92	71.9124	1.47
J-165	0.76	48.98	86.2048	1.76
J-177	0.48	49.15	72.742	1.48
J-60	0.4	49.17	68.838	1.4
J-178	0.83	49.43	90.4569	1.83
J-51	1.08	49.66	103.293	2.08
J-56	0.32	49.76	65.6832	1.32
J-101	6.55	50.18	378.859	7.55
J-182	0.54	50.25	77.385	1.54
J-59	0.23	50.34	61.9182	1.23
J-161	0.59	50.45	80.2155	1.59
J-116	1.41	50.5	121.705	2.41
J-47	0.43	50.58	72.3294	1.43
J-173	0.88	50.69	95.2972	1.88
J-180	0.72	50.92	87.5824	1.72
J-96	1.3	51.23	117.829	2.3
J-145	1.43	51.39	124.878	2.43
J-97	1.45	51.42	125.979	2.45
J-117	2.32	51.52	171.046	3.32
J-98	0.57	51.53	80.9021	1.57
J-191	0.38	51.57	71.1666	1.38
J-194	0.53	51.59	78.9327	1.53
J-104	2.17	51.59	163.54	3.17
J-45	0.17	51.76	60.5592	1.17
J-46	0.1	51.86	57.046	1.1
J-102	0.76	51.92	91.3792	1.76
J-195	0.73	51.96	89.8908	1.73
J-193	0.35	52.18	70.443	1.35
J-167	1.33	52.35	121.976	2.33
J-57	0.34	52.4	70.216	1.34
J-61	0.75	52.45	91.7875	1.75
J-199	0.75	52.55	91.9625	1.75

J-197	0.42	52.56	74.6352	1.42
J-318	0.37	52.67	72.1579	1.37
J-200	2.32	52.75	175.13	3.32
J-114	1.84	52.78	149.895	2.84
J-198	0.56	53.29	83.1324	1.56
J-100	1.01	53.39	107.314	2.01
J-106	0.78	53.96	96.0488	1.78
J-103	0.29	54.17	69.8793	1.29
J-214	0.62	54.58	88.4196	1.62
J-62	0.25	54.6	68.25	1.25
J-218	1.02	55	111.1	2.02
J-213	0.44	55.08	79.3152	1.44
J-229	0.39	55.14	76.6446	1.39
J-105	0.1	55.43	60.973	1.1
J-201	0.67	55.55	92.7685	1.67
J-124	1.04	55.71	113.648	2.04
J-225	0.48	55.8	82.584	1.48
J-125	0.38	55.83	77.0454	1.38
J-107	0.58	56.03	88.5274	1.58
J-226	0.32	56.17	74.1444	1.32
J-209	2.13	56.22	175.969	3.13
J-108	0.29	56.45	72.8205	1.29
J-230	0.85	56.63	104.766	1.85
J-110	1.56	56.82	145.459	2.56
J-232	0.41	57.08	80.4828	1.41
J-231	0.36	57.25	77.86	1.36
J-235	0.27	57.42	72.9234	1.27
J-236	1.13	57.46	122.39	2.13
J-436	6.27	57.48	417.88	7.27
J-63	0.34	57.48	77.0232	1.34
J-216	0.27	57.54	73.0758	1.27
J-234	0.24	57.61	71.4364	1.24
J-237	0.45	57.62	83.549	1.45
J-118	0.74	57.77	100.52	1.74
J-252	1.33	57.77	134.604	2.33
J-240	0.15	57.85	66.5275	1.15
J-241	0.77	57.96	102.589	1.77
J-239	0.52	57.97	88.1144	1.52
J-119	0.49	58.27	86.8223	1.49

J-244	0.59	58.29	92.6811	1.59
J-260	0.58	58.34	92.1772	1.58
J-206	1.03	58.37	118.491	2.03
J-248	0.84	58.47	107.585	1.84
J-210	0.63	58.57	95.4691	1.63
J-250	0.57	58.72	92.1904	1.57
J-251	0.11	58.87	65.3457	1.11
J-249	0.29	58.89	75.9681	1.29
J-389	1.62	59.15	154.973	2.62
J-279	0.24	59.31	73.5444	1.24
J-254	0.31	59.33	77.7223	1.31
J-67	2.16	59.47	187.925	3.16
J-69	1.38	59.79	142.3	2.38
J-255	1.39	59.83	142.994	2.39
J-256	0.41	59.86	84.4026	1.41
J-337	1.26	59.87	135.306	2.26
J-257	0.35	59.89	80.8515	1.35
J-259	0.34	59.93	80.3062	1.34
J-258	0.56	59.95	93.522	1.56
J-263	0.17	60.11	70.3287	1.17
J-336	2.01	60.24	181.322	3.01
J-268	0.19	60.45	71.9355	1.19
J-265	0.39	60.45	84.0255	1.39
J-270	0.58	60.54	95.6532	1.58
J-271	0.4	60.59	84.826	1.4
J-273	0.17	60.82	71.1594	1.17
J-274	0.11	60.96	67.6656	1.11
J-276	0.15	60.98	70.127	1.15
J-275	0.19	61.02	72.6138	1.19
J-278	4	61.06	305.3	5
J-344	1.97	61.22	181.823	2.97
J-128	0.95	61.23	119.399	1.95
J-282	0.11	61.43	68.1873	1.11
J-289	0.46	61.74	90.1404	1.46
J-288	0.27	61.79	78.4733	1.27
J-286	1.09	61.84	129.246	2.09
J-283	0.79	61.94	110.873	1.79
J-290	0.47	62.01	91.1547	1.47
J-292	1.07	62.12	128.588	2.07

J-293	0.68	62.13	104.378	1.68
J-121	1.68	62.35	167.098	2.68
J-133	0.83	62.37	114.137	1.83
J-120	0.96	62.37	122.245	1.96
J-299	1.16	62.41	134.806	2.16
J-301	0.31	62.48	81.8488	1.31
J-302	0.81	62.48	113.089	1.81
J-303	0.41	62.6	88.266	1.41
J-307	1.58	62.73	161.843	2.58
J-305	0.42	62.86	89.2612	1.42
J-309	0.13	63.06	71.2578	1.13
J-306	0.3	63.1	82.03	1.3
J-312	0.26	63.17	79.5942	1.26
J-315	0.37	63.44	86.9128	1.37
J-321	0.64	63.47	104.091	1.64
J-221	0.66	63.68	105.709	1.66
J-329	1.63	63.77	167.715	2.63
J-319	0.11	63.8	70.818	1.11
J-149	2.53	63.85	225.391	3.53
J-326	0.26	63.88	80.4888	1.26
J-324	0.15	63.92	73.508	1.15
J-327	0.14	63.99	72.9486	1.14
J-328	0.09	64.04	69.8036	1.09
J-135	1.57	64.07	164.66	2.57
J-331	1.19	64.09	140.357	2.19
J-122	0.93	64.11	123.732	1.93
J-339	0.32	64.16	84.6912	1.32
J-330	1.24	64.17	143.741	2.24
J-333	0.15	64.28	73.922	1.15
J-341	1.35	64.44	151.434	2.35
J-217	0.57	64.45	101.187	1.57
J-347	0.5	64.66	96.99	1.5
J-345	0.74	64.68	112.543	1.74
J-220	0.53	64.95	99.3735	1.53
J-348	0.06	64.97	68.8682	1.06
J-351	0.38	65.17	89.9346	1.38
J-350	0.13	65.21	73.6873	1.13
J-349	0.23	65.24	80.2452	1.23
J-354	0.38	65.37	90.2106	1.38

J-358	0.16	65.4	75.864	1.16
J-366	0.51	65.63	99.1013	1.51
J-367	0.37	65.63	89.9131	1.37
J-359	0.17	65.87	77.0679	1.17
J-360	0.68	65.91	110.729	1.68
J-277	1.66	66.01	175.587	2.66
J-156	1.22	66.1	146.742	2.22
J-155	3.31	66.1	284.891	4.31
J-377	0.59	66.7	106.053	1.59
J-388	0.57	67.04	105.253	1.57
J-381	2.56	67.05	238.698	3.56
J-295	1.39	67.22	160.656	2.39
J-371	1.7	67.27	181.629	2.7
J-386	0.49	67.36	100.366	1.49
J-157	1.16	67.38	145.541	2.16
J-385	0.73	67.46	116.706	1.73
J-396	0.91	67.48	128.887	1.91
J-393	0.18	67.52	79.6736	1.18
J-391	0.15	67.67	77.8205	1.15
J-475	0.53	68.03	104.086	1.53
J-387	0.82	68.1	123.942	1.82
J-487	3.07	68.16	277.411	4.07
J-403	1.12	68.38	144.966	2.12
J-400	0.75	68.43	119.753	1.75
J-483	1.15	68.43	147.125	2.15
J-162	9.15	68.46	694.869	10.15
J-394	0.58	68.49	108.214	1.58
J-431	2.61	68.78	248.296	3.61
J-395	1.56	68.86	176.282	2.56
J-142	5.39	68.96	440.654	6.39
J-141	4.75	68.98	396.635	5.75
J-450	0.71	69.29	118.486	1.71
J-449	1.14	69.29	148.281	2.14
J-409	0.78	69.31	123.372	1.78
J-413	0.23	69.78	85.8294	1.23
J-406	0.42	69.87	99.2154	1.42
J-419	0.91	69.92	133.547	1.91
J-458	1.28	69.95	159.486	2.28
J-440	1.17	70.03	151.965	2.17

J-452	2.21	70.04	224.828	3.21
J-421	0.13	70.13	79.2469	1.13
J-466	0.98	70.15	138.897	1.98
J-480	0.64	70.54	115.686	1.64
J-426	0.27	70.67	89.7509	1.27
J-428	0.41	70.77	99.7857	1.41
J-465	0.8	70.79	127.422	1.8
J-401	2.53	71.27	251.583	3.53
J-438	0.67	71.32	119.104	1.67
J-441	0.54	71.83	110.618	1.54
J-439	1.07	71.88	148.792	2.07
J-456	0.16	71.91	83.4156	1.16
J-457	1.09	71.96	150.396	2.09
J-364	2.49	72.17	251.873	3.49
J-448	0.67	72.39	120.891	1.67
J-427	1.65	72.54	192.231	2.65
J-433	1.22	72.6	161.172	2.22
J-417	2.78	72.62	274.504	3.78
J-473	2.05	72.82	222.101	3.05
J-471	1.66	72.85	193.781	2.66
J-382	0.92	73.87	141.83	1.92
J-357	0.65	74.63	123.14	1.65
J-461	1.2	74.78	164.516	2.2
J-368	0.77	74.89	132.555	1.77
J-338	3.52	75.63	341.848	4.52
J-462	0.62	75.69	122.618	1.62
J-423	1.13	76.24	162.391	2.13
J-488	0.43	76.76	109.767	1.43
J-446	1.46	76.78	188.879	2.46
J-380	0.84	76.97	141.625	1.84
J-422	1.91	77.05	224.216	2.91
J-474	0.43	77.1	110.253	1.43
J-443	0.58	77.41	122.308	1.58
J-397	0.52	77.44	117.709	1.52
J-430	0.45	77.48	112.346	1.45
J-402	0.39	78.07	108.517	1.39
J-479	0.36	78.16	106.298	1.36
J-468	0.33	78.22	104.033	1.33
J-404	0.36	78.29	106.474	1.36

J-485	0.34	78.31	104.935	1.34
J-467	0.3	78.34	101.842	1.3
J-486	1.59	78.34	202.901	2.59
J-445	2.32	78.4	260.288	3.32
J-405	4.4	78.42	423.468	5.4
J-469	0.95	78.52	153.114	1.95
J-179	5.32	78.53	496.31	6.32
J-411	0.06	78.57	83.2842	1.06
J-470	0.41	78.8	111.108	1.41
J-481	0.64	78.81	129.248	1.64
J-412	0.29	78.97	101.871	1.29
J-507	2.14	79.06	248.248	3.14
J-472	0.58	79.25	125.215	1.58
J-489	0.18	79.29	93.5622	1.18
J-484	0.51	79.37	119.849	1.51
J-478	2	79.38	238.14	3
J-508	1.19	79.39	173.864	2.19
J-477	0.5	79.42	119.13	1.5
J-424	0.55	79.56	123.318	1.55
J-498	0.93	79.61	153.647	1.93
J-398	1.02	79.78	161.156	2.02
J-184	2.55	79.89	283.61	3.55
J-511	1.89	79.89	230.882	2.89
J-496	0.68	80.01	134.417	1.68
J-491	0.31	80.06	104.879	1.31
J-495	0.48	80.06	118.489	1.48
J-243	5.49	80.11	519.914	6.49
J-490	0.22	80.37	98.0514	1.22
J-492	0.25	80.38	100.475	1.25
J-188	2.49	80.38	280.526	3.49
J-451	0.79	80.46	144.023	1.79
J-414	0.86	81.04	150.734	1.86
J-513	1.11	81.11	171.142	2.11
J-501	1.59	81.14	210.153	2.59
J-442	4.82	81.16	472.351	5.82
J-416	1.1	81.22	170.562	2.1
J-420	0.35	81.22	109.647	1.35
J-506	2.45	81.41	280.865	3.45
J-453	0.14	81.51	92.9214	1.14

J-518	0.35	81.59	110.147	1.35
J-509	0.84	81.59	150.126	1.84
J-494	3.04	81.66	329.906	4.04
J-246	0.56	81.69	127.436	1.56
J-516	1.44	81.7	199.348	2.44
J-520	1.35	81.72	192.042	2.35
J-432	0.85	81.77	151.275	1.85
J-502	0.2	81.79	98.148	1.2
J-455	0.47	81.85	120.32	1.47
J-497	0.97	82.03	161.599	1.97
J-429	1.17	82.09	178.135	2.17
J-519	1.59	82.11	212.665	2.59
J-512	0.82	82.33	149.841	1.82
J-515	0.6	82.33	131.728	1.6
J-434	2.22	82.36	265.199	3.22
J-514	1.25	82.4	185.4	2.25
J-435	0.62	82.47	133.601	1.62
J-499	1.52	82.48	207.85	2.52
J-517	1.14	82.51	176.571	2.14
J-504	0.97	82.59	162.702	1.97
J-503	0.62	82.68	133.942	1.62
J-500	2.24	82.79	268.24	3.24
J-207	4.6	82.8	463.68	5.6
J-460	0.68	82.81	139.121	1.68
J-505	0.44	83.07	119.621	1.44
J-510	1.68	83.21	223.003	2.68
J-407	0.24	83.3	103.292	1.24
J-447	1.68	83.48	223.726	2.68
J-521	1.36	83.64	197.39	2.36
J-383	0.58	83.8	132.404	1.58
J-523	0.25	83.91	104.888	1.25
J-493	1.92	83.99	245.251	2.92
J-522	0.9	84.06	159.714	1.9
J-297	3.45	84.52	376.114	4.45
J-524	1.48	84.6	209.808	2.48
J-287	0.22	84.9	103.578	1.22
J-233	3.09	85.16	348.304	4.09
J-247	2.95	85.78	338.831	3.95
J-311	0.18	86.07	101.563	1.18

J-342	0.15	86.38	99.337	1.15
J-374	0.07	87.19	93.2933	1.07
J-291	1.81	87.63	246.24	2.81
J-264	1.3	87.65	201.595	2.3
J-355	0.18	88.64	104.595	1.18
J-378	0.07	88.71	94.9197	1.07
J-392	0.24	89.22	110.633	1.24
J-294	0.23	89.56	110.159	1.23
J-476	2.43	90.26	309.592	3.43
J-280	2.66	90.47	331.12	3.66
J-284	1.26	91.06	205.796	2.26
J-418	2.14	93.88	294.783	3.14
J-373	2.4	94.39	320.926	3.4
J-370	2.89	94.63	368.111	3.89
J-415	0.31	94.66	124.005	1.31
J-375	3.64	94.73	439.547	4.64
J-343	1.23	94.75	211.293	2.23
J-176	2.32	95	315.4	3.32
J-444	0.71	96.13	164.382	1.71
J-408	1.86	97.28	278.221	2.86
J-410	0.76	97.41	171.442	1.76
J-266	0.44	97.54	140.458	1.44
J-185	0.96	97.87	191.825	1.96
J-190	0.44	98.81	142.286	1.44
J-186	0.87	98.88	184.906	1.87
J-134	1.32	99.36	230.515	2.32
J-437	2.32	100.01	332.033	3.32
J-205	0.83	100.12	183.22	1.83
J-281	0.85	100.32	185.592	1.85
J-463	0.79	100.67	180.199	1.79
J-146	1.06	101.14	208.348	2.06
J-219	1.58	101.31	261.38	2.58
J-454	1.19	101.43	222.132	2.19
J-224	0.72	101.65	174.838	1.72
J-459	1.58	101.91	262.928	2.58
J-211	0.5	102.19	153.285	1.5
J-189	0.5	102.22	153.33	1.5
J-196	0.52	103.64	157.533	1.52
J-223	0.34	104.2	139.628	1.34

J-204	1	104.27	208.54	2
J-238	0.49	105.41	157.061	1.49
J-325	0.68	105.63	177.458	1.68
J-158	0.63	106.36	173.367	1.63
J-228	0.47	106.61	156.717	1.47
J-269	0.38	108.13	149.219	1.38
J-242	0.23	108.15	133.025	1.23
J-262	0.55	108.52	168.206	1.55
J-187	0.95	109.2	212.94	1.95
J-272	0.43	109.26	156.242	1.43
J-183	0.59	109.27	173.739	1.59
J-261	0.3	109.99	142.987	1.3
J-310	0.44	110.28	158.803	1.44
J-335	0.94	110.56	214.486	1.94
J-296	0.13	110.83	125.238	1.13
J-304	0.38	111.2	153.456	1.38
J-313	0.24	111.62	138.409	1.24
J-215	1.79	111.77	311.838	2.79
J-317	0.68	112.12	188.362	1.68
J-192	0.49	112.25	167.253	1.49
J-334	0.55	112.55	174.453	1.55
J-285	1.1	112.7	236.67	2.1
J-320	0.43	112.9	161.447	1.43
J-322	0.55	113.37	175.724	1.55
J-346	0.62	113.37	183.659	1.62
J-323	0.97	113.87	224.324	1.97
J-253	0.52	115.67	175.818	1.52
J-314	0.44	116	167.04	1.44
J-267	2.53	117.29	414.034	3.53
J-300	0.86	118.37	220.168	1.86
J-356	0.33	118.68	157.844	1.33
J-308	0.79	118.96	212.938	1.79
J-369	0.41	119.33	168.255	1.41
J-212	2.41	119.35	406.984	3.41
J-361	0.57	120.29	188.855	1.57
J-316	1.13	120.3	256.239	2.13
J-363	0.25	121.03	151.288	1.25
J-362	0.29	121.92	157.277	1.29
J-332	1.03	121.95	247.559	2.03

J-352	0.34	122.07	163.574	1.34
J-340	1.22	122.42	271.772	2.22
J-365	0.91	122.59	234.147	1.91
J-353	1.37	123.17	291.913	2.37
J-379	0.41	123.64	174.332	1.41
J-372	0.5	123.64	185.46	1.5
J-376	0.38	123.8	170.844	1.38
J-384	0.33	123.92	164.814	1.33
J-390	0.67	124.59	208.065	1.67
J-399	0.97	125.35	246.94	1.97
	Summation		47781.8	1221.07
	Average operating pressure		39.1311	

Appendix 22 calculation of average operating pressure for Bishoftu

Label	Demand (L/s)	Pressure (m H2O)	pi*(1+di)	(1+di)
J-158	0.11	5.99	6.6489	1.11
J-299	1.89	15.11	43.6679	2.89
J-120	2.39	15.15	51.3585	3.39
J-298	0.29	15.28	19.7112	1.29
J-159	0.72	16.97	29.1884	1.72
J-254	0.48	17.36	25.6928	1.48
J-140	0.37	17.54	24.0298	1.37
J-134	0.77	17.67	31.2759	1.77
J-255	0.14	18.34	20.9076	1.14
J-313	2.35	19.31	64.6885	3.35
J-256	0.72	19.32	33.2304	1.72
J-252	2.74	19.86	74.2764	3.74
J-253	0.87	19.87	37.1569	1.87
J-132	0.79	21.29	38.1091	1.79
J-297	1.87	21.92	62.9104	2.87
J-382	1.85	21.94	62.529	2.85
J-183	1.66	23.39	62.2174	2.66
J-270	1.63	28.03	73.7189	2.63
J-119	2.3	29.61	97.713	3.3
J-262	4.21	30	156.3	5.21
J-296	2.23	30.17	97.4491	3.23
J-295	2.26	30.38	99.0388	3.26
J-381	0.49	32.13	47.8737	1.49
J-277	0.53	32.2	49.266	1.53
J-133	1.02	32.76	66.1752	2.02
J-167	0.17	32.8	38.376	1.17
J-274	0.61	33.78	54.3858	1.61
J-241	0.52	33.92	51.5584	1.52
J-139	0.46	34.3	50.078	1.46
J-166	0.66	34.79	57.7514	1.66
J-269	0.39	35.17	48.8863	1.39
J-300	1.69	35.31	94.9839	2.69
J-173	0.31	35.34	46.2954	1.31
J-184	0.26	35.41	44.6166	1.26
J-141	0.54	35.65	54.901	1.54
J-244	0.01	35.83	36.1883	1.01

J-243	0.03	35.85	36.9255	1.03
J-242	0.03	35.87	36.9461	1.03
J-276	0.58	35.96	56.8168	1.58
J-174	0.19	36.35	43.2565	1.19
J-153	0.01	37.39	37.7639	1.01
J-170	0.16	38	44.08	1.16
J-185	1.1	38.24	80.304	2.1
J-51	0.16	38.54	44.7064	1.16
J-137	0.7	38.73	65.841	1.7
J-169	0.07	38.99	41.7193	1.07
J-181	0.83	39.29	71.9007	1.83
J-182	0.24	39.29	48.7196	1.24
J-175	0.19	39.42	46.9098	1.19
J-152	0.05	39.42	41.391	1.05
J-164	0.09	39.74	43.3166	1.09
J-168	0.05	39.78	41.769	1.05
J-142	0.22	39.86	48.6292	1.22
J-160	0.05	39.94	41.937	1.05
J-161	0.06	39.94	42.3364	1.06
J-162	0.05	40.15	42.1575	1.05
J-195	0.5	40.41	60.615	1.5
J-143	0.45	40.88	59.276	1.45
J-154	0.32	41.15	54.318	1.32
J-258	1.29	41.17	94.2793	2.29
J-257	0.81	41.18	74.5358	1.81
J-196	0.09	41.41	45.1369	1.09
J-131	0.77	41.66	73.7382	1.77
J-155	0.11	42.06	46.6866	1.11
J-21	0.47	42.11	61.9017	1.47
J-39	0.3	42.57	55.341	1.3
J-177	0.38	43.37	59.8506	1.38
J-135	0.24	43.62	54.0888	1.24
J-110	0.17	44.15	51.6555	1.17
J-109	0.35	44.21	59.6835	1.35
J-180	0.26	44.29	55.8054	1.26
J-163	0.26	44.31	55.8306	1.26
J-192	0.45	44.39	64.3655	1.45
J-273	0.51	44.76	67.5876	1.51
J-278	0	44.96	44.96	1

J-40	0.18	45.56	53.7608	1.18
J-303	5.77	46.16	312.503	6.77
J-279	0.03	46.18	47.5654	1.03
J-194	0.42	46.43	65.9306	1.42
J-41	0.08	46.55	50.274	1.08
J-136	0.05	46.61	48.9405	1.05
J-250	1.04	47.09	96.0636	2.04
J-265	0.2	47.11	56.532	1.2
J-380	1.69	47.2	126.968	2.69
J-117	0.88	47.22	88.7736	1.88
J-52	0.07	47.54	50.8678	1.07
J-138	0.09	47.67	51.9603	1.09
J-251	1.25	48.08	108.18	2.25
J-261	1.44	48.11	117.388	2.44
J-245	1.57	48.35	124.26	2.57
J-38	0.09	48.56	52.9304	1.09
J-97	2.37	48.66	163.984	3.37
J-179	0.38	48.87	67.4406	1.38
J-102	0.18	48.96	57.7728	1.18
J-111	0.3	49.04	63.752	1.3
J-271	1.17	49.2	106.764	2.17
J-186	0.07	49.22	52.6654	1.07
J-187	0.04	49.22	51.1888	1.04
J-246	0.18	49.35	58.233	1.18
J-36	0.07	49.58	53.0506	1.07
J-31	0.15	50.05	57.5575	1.15
J-127	0.13	50.06	56.5678	1.13
J-128	2	50.16	150.48	3
J-191	0.16	50.22	58.2552	1.16
J-92	4.15	50.25	258.788	5.15
J-176	0.5	50.29	75.435	1.5
J-50	0.35	50.39	68.0265	1.35
J-197	0.1	50.45	55.495	1.1
J-125	0.45	50.58	73.341	1.45
J-101	0.63	50.69	82.6247	1.63
J-100	1.92	50.74	148.161	2.92
J-165	0.01	50.76	51.2676	1.01
J-302	5.7	51.05	342.035	6.7
J-34	0.07	51.61	55.2227	1.07

J-199	0.01	51.77	52.2877	1.01
J-198	0.1	51.78	56.958	1.1
J-355	0.26	51.88	65.3688	1.26
J-19	1.37	52.1	123.477	2.37
J-356	0.08	52.29	56.4732	1.08
J-275	0.83	52.4	95.892	1.83
J-203	0.33	52.49	69.8117	1.33
J-373	0.28	52.49	67.1872	1.28
J-49	0.08	52.52	56.7216	1.08
J-37	0.04	52.57	54.6728	1.04
J-33	0.1	52.77	58.047	1.1
J-188	0.14	53.21	60.6594	1.14
J-20	0.64	53.26	87.3464	1.64
J-263	1	53.3	106.6	2
J-200	0.1	53.44	58.784	1.1
J-42	0.07	53.55	57.2985	1.07
J-357	0.36	54.06	73.5216	1.36
J-268	0.87	54.14	101.242	1.87
J-55	0.11	54.36	60.3396	1.11
J-374	3.63	54.51	252.381	4.63
J-22	0.12	54.53	61.0736	1.12
J-264	0.62	54.54	88.3548	1.62
J-18	0.18	54.65	64.487	1.18
J-30	0.09	54.76	59.6884	1.09
J-32	0.13	55.09	62.2517	1.13
J-189	0.44	55.17	79.4448	1.44
J-23	0.12	55.21	61.8352	1.12
J-272	0.57	55.22	86.6954	1.57
J-178	0.76	55.23	97.2048	1.76
J-56	0.12	55.23	61.8576	1.12
J-260	0.54	55.35	85.239	1.54
J-259	0.73	55.35	95.7555	1.73
J-2	2.49	55.52	193.765	3.49
J-239	3.21	56.12	236.265	4.21
J-267	0.37	56.14	76.9118	1.37
J-57	0.13	56.18	63.4834	1.13
J-24	1.16	56.35	121.716	2.16
J-193	0.2	56.48	67.776	1.2
J-54	0.09	56.54	61.6286	1.09

J-26	0.14	56.7	64.638	1.14
J-266	1.1	57.15	120.015	2.1
J-151	0.38	57.16	78.8808	1.38
J-53	0.1	57.62	63.382	1.1
J-312	2.75	57.72	216.45	3.75
J-218	0.11	57.77	64.1247	1.11
J-360	1.06	57.9	119.274	2.06
J-130	0.71	58.11	99.3681	1.71
J-156	0.32	58.47	77.1804	1.32
J-202	0.27	58.5	74.295	1.27
J-43	0.12	58.53	65.5536	1.12
J-310	2.73	58.65	218.765	3.73
J-28	0.19	58.71	69.8649	1.19
J-129	0.21	59.19	71.6199	1.21
J-121	2.95	59.32	234.314	3.95
J-48	0.29	59.51	76.7679	1.29
J-190	0.45	59.62	86.449	1.45
J-96	0.18	59.75	70.505	1.18
J-98	0.59	60.31	95.8929	1.59
J-362	0.8	60.37	108.666	1.8
J-201	0.19	60.96	72.5424	1.19
J-383	2.32	61.16	203.051	3.32
J-371	0.13	61.3	69.269	1.13
J-150	0.04	61.33	63.7832	1.04
J-126	0.01	61.33	61.9433	1.01
J-204	0.08	61.34	66.2472	1.08
J-376	0.89	61.4	116.046	1.89
J-46	0.13	61.51	69.5063	1.13
J-249	1.68	61.61	165.115	2.68
J-87	2.39	61.65	208.994	3.39
J-285	1.46	62.06	152.668	2.46
J-225	0.37	62.1	85.077	1.37
J-84	0.8	62.12	111.816	1.8
J-294	0.56	62.15	96.954	1.56
J-93	1.55	62.23	158.687	2.55
J-27	0.75	62.24	108.92	1.75
J-149	0.37	62.39	85.4743	1.37
J-215	0.67	62.42	104.241	1.67
J-47	0.26	62.5	78.75	1.26

J-45	0.05	62.51	65.6355	1.05
J-44	0.04	62.51	65.0104	1.04
J-205	0.22	62.58	76.3476	1.22
J-238	0.91	62.62	119.604	1.91
J-29	0.26	62.63	78.9138	1.26
J-368	0.8	62.65	112.77	1.8
J-95	1.72	62.82	170.87	2.72
J-367	0.45	62.83	91.1035	1.45
J-217	0.07	63.08	67.4956	1.07
J-80	1.3	63.57	146.211	2.3
J-230	0.04	63.61	66.1544	1.04
J-363	0.57	63.85	100.245	1.57
J-221	4.83	63.93	372.712	5.83
J-216	0.02	64.01	65.2902	1.02
J-83	0.6	64.5	103.2	1.6
J-308	2.72	64.58	240.238	3.72
J-366	1.56	64.78	165.837	2.56
J-314	1.05	64.79	132.82	2.05
J-112	1.33	64.92	151.264	2.33
J-99	0.35	64.93	87.6555	1.35
J-315	1.84	64.97	184.515	2.84
J-63	0.12	65.11	72.9232	1.12
J-58	0.09	65.12	70.9808	1.09
J-62	0.11	65.14	72.3054	1.11
J-358	0.17	65.22	76.3074	1.17
J-108	0.14	65.45	74.613	1.14
J-284	1.42	65.57	158.679	2.42
J-82	0.23	66.03	81.2169	1.23
J-148	0	66.11	66.11	1
J-334	1.49	66.15	164.714	2.49
J-61	0.1	66.16	72.776	1.1
J-228	0.26	66.44	83.7144	1.26
J-226	0.04	66.47	69.1288	1.04
J-293	1.06	66.5	136.99	2.06
J-283	0.91	66.56	127.13	1.91
J-85	0.16	66.72	77.3952	1.16
J-107	2.22	66.73	214.871	3.22
J-359	0.3	66.82	86.866	1.3
J-335	1.03	67.03	136.071	2.03

J-64	0.26	67.11	84.5586	1.26
J-213	0.12	67.2	75.264	1.12
J-59	0.12	67.3	75.376	1.12
J-72	0.11	67.31	74.7141	1.11
J-227	0.18	67.46	79.6028	1.18
J-207	0.13	67.52	76.2976	1.13
J-223	0.08	67.59	72.9972	1.08
J-124	0.11	67.63	75.0693	1.11
J-247	0.28	67.66	86.6048	1.28
J-113	0.45	67.85	98.3825	1.45
J-280	5.78	67.99	460.972	6.78
J-73	0.09	68.06	74.1854	1.09
J-66	0.1	68.09	74.899	1.1
J-65	0.07	68.09	72.8563	1.07
J-212	0.06	68.21	72.3026	1.06
J-94	0.92	68.23	131.002	1.92
J-60	0.24	68.4	84.816	1.24
J-208	0.08	68.42	73.8936	1.08
J-103	2.87	68.5	265.095	3.87
J-220	0.59	68.94	109.615	1.59
J-289	1.34	68.96	161.366	2.34
J-219	0.56	69.01	107.656	1.56
J-105	0.64	69.02	113.193	1.64
J-248	0.47	69.06	101.518	1.47
J-67	0.14	69.06	78.7284	1.14
J-74	0.22	69.07	84.2654	1.22
J-292	0.16	69.07	80.1212	1.16
J-214	0.35	69.19	93.4065	1.35
J-211	0.09	69.25	75.4825	1.09
J-75	0.69	69.31	117.134	1.69
J-209	0.13	69.36	78.3768	1.13
J-333	0.87	69.59	130.133	1.87
J-365	0.61	69.62	112.088	1.61
J-369	0.88	69.69	131.017	1.88
J-332	1.66	69.76	185.562	2.66
J-104	1.9	69.94	202.826	2.9
J-106	0.36	70.05	95.268	1.36
J-210	0.12	70.29	78.7248	1.12
J-3	1.57	70.6	181.442	2.57

J-237	2.8	70.89	269.382	3.8
J-222	0.46	70.91	103.529	1.46
J-282	5.74	70.95	478.203	6.74
J-240	1.2	70.96	156.112	2.2
J-69	0.32	71.01	93.7332	1.32
J-71	0.25	71.33	89.1625	1.25
J-286	2.5	71.74	251.09	3.5
J-288	0.88	72.17	135.68	1.88
J-86	0.2	72.28	86.736	1.2
J-79	0.55	72.36	112.158	1.55
J-78	0.18	72.38	85.4084	1.18
J-1	0.67	72.48	121.042	1.67
J-4	0.97	72.76	143.337	1.97
J-233	0.74	72.86	126.776	1.74
J-379	1.15	72.9	156.735	2.15
J-236	0.11	72.9	80.919	1.11
J-231	0.13	72.9	82.377	1.13
J-229	4.62	73.32	412.058	5.62
J-290	0.26	73.32	92.3832	1.26
J-291	0.39	73.32	101.915	1.39
J-17	1.11	73.5	155.085	2.11
J-91	2.71	73.52	272.759	3.71
J-224	0.22	73.62	89.8164	1.22
J-16	0.25	73.73	92.1625	1.25
J-377	2.69	73.86	272.543	3.69
J-281	6.62	73.97	563.651	7.62
J-76	0.28	74.33	95.1424	1.28
J-11	2.63	74.36	269.927	3.63
J-7	0.98	74.47	147.451	1.98
J-235	0.64	74.89	122.82	1.64
J-232	0.31	75.04	98.3024	1.31
J-77	0.27	75.22	95.5294	1.27
J-70	0.81	75.35	136.384	1.81
J-68	0.22	75.97	92.6834	1.22
J-234	1.62	76.8	201.216	2.62
J-114	0.21	76.92	93.0732	1.21
J-88	1.39	76.94	183.887	2.39
J-89	5.81	77.45	527.435	6.81
J-116	1.74	78.59	215.337	2.74

J-90	5.74	79.41	535.223	6.74
J-287	5.13	79.74	488.806	6.13
J-115	0.71	80.63	137.877	1.71
J-316	1.05	86.14	176.587	2.05
J-340	2.34	89.04	297.394	3.34
J-347	1.96	90.52	267.939	2.96
J-341	0.09	91.24	99.4516	1.09
J-317	0.44	93.15	134.136	1.44
J-301	3.03	95.25	383.858	4.03
J-344	2.91	98.64	385.682	3.91
J-307	2.43	98.95	339.399	3.43
J-305	1.18	101.38	221.008	2.18
J-339	1.39	104.01	248.584	2.39
J-336	1.8	104.98	293.944	2.8
J-338	0.13	105.19	118.865	1.13
J-346	0.71	105.95	181.175	1.71
J-345	0.46	106.73	155.826	1.46
J-318	0.71	107.11	183.158	1.71
J-337	0.06	107.97	114.448	1.06
J-350	0.43	108.19	154.712	1.43
J-304	0.44	108.82	156.701	1.44
J-328	0.64	109.03	178.809	1.64
J-349	0.05	109.2	114.66	1.05
J-348	0.56	109.23	170.399	1.56
J-311	1.91	109.74	319.343	2.91
J-329	0.96	114.76	224.93	1.96
J-351	0.61	115.51	185.971	1.61
J-352	1.29	116.5	266.785	2.29
J-326	0.59	116.77	185.664	1.59
J-330	0.4	117.12	163.968	1.4
J-327	0.76	118.01	207.698	1.76
J-324	0.3	119.05	154.765	1.3
J-353	0.86	119.19	221.693	1.86
J-323	0.98	120.4	238.392	1.98
J-354	1.54	95.25	306.095	2.54
J-342	1.45	120.94	296.303	2.45
J-325	0.54	121.2	186.648	1.54
J-322	0.32	122.49	161.687	1.32
J-343	1.95	123.9	365.505	2.95

J-321	0.74	126.3	219.762	1.74
J-320	0.25	129.04	161.3	1.25
J-331	2.62	130.37	471.939	3.62
J-384	2.57	138.55	494.624	3.57
J-319	0.37	139.73	191.43	1.37
J-306	2.36	148.66	499.498	3.36
J-123	0.42	210.56	298.995	1.42
J-122	0.56	222.98	347.849	1.56
Summation			42954.7	686
		AOP	62.6	

Appendix 23 calculation of average operating pressure for Mojo

Label	Demand (L/s)	Pressure (m H2O)	pi*(1+di)	(1+di)
J-10	1.15	15.54	33.411	2.15
J-58	2.68	35.34	130.051	3.68
J-43	1.14	36.23	77.5322	2.14
J-57	0.51	40.1	60.551	1.51
J-59	2.06	40.17	122.92	3.06
J-63	0.4	42.71	59.794	1.4
J-13	0.53	42.72	65.3616	1.53
J-31	0.47	42.75	62.8425	1.47
J-80	0.42	43.03	61.1026	1.42
J-66	1.68	43.63	116.928	2.68
J-79	0.23	44.53	54.7719	1.23
J-49	1.41	45.39	109.39	2.41
J-30	0.29	46.33	59.7657	1.29
J-72	1.73	47.23	128.938	2.73
J-68	0.75	50.05	87.5875	1.75
J-96	0.11	51.41	57.0651	1.11
J-45	0.03	51.5	53.045	1.03
J-47	0.02	51.56	52.5912	1.02
J-23	0.05	51.61	54.1905	1.05
J-25	0.02	51.61	52.6422	1.02
J-48	0.02	51.62	52.6524	1.02
J-40	0.13	51.66	58.3758	1.13
J-50	0.03	51.67	53.2201	1.03
J-37	0.02	53.6	54.672	1.02
J-53	0.06	53.65	56.869	1.06
J-71	1.13	53.81	114.615	2.13
J-19	0.14	54.54	62.1756	1.14
J-26	0.13	54.54	61.6302	1.13
J-27	0.02	54.55	55.641	1.02
J-28	0.03	54.55	56.1865	1.03
J-29	0.01	54.56	55.1056	1.01
J-32	0.01	54.56	55.1056	1.01
J-34	0.01	54.56	55.1056	1.01
J-35	0.01	54.57	55.1157	1.01
J-36	0.01	54.57	55.1157	1.01
J-16	0.06	55.31	58.6286	1.06

J-38	0.74	55.32	96.2568	1.74
J-22	0.19	55.43	65.9617	1.19
J-17	0.03	55.51	57.1753	1.03
J-15	0.08	55.52	59.9616	1.08
J-24	0.05	55.53	58.3065	1.05
J-39	0.46	55.55	81.103	1.46
J-42	0.07	55.56	59.4492	1.07
J-44	0.07	55.56	59.4492	1.07
J-97	0.51	55.59	83.9409	1.51
J-18	0.02	55.72	56.8344	1.02
J-20	0.12	55.86	62.5632	1.12
J-21	0.14	56.52	64.4328	1.14
J-51	0.21	56.56	68.4376	1.21
J-52	0.02	56.56	57.6912	1.02
J-54	0.06	56.6	59.996	1.06
J-94	1.04	58.44	119.218	2.04
J-33	0.63	58.51	95.3713	1.63
J-83	1.06	58.6	120.716	2.06
J-74	0.19	60.84	72.3996	1.19
J-88	1.17	60.87	132.088	2.17
J-14	0.28	54	80.3328	1.28
J-12	0.11	62.87	69.7857	1.11
J-69	1.36	65.21	153.896	2.36
J-55	0.16	67.94	78.8104	1.16
J-87	0.47	68.18	100.225	1.47
J-56	0.77	68.26	120.82	1.77
J-100	1.77	94.6	190.548	2.77
J-84	0.77	68.97	122.077	1.77
J-5	1.07	69.1	143.037	2.07
J-1	1.87	69.31	198.92	2.87
J-3	0.21	69.96	84.6516	1.21
J-60	0.17	71.36	83.4912	1.17
J-61	0.19	71.56	85.1564	1.19
J-103	0.2	71.75	86.1	1.2
J-91	1.08	71.83	149.406	2.08
J-67	0.37	71.84	98.4208	1.37
J-73	0.38	71.98	99.3324	1.38
J-70	0.36	72.86	99.0896	1.36
J-65	0.53	65.7	111.568	1.53

J-46	0.14	72.93	83.1402	1.14
J-105	0.52	73.14	111.173	1.52
J-81	0.3	73.17	95.121	1.3
J-108	0.83	73.24	134.029	1.83
J-2	0.19	73.99	88.0481	1.19
J-4	0.38	73.99	102.106	1.38
J-78	0.37	74.44	101.983	1.37
J-101	0.84	74.83	137.687	1.84
J-6	0.07	75.14	80.3998	1.07
J-7	0.32	75.17	99.2244	1.32
J-113	0.74	75.56	131.474	1.74
J-8	0.16	75.58	87.6728	1.16
J-9	0.01	75.75	76.5075	1.01
J-82	0.56	76.37	119.137	1.56
J-62	0.11	77.19	85.6809	1.11
J-64	0.04	77.24	80.3296	1.04
J-41	0.13	77.4	87.462	1.13
J-85	0.23	77.48	95.3004	1.23
J-76	0.48	78.32	115.914	1.48
J-86	0.25	78.81	98.5125	1.25
J-109	0.26	79.11	99.6786	1.26
J-104	1.03	80.57	163.557	2.03
J-95	0.42	81.33	115.489	1.42
J-112	0.68	81.39	136.735	1.68
J-11	0.67	95.07	136.339	1.67
J-75	0.38	81.75	112.815	1.38
J-110	0.1	81.8	89.98	1.1
J-90	0.18	81.81	96.5358	1.18
J-89	0.17	81.93	95.8581	1.17
J-102	0.2	81.95	98.34	1.2
J-92	0.2	82.52	99.024	1.2
J-93	0.06	82.65	87.609	1.06
J-111	1	82.77	165.54	2
J-106	1.39	83.35	199.207	2.39
J-99	0.14	84.36	96.1704	1.14
J-107	0.91	85.45	163.21	1.91
J-98	0.73	86.31	149.316	1.73
J-77	1.03	91.32	185.38	2.03
J-114	0.85	95.07	175.88	1.85

J-118	0.28	95.87	122.714	1.28
J-119	0.53	96.29	147.324	1.53
J-115	0.24	96.36	119.486	1.24
J-116	0.45	97.34	141.143	1.45
J-120	0.19	98.5	117.215	1.19
J-122	0.08	98.86	106.769	1.08
J-123	0.02	98.86	100.837	1.02
J-121	0.35	98.94	133.569	1.35
J-124	0.39	99.04	137.666	1.39
J-117	0.91	99.87	190.752	1.91
J-125	0.04	102.49	106.59	1.04
J-126	0.24	102.69	127.336	1.24
J-127	0.96	105.05	205.898	1.96
J-129	1.4	129.68	311.232	2.4
J-128	1.51	166.46	417.815	2.51
Summation			13182.8	236.97
Average operating pressure			55.6307	