JIMMA UNIVERSITY, JIMMA INSTITUTES OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING,

HYDRAULIC ENGINEERING MASTER PROGRAM

ASSESSING WATER SUPPLY COVERAGE AND WATER LOSS IN DISTRIBUTION SYSTEM OF WELISO TOWN, SOUTH WEST SHOA ZONE, OROMIA REGION, ETHIOPIA

A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

BY NIGUSIE KEBEDE DEGEFU

October, 2016

Jimma, Ethiopia

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Declaration

I, the undersigned, declare that this thesis is my original work, and it has not been presented for a degree in this or any other university and that all sources of materials used for the thesis have been fully acknowledged.

Name: ____

Signature: _____________________________________

Name of the institution: _________________________

Date of submission: _____________________________

Abstract

Water is the most important element for human survival and for all public services. But, problems in providing satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Moreover, reduction of non-revenue water remains one of the major challenges facing many water utilities in Ethiopia in general and Weliso town water supply system in particular. The main objective of this study was assessing the water supply coverage of Weliso town and total water loss in the distribution system.

Surveys, key informant interviews, and observation were used to collect needed data for the study. A random sampling technique was utilized and software such as WaterCADV8i, GIS map9.3 and SPSS were used to analyse the data.

From the result of the analysis, it was observed that the average daily per capita water consumption of the town is 15.3l/p/d. Thus, nearly 76.5% of the entire town population is getting water less than the basic service level and the average in-house or yard connection of the town is 38%. The existing water supply was not meeting the water demand of the town. There was a supply gap about 56.6%. This was mainly due to water shortage at the source. Besides, the total annual volume of water loss of the town was increased from year to year (2010-2015) and loss at 2015 was 18.2% of total water production.

The main causes of water loss were leakage and the under-capacity of operation and maintenance due to large area coverage to maintain on time. Aged pipe, late reporting for leakage, late respond for maintenance, pressure and defective meters were also other causes.

To improve the water supply coverage, to reduce water loss from the distribution system and to meet the water demand of the town the recommended actions are: constructing of additional borehole, rehabilitation and replacement of aged pipes, operation and maintenance strategy, implementing active leakage control method, continuous meter repair and replacement, using proper sized pipes during the implementation of projects.

Key words: *Water Consumption: Water loss: Water production: Water supply coverage:*

Acknowledgement

First of all, I would like to thank the almighty GOD for His mercy and grace upon me during all my works and in all my life for his countless gifts. I would like to express my sincere gratitude to Ministry of Water, Irrigation and Electricity for the academic admission to attend this Master Program in the University. I would like to express my wholehearted gratitude to my advisors Dr.Ing. Tamene Adugna (PhD) and my co advisor Keneni Elias (PhD candidate) for their support in supervising my thesis work, providing me with important references, constructive comments and encouragements since early age of the thesis work. I would like to thank also Weliso Town Water Supply and Sewerage Enterprise experts and Oromia Water Resource office for providing me the necessary data. Lastly, I would like to thank my beloved wife Yenenesh Endale and all friends for their unlimited support and encouragement.

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List of abbreviations

ADB	African Development Bank
ALC	Active Leakage Control
AWWA	American Water Works Association
C^0	Degree Cellecious
CSA	Central Statistics Agency
EC	Ethiopian Calendar
GC	Gregorian calendar
GIS	Geographic Information System
GPS	Global positioning system
IWA	International Water Association
JiT	Jimma Institute of Technology
km	Kilometre
m.a.s.l	meters above sea level
mm	millimeter
MNF	Minimum Night Flow
MoWR	Ministry of Water Resource
NRW	Non-Revenue Water
PLC	Passive Leakage Control
SPSS	Statistical Program for Social Science
UFW	Unaccounted For Water

UN-HABITAT	United Nations Centre for Human Settlements
WB	World Bank
WHO	World Health Organization
WWSSE	Weliso Water Supply and Sewerage Enterprise

CHAPTER ONE

1. Introduction

1.1. Background

Water is the lifeblood of the world and is considered as a national resource of utmost importance. Next to oxygen, water is the most important element for human survival. Provision of adequate and safe water supply was one of the basic urban services, which highly influence economic progress of the city and the health of the people. The water resource availability was linked to economic and social progress, which suggests that the development was strongly influenced by water resource availability and management (Sullivan, 2002). Problems in provision of satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Water supply systems in urban areas are often unable to meet existing demands and are not available to everyone rather some consumers take disproportionate amounts of water and the poor is the first victim to the problem (Bereket, 2006).

The percentage of population with or without piped water connection is a relevant indicator to compare the coverage of water supply in urban areas. According to the Global Water Supply and Sanitation Assessment 2000 Report, the African largest cities are having 43% house connection or yard tap, 21 % served by public tap while 31% of the population are un-served (WHO, 2000). Moreover, managing and reducing losses of water at all levels of a distribution system remains one of the major challenges facing many water utilities in most developing countries including Ethiopia. As a result of the overall shortage of water many water utilities are facing a problem in distributing the available water impartially among the residents. Beside this, poor management of the existing infrastructural asset increases the level of water losses in water supply (Mebet, 2007). A recent study made by the African Development Bank (ADB, 2006) concluded that the average level of water loss was 30% of the water produced, with wide variations among individual suppliers ranging from 4 to 65%. The World Bank (WB, 2005) study also found that more than 900 utilities in 44 developing countries around the world have approximately 35% in water loss level. The actual figure for overall water loss levels in the developing countries was more in the range of 40-50% of the water produced.

Besides too low coverage, water losses (physical loss) in urban water supply were accounted to more than 50% (Shimeles, 2011).

There are many reasons for minimizing losses in municipal water distribution networks, perhaps the most important one relates to quality of service. Additional, during drought periods, system with a high losses index cannot be properly manage and may demand frequency service interruption. Reducing water losses volume has the advantage of diminishing costly expansion of the system through hydraulic works. Water loss was also costly in terms of energy losses and causes high environmental cost. In fact, a lot of time was required in order to detect the loss of water in a wide water supply distribution networks and large amount of water goes waste. Non-revenue water (NRW) in a water distribution networks was determined by deduction of meter and authorize un-metered consumptions from total inflow. Non-revenue water was divided into apparent losses and real losses. Apparent losses: losses were produced by metering, human and management errors, and lead to consumption of water without charging. Real losses: real losses include wastewater and could be categorized to pipe system leakage (report and unreported bursts and background losses), reservoir leakage and over flow and finally leakage from valves and pumps.

Losses from a water distribution network can be determined by adopting several approaches. By using a field studies concept of yearly balance and minimum night flow (MNF) assessment, possibly in combination with “burst and background losses estimation”, the total value of leakage in water supply networks (at district meter area, DMA, level)can be evaluated and it’s was component determined (Tabesh et al., 2008)

A more rigorous and refine approach, applicable to the distribution of water losses in the entire network, was to use the earlier approaches (water balance and minimum night flow). WaterCADV8i is an extremely efficient tool for laying out a water distribution networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. It was easy to prepare a schematic or scaled model and let WaterCADV8i takes care of the link-node connectivity. In construction a distribution networks for this study, you do not need to be concerned with assigning labels to nodes, because WaterCADV8i would assign labels automatically. When creating a schematic drawing, pipe lengths are entered manually. In a scaled drawing, pipe length automatically calculated from the position of the pipes' bends, start, and stop nodes on the drawing pane.

The reduction and control of water loss has become even more vital in this age of increasing demand and changing weather patterns that brought droughts to a considerable number of locations in the world. Many water utilities have been developing new strategies to reduce losses to an economic and acceptable level in order to preserve valuable water resources.

In Weliso town, the component of water demand were residential, commercial, industrial, institutional or public water uses and unaccounted system losses and leakages. While all components generate revenue to the utility, the unaccounted system loss and leakages were not associated with total cost revenues, and were a source of wasted production costs. With high today's water production costs and rates, the expense of detecting and mitigating the unaccounted water and leakage was an attractive option for reducing waste.

The water utility benefits by:-

- Saving the production costs of the water
- Increasing revenues through the sales of water saved
- Deferring the system expansion and capital expenditures through the capture of lost water
- Reducing increases in utility rates, and thus maintaining better consumer relations

The annual volume of water loss was an important indicator of water distribution system, both individual years and as trend over a period of years. High and increasing water losses were an indicator of ineffective planning and construction, and low operational maintenance activities.

The main objective of this study was assessing the water supply coverage of Weliso town and total water loss in the distribution system.

1.2. Statement of the problem

Sufficient potable water supply is one of the basic urban services, which highly affects the economic progress of towns and the health of their people. Problems in provision of satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Water supply systems in urban areas are often unable to meet existing demands and are not available to everyone (Bereket, 2006). Moreover, managing and reducing losses of water at all levels of a distribution system remains one of the major challenges facing many water utilities in most developing countries including Ethiopia. As a result of the overall shortage of water many water utilities are facing a problem in distributing the available water impartially among the residents. Besides, the poor management of the existing infrastructural asset increases the level of water losses in water supply (Mebet, 2007).

Water losses from a utilities distribution system was a growing management problem that was not only confined to losses in revenue. Water losses in the distribution system require more water to be treated, which require additional energy and chemical usage, resulting in wastage of resources and losses of revenue.

Weliso town is one of the towns that have been getting potable water supply system since 1991. The rapid increase in population, economic development and awareness of health benefits of improved water and sanitation have to cause rise in water demand, necessity of improved system infrastructure management and strategies to deliver clean and safe drinking water to customers. Even though distributing the available water and water loss from a utility's distribution system is a growing management problem in Ethiopia, there are few studies conducted on the existing water utilities in the country related to water loss and coverage. Although the Weliso town water utility distribution system components were built two decades ago and are currently in need of attention, issues related to the overall coverage of water supply and water loss from the utility are not investigated yet. Therefore, assessing the water supply coverage and water loss in distribution system of Weliso town is more urgent than ever.

1.3. Objective of the study

1.3.1. General objective

The main objective of this study was assessing the water supply coverage of Weliso town and total water loss in the distribution system.

1.3.2. Specific objectives

- To evaluate water supply coverage of Weliso town
- To assess water loss in distribution system of Weliso town
- To identify the causes of water losses in distribution system
- To assess water demand and distribution system of Weliso town

1.4. Research questions

In order to achieve the above mentioned research objectives and seek answers for the stated objectives the following major research questions were designed.

- What is the current status of water supply coverage of Weliso town?
- How much water is being lost from the distribution system?
- What are the possible causes and consequences of water losses?
- In what situation are the water demand and distribution system of Weliso town currently?

1.5. Significance of the study

This study is expected to increase the understanding and provide up to date information of the town water supply size and its undesirable impacts on the urban community due to shortage of water supply. It would also serve as a working document to decision makers in the water sector and the non-governmental organizations. Moreover, the findings would further serve as reference material for any further investigation in the area.

1.6. Scope of the study

The scope of the research was limited in space and subject. Spatially, the research was conducted on Weliso town. In subject matter, the study is limited to assess the water supply coverage and water loss in distribution system of Weliso town.

CHAPTER TWO

2. Literature review

2.1. General

Adequate potable water supply is one of the basic urban services, which highly affects the economic progress of towns and the health of their people (Assefa, 2006). However, Problems in providing satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Water supply systems in urban areas are often unable to meet existing demands and are not available to everyone rather some consumers take disproportionate amounts of water and the poor is the first victim to the problem (Bereket, 2006). The developing cities have great difficulty both financial and technical to develop and expand water supply projects and one of the difficulties among the others is managing and reducing losses of water at all levels of a distribution system. As a result of the overall shortage of water many cities are faced a problem in distributing the available water impartially among the residents. Beside to this poor management of the existing infrastructural asset increases the level of water losses in water supply (Mebet, 2007). As this research was aimed to deal with over all coverage of water supply and water losses in distribution systems, issues related to water coverage and loss, identifying causes of losses was reviewed in this chapter.

2.2. Urban Water Demand and Supply Coverage

2.2.1. Urban Water Supply Coverage

Water supply coverage provides a picture of the water supply situation of one specific country or city and helps to compare one country with others and the inter and intra city distribution with in specific country. The percentage of population with or without piped water connection is a relevant indicator to compare the coverage of water supply in urban areas. Although the water supply coverage is better in urban areas compared with the rural, the actual water supply coverage in cities of developing countries in general and African cities in particular is very low while demand is very high.

According to the Global Water Supply and Sanitation Assessment 2000 Report, the African largest cities are having 43% house connection or yard tap, 21 % served by public tap while 31% of the population are un-served (WHO, 2000).

A household is considered to have access to improved drinking water if it has sufficient amount of water (20liters/person/day) for family use, at an affordable price (less than 10% of the total household income), available to household members without being subject to extreme effort (less than one hour) a day for the minimum sufficient quantity), especially to women and children) (UN-Habitat, 2003).

On the other hand a minimum quantity of 25 litres of potable water per person per day provided at a minimum flow rate of not less than 10 litres per minute with the source being available within 200 meters from a household and the supply not interrupted for more than seven days per year (i.e. water should be available 98%of time) is considered as a basic service for southern African cities' domestic water supply (Wallingford HR., 2003).

2.2.2. Classification of water consumption

Water consumption is divided in two major consumption categories, i.e.

- Domestic water consumption and
- Non domestic consumption

2.2.2.1. Domestic Water Consumption

Domestic water consumption is the amount of water needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes.

2.2.2.2. Non-Domestic Water consumption

Non-domestic water consumption includes major categories of:

- Institutional water consumption,
- Commercial water consumption,
- Animal consumption,
- Industrial water consumption,
- Fire fighting consumption

2.3. Water Demand Management

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Wallingford HR., 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use.

Water demand management refers to any socially beneficial action that reduces average or peak water withdrawals or consumption form either surface or ground water, consistent with the protection or enhancement of water quality (Tate, 2000). According to Rothert and Macy (2000), water demand management is the adaptation and implementation of a strategy by a water institution to influence the water demand and usage in order to meet any of the following objectives: economic efficiency, social development, social equity.

Urban water demand is classified in to different category that domestic water demand that includes in-house-use and out-of-house-use is among the others. In-house-use includes demands for drinking, cooking, sanitation, house cleaning, laundry and car washing while out-of-house-use includes like garden watering, swimming pools, public stand pipes for public uses and fountains, etc. Urban water demand is usually quoted in terms of litre per capita per day (l/cap/day).

Despite the variation in residential indoor water use from household to household, a typical pattern (referred to as the water use profile) can be developed to provide a reasonable representation of indoor water use, based on the different indoor water use components (kitchen, bathroom, laundry, and toilet) and household occupancy. (Mitchell et al., 2000).

In many African cities urban water demands are often non-homogeneous owing to a range of levels of service occurring within the same urban area. Levels of service can vary from household connections to standpipes or to no service at all (Wallingford HR., 2003). As an example, an overview of urban water supply for southern African largest cities is shown in table below.

Table 2-1 Overview of urban water supply for southern African largest cities

Country	Largest city	Population of largest city (million)	Water production for the largest cities (l/person/day)
Angola	Luanda	4.0	30
Botswana	Gaborone	0.13	286
Democratic Republic of Congo	Kinshasa	5.7	86
Lesotho	Maseru	0.27	81
Mauritius	Port Louis	0.15	200
Mozambique	Maputo	0.97	133
Namibia	Windhoek	0.27	-
Seychelles	Great Victoria	0.12	140
Swaziland	Mbabane	0.94	100
Tanzania	Dar Es Salaam	3.0	150
Zambia	Lusaka	1.21	225
Zimbabwe	Harare	2.38	156

2.4. Water loss in distribution system

The amount of water loss differs from country to country, city to city and even from network to another network in the same city, water loss is a problem experienced in all water distribution systems. The first and foremost cause of water loss is leakage. Leakage can be defined as unintentional or accidental loss of water from the pipe distribution network (Smith et al, 2000). Leaking pipes are a major concern for water utilities around the globe. One of the primary reasons for leakage in pipes is aged and deteriorated networks. The condition of existing old networks can only worsen and further increase water losses. In the globe alone, 50% of supplied water is lost as leakage in some of the older networks (Jowitt and Xu, 1990). Leakage rates are also related to length of pipes and number of connections. Improper connections can sometimes result in continuous escape of water from the distribution pipes. Water put to inappropriate or excessive uses may also be considered as loss. Water that is unaccounted for because of measurement errors, including inaccurate meters, forgotten users, and unmeasured uses, are also some of the causes for water losses.

2.5. Methods of measuring and comparing water losses

Unaccounted for water (UFW) is one of the commonly used methods for evaluating the water loss that is usually defined differently by different writers that some of the definitions indicated here under.

There is no universally applied or accepted definition of unaccounted-for water. In general, unaccounted-for water (UFW) is the difference between the water supplied to a distribution system and the water that leaves the system through its intended use (Richard G. et al., 2000).

UFW may be defined as percentage of the water produced from the raw water source which is not accounted for (MWAC, 1999).

UFW is defined as the difference between water delivered to the distribution system and water sold (Yepes, 1995).

The term Unaccounted-for Water (UFW) refers to an accumulated range of losses that will be experienced by a Water Utility when comparing the system demand of a hydraulic water network with the quantity of water that is acknowledged as consumed by the water consumers residing within the network (UNEP, 2000).

Although the above definitions seem to have differences, all have in common that they took the water produced and distributed to the system as an input and the water consumed or exported from the distribution system as an output.

From the local context, the UFW has been defined as the water loss calculated as the difference between the amount of treated water produced and supplied and the total amount of water billed and collected. The volume of water consumption due to the inaccuracy of the water meters as well as the lump sum payments made by the customers when their meters cannot be repaired are also taken in to account for the determination of the UFW (AAWSA, 1997).

On the other hand because of the widely varying interpretation of the term 'Unaccounted-for water' (UFW) worldwide, the IWA task forces do not recommend use of this terms. If the term UFW is used at all, it should be defined and calculated in the same way as (NRW) (Farley and Trow, 2003).

2.5.1. Measuring water losses

The unaccounted for water (UFW) expressed as percentage of the total consumption and the minimum night flow (MNF) per connection are the most commonly used methods of measuring losses. UFW is the measure of losses over a period as the difference between the amount of water put in to a system and the metered or estimated quantity of water taken by consumers, while MNF is an indicator of the probable rate of losses at a given time.

Night flow measured in moderately sized sectors (up to around 3000 service connections) are extremely useful for identifying the presence of existing unreported leaks and bursts, and the occurrence of new ones. However, continuous night flows can also be used for assessing annual average real losses (Farley and Trow, 2003).

Unaccounted for water is a useful indicator of probable losses, but it may overestimate them because supply meters tend to under-record consumption. In UK, figures for unaccounted for water tend to be unreliable because the un-metered consumptions have to be estimated and can be 10% in error. Attempts to compare the performance of different undertakings by measuring some uniform figure for domestic consumption can be misleading. Many factors influence unaccounted for water and differ from one undertaking to another, standards of housing, rates of occupancy, age of mains, length of mains per 1000 population served, proportion of trade and bulk supplies, ground condition, etc. (Twort et al., 1994).

The minimum night flow (MNF) per property connection is a better indicator of loss rates on part of a system. However, figures of this type are affected by the characteristics of an area; in dense urban areas there will be more blocks of flats with large storages which may fill at night. Nevertheless, the MNF is a good direct indicator of the state of parts of a system (Twort et al., 1994).

On the other hand, “Weimer referring to fully metered situations, considers that “the annual water balance can initially only be taken as a guide as the calculations are susceptible to errors, analyses show this uncertainty in the calculated annual losses to be +/- 46% (Lambert and Wallace, 1993).

Different countries use different methodologies to evaluate the losses like the U.K. leakage practitioners and planners consider leakage almost exclusively in terms of night flow rates, rather than as a calculation of annual losses as in West Germany. Each method has its respective merits. 'Annual losses' are used for retrospective assessment of overall performance and long-term demand forecasting. 'Night flows' are used by practitioners responsible for leakage control and prioritization of leakage control activities. Any conceptual model therefore needs to be able to link night flows with annual losses in a consistent manner (Lambert and Wallace, 1993).

Although percentage figures are rarely meaningful when comparing different organizations, they can be used to indicate the extent of reduction of water loss by a single water supplier (WHO, 2001).

2.5.2. Comparing water losses

The amount of water loss differs from country to country, city to city and even from network to another network with in one city. Different countries use different indicators to evaluate their status in comparison with others and to compare the distribution of water loss from one location to other location of a distribution system in order to take action based on the level of loss. As stated above comparison using UFW expressed as a percentage has limitation when used for comparison as it highly depends with the volume of the water produced.

The traditional performance indicators of water losses are frequently expressed as a percentage of input volume. However, this indicator fails to take account of any of the main local influences. Consequently it cannot be considered to be an appropriate performance indicator (PI) for comparisons (WHO, 2001).

Depending upon the consumption per service connection, the same volume of real losses/service connection/day, in percentage terms, is anything from 44% to 2.4%. Thus countries with relatively low consumption like the developing countries, can appear to have high losses when expressed in percentage terms; in contrast, percentage losses for urban areas in developed countries with high consumption can be equally misleading (Farley and Trow, 2003).

2.6. Common international terminology

To avoid for the wide diversity of formats and definitions related to water loss, many practitioners have identified an urgent need for a common international terminology that among them task forces from the international water association (IWA) recently produced a standard approach for water balance calculation with a definition of all terms involved as indicated below.

System input volume (A1): was defined as the amount of water that was produced and added to a distribution system by a public water system (PWS). It also includes water that may have been purchased from another water supplier to supplement the needs of the PWS. System input volume =authorized consumption + water losses

Metering the water supplied into the water distribution system was critical if a municipality wants to understand where water was used and lost in the system. The right size and appropriate calibration frequency of the system input meters monitoring the flow to the water distribution system would reduce unregistered water and meter inaccuracies.

Water losses (A2): the quantity of water loss is the difference between the total water supplied to the distribution system less the authorized consumption.

- Water losses = water produced – water billed or consumed (Farley, 2001)
- Water losses =Real losses +Apparent losses (Mathias, 2011)

Apparent losses (A3): losses that are produced due to water meter inaccuracies at customer building, accounting procedure error, and lead to consumption of water without charging and unauthorized consumption. Accounting procedure errors may occur due to overlapping billing cycles, misread meter, improper calculations, or computer programming errors. These types of losses were mistakes that could be identified and corrected. The entire billing procedure should be reviewed to make certain that issues are addressed. Apparent losses consist of unauthorized consumption, and all types of metering inaccuracies (Trow and Farley, 2006). Apparent losses include:

- Errors in sources, production and consumption (household) meters
- Theft and Illegal use
- Unmetered public use (council pars and garden)
- Fire fighting and Training
- Water used in processing (filter back-washing)
- Water used in infrastructure maintenance (pipe scouring and reservoir cleaning)

Real losses (A4): Real losses are the annual volume lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connection, up to the point of customer metering (Trow and Farley, 2006). Real losses were water that physically disappears from the distribution system through problems such as holes, cracks, and fissures in pipes, joints and fittings, reservoir overflows and leakage through reservoir floor and walls or through evaporation. This water does not disappear from the hydrological cycle obviously. It was water that the service provides has invested in which does not reach the customer. If real losses are reduced, more water would be available for distribution to customers at a much lower economic and environmental cost than augmentation of supplies. Real losses include:

- Background leakage in pipes, joints and fittings
- Reported and unreported burst in pipes
- Leakage and overflows from reservoirs

Authorized Consumption (A5): Authorized consumption is the annual volume of metered or non-metered water taken by registered customers, the water suppliers and others who implicitly are or explicitly authorized to do so (Trow and Farley, 2006). Authorized consumption includes:

- Residential properties
- Educational facilities
- Local government/ council operation
- Fire fighting
- Irrigation of public parks

Billed Metered Consumption (A6): is an authorized consumption that was directly measured. There were quantity of water metered and generates revenue through the periodic billing of the consumer.

Billed Un-metered Consumption (A7): is an authorized consumption that was based on an estimate or flat fee. This billing method was used for customers that do not have meters. Estimated use was often based on historical or average use data. The fee may vary for different types of customers such as residential or industrial.

Unbilled Authorized Consumption (A8): consists of known uses, condoned by the utility, for which no revenue was received. Unbilled authorized consumption could be either metered or un-metered.

Billed Authorized Consumption (A9): is that quantity of water that does not generate revenues, which is accounted and not lost from the system. Water used in the treatment process or water provided without charges are example of these quantities.

Revenue Water (A10): is water that is consumed and for which the utility receives payment. Revenue water consumption was measured or estimated. Revenue water includes metered and unmetered billed authorized consumption.

Non-Revenue Water (A11): water that is not billed and no payment were received. It could be authorized, unauthorized or measured result from water loss.

Unbilled Un-Metered Consumption (A12): is the quantity of water that was authorized for use by the PWS but is not directly measured and creates no revenues. Water main flushing and fire fighting were often example of this category.

Unbilled Metered Consumption (A13): is directly measured water use for which there was no change. This category can include water use at city government offices, street cleaning, or city park irrigation.

Unauthorized Consumption (A14): is that quantity of water that is removed from the system without authorized and presumably without the PWS's knowledge.

Table 2-2 Water Balance

<table>
<tr><td rowspan="9">System input volume (A1)</td><td rowspan="4">Authorized Consumption (A5 =A8+A9)</td><td rowspan="2">Billed Authorized consumption (A9 =A6+A7)</td><td>Billed Metered Consumption (A6)</td><td rowspan="2">Revenue Water (A10 =A6+A7)</td></tr>
<tr><td>Billed un-metered Consumption (A7)</td></tr>
<tr><td rowspan="2">Unbilled Authorized consumption (A8 =A12+A13)</td><td>Unbilled Metered Consumption (A13)</td><td rowspan="7">Non-Revenue water(NRW) (A11=A1-A10)</td></tr>
<tr><td>Unbilled Unmetered Consumption (A12)</td></tr>
<tr><td rowspan="5">Water losses (A2 =A1-A5)</td><td rowspan="2">Apparent losses (Commercial losses) (A3 =A13+A15)</td><td>Unauthorized Consumption (A14)</td></tr>
<tr><td>Customer Metering Inaccuracies and Data Handling Error (A15)</td></tr>
<tr><td rowspan="3">Real loss (Physical losses) (A4 =A2-A3)</td><td>Leakage in transmission and Distribution mains (16)</td></tr>
<tr><td>Storage leaks and Over flow from water storage tanks (17)</td></tr>
<tr><td>Service Connection leaks up to the Meter(18)</td></tr>
</table>

Source; (AWWA/IWA, 2012)

2.7. Causes of water losses

Water produced and delivered to the distribution system is intended to be sold to the customer, not to be lost from the distribution system without authorization. Not long ago, water companies sold water at a flat rate without metering. As water had become more valuable and metering technology had improved, more and more water system in the US meters their customers. Although all customers may be meter in a given utility, a sizable portion of the water most utilities produce does not pass through customer meters. Unmetered water includes unauthorized users, including losses from accounting errors, malfunctioning distribution system controls, thefts, inaccurate meters, or leaks.

Leakage is usually the major components of water loss in developing countries, but this was not always the case in developing or partially developed countries, where illegal connection, meter error, or an accounting error were often more significant (Farley and Trow, 2003). The other components of total water loss were non-physical losses, meter under registration, illegal connections, and unknown use (WHO, 2001).

2.7.1. Leakage in water distribution system

Leakage was usually the major components of water loss in developing countries. From one municipality to another and even from one location to another, the causes of leaks will vary depending on the nature of the soil, the quality of construction, the materials used, the pressure levels and the utilities operating and maintenance practice(AWWA, 1987).

Leakage is often a large source of unaccounted for water (UFW) and is a result of either lack of maintenance or failure to renew ageing systems. Leakage may also be caused for poor management of pressure zones, which result in pipe or pipe-join failure. Although some leakage may go unnoticed for a long time, detection of visible leakage also requires good reporting which also needs a strong public participation. Although leakages after water meter has its own contribution to the overall wastage of water, it is not considered as of the total unaccounted for water, as it would be paid for.

There were different types of leakage including service line leakage, illegal connection, meter error and valves leakage (Farley and Trow, 2003), but in most cases, the largest portion of unaccounted for water was loss through leaks in the mains. There were many possible causes of leaks and often a combination of factors leads to their occurrence. The material, composition, and age joining methods of the distribution system components could influence leaks occurrence. There were a whole range of factors that were, to varying degrees in space and time, responsible for water loss (Mathias, 2011).

2.7.2. Pressure and leakage

In many water network systems, even though the total demand and the total loss of water can be known rather easily, information about the possible influence of local pressure upon demand is sadly lacking that as a result creates difficulty to assess and compare the demand and loss of water in its spatial distribution. Pressure distribution system on the one hand contributes to the increase of leakage, when it is more, and on the other hand when it is low contributes to the shortage of water that as a result causes for unequal distribution of water among residents. To alleviate such problems, some water authorities develop a zoning scheme whereby the complete water distribution network is broken down in to manageable segments that can be easily metered and monitored and analysed. The leakage from water distribution systems has been shown to be directly proportional to the square root of the distribution system pressure (Wallingford HR., 2003).

Burst rates are also a function of pressure. The strength of the relationship, and the quantification of it, is not as well understood as the relationship between flow rate and pressure. However, there is still considerable evidence to show that burst frequency is very sensitive to pressure. Evidence shows that the rate of increase of bursts is more than linearly proportional to pressure. Indeed it has even been suggested that there could be a cubic relationship i.e. burst frequency proportional to pressure cubed (Farley and Trow, 2003).

Pressure variation in distribution network is caused, among others, by changes of demand of users. The demand usually reaches a peak in the morning when people are at home and preparing their meal and its second peak in the evening.

If one compares daily diagram for total demand of the whole system with corresponding data captured at the level of (relatively small) demand management areas one will discover that the first has much smaller amplitude in comparison with the later. The minimum night flow (MNF) is relatively higher and the morning/evening peaks are less prominent (Obradovie, 2000).

Frequent starts and stops of pumps, closure and openings of control valves that induce water hammer are also some of the causes to be mentioned for pipe breakage and water loss through leakage. The position of reservoirs also has a great impact on the pressure distribution.

Distribution Losses is the sum of losses from four different parts of the distribution system; trunk mains, service reservoirs, distribution mains and communication pipes. The combination of these assets in individual Companies and supply areas are widely variable, as are the variations of pressure which are known to significantly affect leakage (Lambert and Wallace, 1993).

The elevation at which it is desirable to position a service reservoir depends upon both the distance of the reservoir from the distribution area and the elevation of the highest buildings to be supplied. If the distribution area varies widely in elevation it may be necessary to use two or more service reservoirs at different levels, so that the lower areas do not receive an unduly high pressure. Generally, 45 to 75 meters static pressure is that which best suits the domestic distribution systems. Pressure below 45 meters will be likely to cause trouble in supplying extensive distribution areas; pressure above 90 meters, tend to result in excessive leakage losses (Twort et al., 1994).

The critical points which would first run dry if pressure is reduced are usually areas located at the highest elevation and excessive pressures can be reduced by adjusting the speed of pumps in areas supplied by pumping, installing a pressure reduction valves (PRV) and dividing the system in to different pressure zones.

Pressure control valves are sometimes installed in outlet mains from service reservoirs in order to reduce the pressure to low lying zones, or to limit increases of pressure at night to reduce leakage. Pressure reducing valves (PRVs) throttle automatically to prevent the downstream hydraulic grade from exceeding a set value, and are used in situations where high downstream pressures could cause damage (Walski et al., 2003).

2.7.3. Ages of Pipes and leakage

Although there are no scientifically based criteria for defining the useful life for water mains, there has been a growing concern that many older urban water distributions are deteriorating that as a result massive rehabilitation will be required to replace mains older than some predetermined number of years in age or “useful life”.

Pipe age and material are important factors contributing to the burst probability of pipes that as a result cause lots of water loss. However, as this information is mostly not available especially for aged pipes, it is usually estimated using the history of the urban development. Reports from undertakings collected by the WRC, and evidence from elsewhere suggest that leakage rates from mains are of the order of 100 to 200 l/hr. per km for newer mains and 150 to 300l/hr. per km for older mains. Assuming an average of 100 connections per km these figures would represent 1.0 to 3.0 l/hr. per connection (Twort et al., 1994).

Leakage is frequently the largest component of UFW and includes distribution losses from supply pipes, distribution and trunk mains, services up to the meter, and tanks. The amount of leakage varies from system to system, but there is a general correlation between the age of a system and the amount of UFW. Newer systems may have as little as 5% leakages, while older systems may have 40% leakage or higher (Walski et al., 2003).
Although age is considered as an indicator for predicting the break rate of mains, some studies have shown that it is not the major determinant factor for main water break rates. Poor design, deterioration of pipe material and unanticipated load condition will also result in pipe breakage.

2.7.4. Meter error and water loss

Under registration of customer meters is also one of the causes of water loss. Like the ages of pipes, ages of meters also has an impact to the increase of water loss. Customer meter errors include errors due to accounting procedure and errors due to under or over registration of the meters. Many countries especially developing countries are experienced losses of water due to under registration of meters that many of them put meter replacement policies to alleviate the problem.
The selection of customer meter types and classes may be limited by water quality considerations, as well as technical and economic considerations. Economic replacement policies for residential meters based on selective testing programs in the National Reports generally indicate changeover periods between 5 and 10 years. Where customers are served by way of roof tanks, the probability of customer meter under-registration is increased, because of the tendency for a greater part of the consumption to pass through the meter at rates less than the Q minimum specified for the meter (Lambert, 2003).
The cities of Africa appear to use meters for 78% of domestic consumption and the yearly meter replacement is about 8.8%. Considering that meters typically under read as they age, it is likely that considerable proportion of unaccounted for water is experienced by metering errors (WHO, 2000).
Domestic water meters tend to under register for two reasons, i) malfunctioning due to deterioration with use, and ii) inability to measure low flows accurately. Much larger under registration can occur where maintenance of meters is poor (Twort et al., 1994).

An under registering meters and any meter stoppage could be noted immediately if meter readers are alert to compare readings of one specific meter with its past readings, but in reality this situation doesn’t happen.

2.8. Consequences of water loss and Leakage

The primary consequence of leaks in a distribution system is financial. Reduction in water loss enables water utilities to use existing facilities efficiently, alleviate shortage of water supply, improving the supply capacity to consumers and the reduction of operational expenditures that are related to power and chemical costs. Reduction of water losses extends the service life of existing water supply components that as a result to meet the present as well as the future needs of residents without construction of many new water facilities. Beside to low revenue generation as a result of under-recording of faulty meters, or totally uncharged due to illegal connections and unregistered consumption, leakage also greatly contributes to loss of revenue. The operation and maintenance costs including price of energy, chemicals and other items that are constantly rising will also be aggravated by the increase of water loss due to leakage.

Beside to directly affected production and management costs, leaks have great consequence on the quality of services. The water that escapes from leaks may also cause a damage of structures such as sinking of roads and other properties. When the leak becomes more serious or a pipe bursts, service may be interrupted totally that many people will be severely affected.

2.9. Water loss management

Water encompasses a set of different values in different contexts (ecological, economical, and social). Water users depend upon a steady supply of enough hygienically safe water to be used for drinking, cooking washing. In urban areas, normally a water service provider has the responsibility to cater for these needs. Water loss management thus entails all the efforts a water service provider make in order to account for all the water that was being invested in it through production and distribution. The ultimate goal of this effort was to make sure that water losses were kept at a minimum. There would always be certain amount of leakage to varying degrees in any distribution system, but the key point was to try to get as much as possible of the water supplied to reach its intended users (Mathias, 2011). In order to make the water distribution system more efficient, utmost importance must be placed on water loss management. Independent of the type of method being used for performing a water audit, there would always be an uncertainty while calculating non-revenue water, apparent losses, and real losses.

There are four methods of managing real losses:

- Improve Maintenance, Replacement and Rehabilitation
- Pressure Management
- Improve response time for leak repairs
- Active Leakage Control

Putting a focus on these four management methods could reduce real losses, but at a given average system operating pressure, the total real losses cannot be economically reduced any further than the value of unavoidable real losses. There are four methods for managing apparent losses:

- Unauthorized consumption (theft and illegal use)
- Analysis errors between archived data and data for billing or water balance
- Meter accuracy error
- Transfer errors between meter reading and archived data

Depending upon the amount of attention given to each component apparent losses would increase or decrease. A primary purpose of the utility was to keep real and apparent losses at minimum to minimize use of water resources and maximize revenue.

2.9.1. Leakage management

Even if, operational improvements over the last 10-15 years, water utilities still lose a significant amount of potable water from their networks through leakage. The most effective way to combat leakage is on one hand to locate and physically repair bursts and on the other hand to introduce pressure control to reduce background leakage from connection and joints. Reduction of leakage has two positive impacts on the environment and it minimizes clean water losses and energy used for pumping and treatment of water (Hossam, 2011).

Water companies have tried many management strategies, which were general pipe rehabilitation, direct detection, and repair of existing leaks and operational pressure management. Direct detection and repair of existing bursts was one of the most powerful policies that were used to prevent the high-level leakage from bursts. Detecting and reducing burst was an attractive solution, and many algorithms have been developed to predict and detect the location and quantify the leakage in water distribution (Hossam, 2011).

2.9.2. Leakage monitoring and control

The losses of water are inevitable in the process of supplying thousands of customers spread over a large area started from reservoirs at the treatment plants, through a complex network to the individual customer.

Leakage monitoring and control in pipe reticulation systems is critical in ensuring the efficient performance of the system. Pipe systems are commonly used for distributing water to areas of consumption. If pipes are worn out, large volumes of treated water may be lost through leakage as a result of high pressures of flow. Leakage control is possibly one of the most difficult tasks for water engineers. Even in developed countries, about 15–20% of the distributed water is lost through pipe leakage. It is therefore important to ensure that leakage monitoring and control is given the attention it deserves by all water supply authorities and consumers (Mulwafu W. et al., 2003).

Water leak detection is a systematic method of locating visible and non-visible leaks in a distribution system through visual inspection; pipe locators and leak detection equipment (proactive leak detection); and Pressure control, etc. Depending on the type, leakage could be identified from the simplest of using visualization till using sophisticated equipment.

Identifying Leaks through Visual inspection: in this method only those leaks that become self-evident are located and repaired. A leak may be self-evident because water shows on the surface or may become so upon investigation following consumer complaints such as poor pressure or noise in the plumbing system (Wallingford HR., 2003).

2.9.2.1. Classification of leakage control

Leakage management could be classified into two groups including passive leakage control and active leakage control.

Passive leakage control (PLC) is reactive to report bursts or a drop in passive, usually report by customer or notes by the company’s own staff while carrying out duties other than leaks detection. This method could apply in areas with low cost supplies.

Active leakage control (ALC) is when customer deployed company staff to find leaks, which have no reports. The main ALC methods are regular survey and leakage monitoring.

Leakage monitoring is flow monitoring into zones to measure leakage and to prioritize leaks detection activities. This has now become one of the most cost effective activities for leakage management programs.

The most appropriate leakage control policy would mainly dictated by the characteristics of the networks and local condition, which may include financial constraints on equipment and other resources.

2.9.3. Pressure management

Operational pressure management was a cost-effective method for leakage reduction over entire DMAs, and for minimizing the risk of the further leaks by smoothing pressure variations. Many researchers have presented, developed, and implemented various methods and algorithms to optimize the operational pressure, and the results showed that, the leakage could be reduced by up to 60%. Hossam (2011) analysed the effect of employing pressure management techniques on the operating costs of water distribution systems, which increases the savings by a 20-55% (Girard and Stewart, 2007).

Water pressure has a substantial impact on water loss, as the higher the system pressure, the more water was lost through leaks. Typically, 1 percent reduction in pressure should reduce existing system leaks flow rates between 0.5 percent and 1.5 percent, depending upon pipe materials and type of leaks (Federation of Canadian Municipalities, 2003). In some countries, it was recognized for many years that effective management of pressure was the essential foundation for an effective leakage management strategy. The Spanish National Report considers pressure reduction to be 'the preventative measure par excellence'. Pressure management could thus be an immediate and cost-effective solution for decreasing real water losses in a distribution network, even at low initial pressure. However, leakage reduction was not the sole benefit. Pressure management also offers water conservation benefits because, some types of water consumption would decline due to reduce average zone pressure. A study by the IWA water loss task force found that pressure reduction result in a significant decrease in new pipe breaks and bursts (Thornton and Lambert, 2007). All of these positive effective of pressure management usually result in high water saving and thus have very short payback time. Pressure management was a relatively new enterprise in the world of water supply, being recognized in Japan and the UK more than 20 years ago, but not until recently seen as the essential foundation for an effective leakage management strategy in most utilities, both in the developed and developing world (Mathias, 2011). The rate of leakage in water supply networks was a function of the pressure applied by pumps or gravity head and there exists a physical relationship between leakage flow rate and pressure. This has now documented through numerous tests both in laboratories and in underground systems (Trow and Farley, 2006). There was also strong evidence that burst rates were functions of pressure as well (Thornton and Lambert, 2006). This evidence now available and the ever-improving reliability, with which technical and economical predictions could be made, were such that progressive water service providers could no longer afford to ignore investigating possibilities of pressure management in their systems and it was the foundation for effective leakage management (Thornton and Lambert, 2005). Some of the pressure management reports by different utilities include:

- Fewer emergency repairs, more planned work.
- Reduced inconvenience to customers extension of the life the distribution infrastructure.
- Reduction of new burst frequencies on distribution mains and service connection
- Reduction of flow rates of all leaks and bursts present in the system at any time.
- Reduction of new leaks on private pipes and overflows at storage tanks.
- Reduction of some components of consumption subject to direct mains pressure.
- Reduction in annual repair cost.

2.9.4. Water loss reduction practices

In order to ensure that the utilization is made of the assets and the water supply itself, it is essential that the water flows are measured within the supply network. The design of the water supply system and construction, management, operation and maintenance must be understood and optimized. This issue would vary for each unique water supply system.

There were a series of connected techniques, procedure, and methods to be applied to get a better managed.

A diagnostic approach, followed by the practical by implementation of achievable solutions could be applied to any water company, anywhere in the world, to develop water loss management strategy (Trow and Farley, 2006).

In order to control water losses:

- Water audit or water balance.
- Meter testing repair replacement, improving billing procedure.
- Leak detection and control program.
- Corrosion control.
- Pressure reduction.
- Public education program.
- Rehabilitation and Replacement program have to implement.

2.10. Activities to reduce water losses

Effective and pro-active infrastructure management could prevent most water losses. The following infrastructure management activities would help to reduce real losses:

- Distribution system operation and maintenance to prevent breakdowns in equipment and the associated leakage.
- Material and construction standards to assure quality of future infrastructure installation.
- Maintain prober inventory to repair all sizes of main breaks or leaks.
- GIS mapping of system components to order quickly find valves to isolates main breaks.
- Increased surveillance in areas with aging infrastructure or reported leaks.
- Periodically checking proper operation and control of pumps used to fill storage tanks.
- Leak detection surveys or studies and leak repair.
- Water main rehabilitation and replacement.
- Pressure management

The following activities would help reduce apparent water losses:

- Metering of all source inputs, water experts or sales and customer accounts (includes billed, authorized use and non-billed authorized)
- If not going to meter hydrants usage, accurately estimate and record the water used for fire fighting or flushing.
- Accounting and record keeping practice to improve reliable and accuracy of the water balance; more easily pinpoint areas with water losses (EPD, 2007).

2.11. Acceptable water loss

It is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost of water saved. AWWA leak detection and accountability committee (1996) recommended 10% as a benchmark for UFW.

Table 2-3 UFW levels and action needed

UFW level (%)	Action needed
<10%	Acceptable, Monitoring and Control
10-25%	Intermediate, could be reduced
>25%	Matter of concern, reduction

Source; (Sarjo, 2008).

In general, the literature review was focusing on the issues related to the water supply coverage and losses of water in a distribution system, causes of water losses, the consequence of water loss, methods of evaluating water loss, etc. The literatures were reviewed considering expected methods and approaches needed in the following analysis chapters. Although it was tried to assess relevant literatures, some additional inputs from literatures will be referred while discussing relevant issues in each analysis chapters.

CHAPTER THREE

3. Methods and materials

Depending on the research objectives and the research questions stated in the introduction chapter the method how the research was carried out and the materials used is discussed in this chapter. Data collection, data preparation and sampling methods are also discussed in this chapter.

3.1. Description of the study area

Weliso town is located in Oromia Regional State, South-West Shewa Zone, Weliso Wereda. The town is located at a distance of about 115 km away from Addis Ababa the capital city of Ethiopia. It is a capital town of South-West Shewa Zone and the town is divided into four kebeles namely, kebele 01, 02, 03 and 04. The total area of the town is 2225.25 hectare. According to population and housing census conducted by Central Statistical Agency (CSA, 2007), the total population of Weliso town projected to 2015 was 95273. The town is geographically located between a latitude of 8^0 16' to 9^0 56' North and at longitude of 37^0 5' to 38^0 46' East. The altitude of the town ranges between 1,900 and 2,150m.a.s.l. The mean maximum and minimum annual temperature of the area is 25.01^0C and 12.9^0C, respectively with mean annual temperature of 18.9^0 C, and its mean annual rainfall is 1309.4mm.

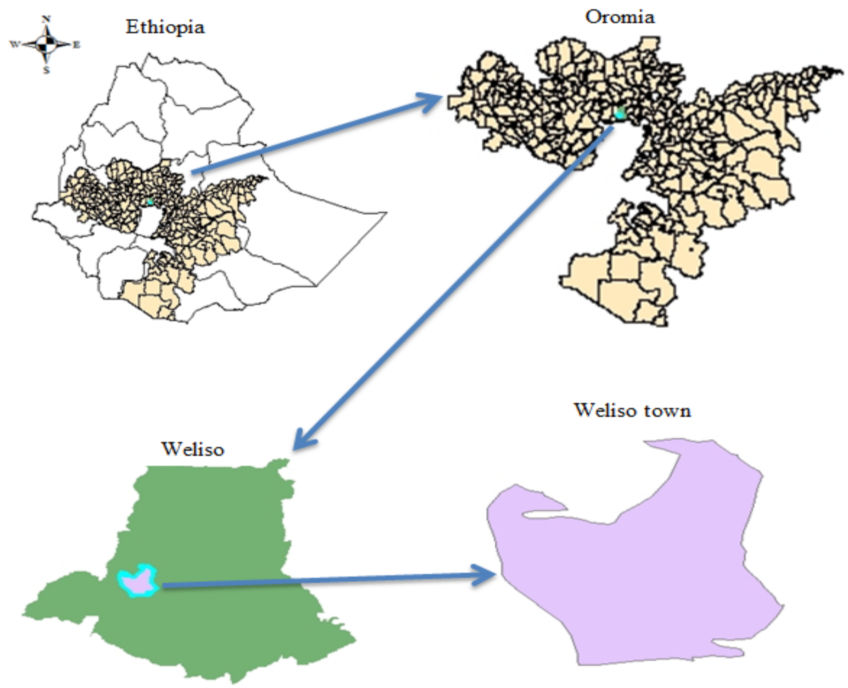

Figure 3-1 Study area

3.1.1. Existing water supply system

The existing improved water supply system of the town was first introduced in 1974 and further improved in 1991. The source of the water supply system was from Rebu River and ground Water through BH and it was designed to serve a population of 20,000 people. Currently, there are three reservoirs having a capacity 2*500m^3 and 80m^3. Both of the reservoirs that have a capacity of 500m^3 are ground level reservoir whereas the 80m^3 is elevated reservoir. These service reservoirs are used to supply the water to the most part of the distribution network, with no demarcation in supply zone. As per the information obtained from WWSSE, the water supply system distribution network is looped system with a pipe sizes ranging from 25mm to 200mm and pipe materials of DCI (Ductile Cast Iron), PVC (Polyvinyl Chloride) and GI (Galvanized Iron). The pipes were laid in different years starting from 1991 and are assumed to have a total pipe length of about 38kms.

3.2. Study design

To collect, generate and analyse relevant data on the existing water supply coverage and loss in distribution system observation and exploratory survey design were used in this study.

Observation: Site observations have been conducted and data on the causes of water loss on distribution system were collected. Information has been collected by four data collectors, by distributing questionnaires, and by making structural interviewing for local administrative, local communities and concerning sectors.

3.3. Data type

In this research both primary and secondary data were collected. The data type and the sources of the data used are listed below.

- Water production and consumption data from WWSSE.
- Survey and design data of the existing water supply distribution system from WWSSE and MoWR.
- Source of leakage data from field observation and respondents.

3.4. Population

The total number of population were considered in this research are population of existing water supply demanders and existing water distribution system.

3.5. Sample size and sampling Techniques

3.5.1. Sampling size

The sample size of households was 240 from residents of the town and 10 respondents from WWSSE were selected randomly, making a total of 250 respondents. As to the sample size determination, from among different methods, the one which has been developed by Carvalho 1984, as cited by Wonduante (2013), was used (see table below).

Table 3-1 Sample size determination

Population size	Sample size		
	Low	Medium	High
51-90	5	13	20
91-150	8	20	32
151-280	13	32	50
281-500	20	50	80
501-1200	32	80	125
1201-3200	50	125	200
3201-10000	80	200	315
10001-35000	125	315	500
35001-150000	200	500	800

Source; Carvalho 1984, Wonduante, (2013) Taking into account the resemblance of the town, resource and time limitation, a sample size of 250 which is in between the low and medium sample sizes was applied.

3.5.2. Sampling Techniques

Random sampling method was applied in order to select respondents from the residents and experts of WWSSE.

3.6. Study variable

Independent variables: more related with specific objectives. However, each specific objective was affecting one another.

- Joints of pipe
- Sizes of pipe

Dependent variable: those variables which have been observed and measured to determine the effect of the independent variables, which are directly, related to the general objectives.

- Per capita consumption
- Water losses

3.7. Data collection process

Data were collected through questionnaire, personal observation, structured interview, and reviewing of archived secondary data. The questionnaire was open-ended and close-ended. The interview type was structured.

3.7.1. Primary data collection

Primary data were collected from customers through household survey, face-to-face interview with local administrative (WWSSE) and field observations.

Questionnaire:

The questionnaire consists of two sections for community respondents (twelve questions) and for WWSSE experts (eleven questions) with various sub questions dealing with different issues related to water service such as water supply coverage, water losses, water supply service, and causes of water loss.

3.7.2. Secondary data collection

Secondary data were collected from reviewing of documents from archives of Weliso town Water Supply and Sewerage Enterprise, journals, reports, and internet.

3.8. Data processing and analysis

Arc GIS map 9.3 was used for delineating and locating the study area. To analyse the data collected a combination of quantitative and qualitative analysis methods were employed. Quantitative data which were generated from household survey, WWSSE archives were analysed using descriptive statistical tools like frequency and percentages and it was operated with Statistical Package for Social Studies (SPSS) and Micro Soft Excel. The survey data of the distribution system was evaluated using WaterCADV8i. The qualitative data were collected through the key informant interviews; Focus group discussion and field observation were used to triangulate the findings of the quantitative survey.

The water supply coverage of the town was first evaluated before analysing the water loss. In evaluating the water supply coverage the focus were on the volume of consumption and level of water connection as these are highly related to the issue of water loss. After evaluating the distribution of water supply coverage in the town, the water loss from the distribution system of the utility was analysed. The total water produced and the actual water consumption as aggregated from the individual contracts (customer meters) was used as an input for the water loss analysis.

3.8.1. Water supply coverage analysis

The water supply coverage of the town has been evaluated based on the average per capita consumption and level of connection per family. Statistical analysis was used to evaluate the supply coverage of the town.

Average daily per capital consumption:

The average per capita consumption has been derived from the yearly consumption of the town that has been aggregated from the individual customer water meters and total number of population.

$$\text{Per capital consumption (l/p/d)} = \frac{\text{Annual consumption } (m^3) \times 1000 l/m^3}{\text{Population number of the town} \times 365 \text{ days}}$$

Level of connection per family:

Beside to the average per capita water consumption, the distribution of number of connection per family has been also evaluated. It was derived from total number of connection in the town, total number of population and average family size.

$$\text{Connection per family} = \frac{\text{Total number of connection in the town}}{\text{Total number of population of the town } / \text{Average family size}}$$

Number of population as forecasted to the year 2015 has been used to evaluate the average per capita consumption.

3.8.2. Water loss analysis

The annual volume of water loss was an important indicator of water distribution system, both individual years and as trend over a period of years. High and increasing water losses were an indicator of ineffective planning and construction, and low operational maintenance activities.

To identify the total loss of water in the town, the total volume of water produced and supplied to the network distribution system was compared with the actual water consumption. The data on consumption were aggregated to town level from individual customer meters. The water production that was only found at town level was used.

$$\text{Total water loss}(\%) = \frac{\text{Total water production} - \text{Total water consumption}}{\text{Total water production}} \times 100$$

3.8.3. Water distribution system analysis

A water distribution system is a pipe network that delivers water from single or multiple supply sources to consumers. There is a general belief arising out of negligence on behalf of service providers, that water supply networks can be expanded indefinitely. Many water supply providers, in a drive to provide wide water supply coverage increase the number of customer connection through a massive network expansion. Because of rapid population growth and high water losses from the distribution network, the total water demand of the system in Weliso exceeds available production capacity.

The flow and pressure distributions across a network are affected by the arrangement and sizes of the pipes and the distribution of the demand flows. Since a change of diameter in one pipe length will affect the flow and pressure distribution everywhere, network simulation is not an explicit process. Pipe network simulation involves the determination of the pipe flows and pressure heads that satisfy the continuity and energy conservation equations. But, the objective of this analysis was to assess the pressure distribution on nodes and velocity within the pipes. According to this study, Hazen-Williams equation was used, which is commonly used in the design, modelling and analysis of water distribution systems because of its simple form.

Table 3-2 Pipe head loss formula for full flow

Formula	Resistance Coefficient (A)	Flow Exponent (B)
Hazen-Williams	$4.727\ C^{-1.852}\ d^{-4.871}\ L$	1.852
Darcy-Weisbach	$0.0252\ f(\varepsilon, d, q) d^{-5} L$	2
Chezy-Manning	$4.66\ n^{2}\ d^{-5.33}\ L$	2

C = Hazen-Williams roughness coefficient

ε = Darcy-Weisbach roughness coefficient (ft)

f = friction factor (dependent on ε, d, and q)

n = Manning roughness coefficient

d = pipe diameter (ft)

L = pipe length (ft)

q = flow rate (cfs)

According to this study, SI unit could be used

Source; (Rossman, 2000)

3.8.3.1. Initial setup

Throughout the process, International System Unit (SI) has been used. To request the use of these units in WaterCADV8i, the user chooses SI flow unit under the hydraulics option. In this study, it was selected litres per second for flow in this analysis, which also defines all other units using the SI system. Hence, lengths, pressure, head, elevations are taken in meters, and diameters of pipes are defined as millimetres. The network elements are:

- Reservoir
- Pump
- Tanks
- Pipes
- Nodes

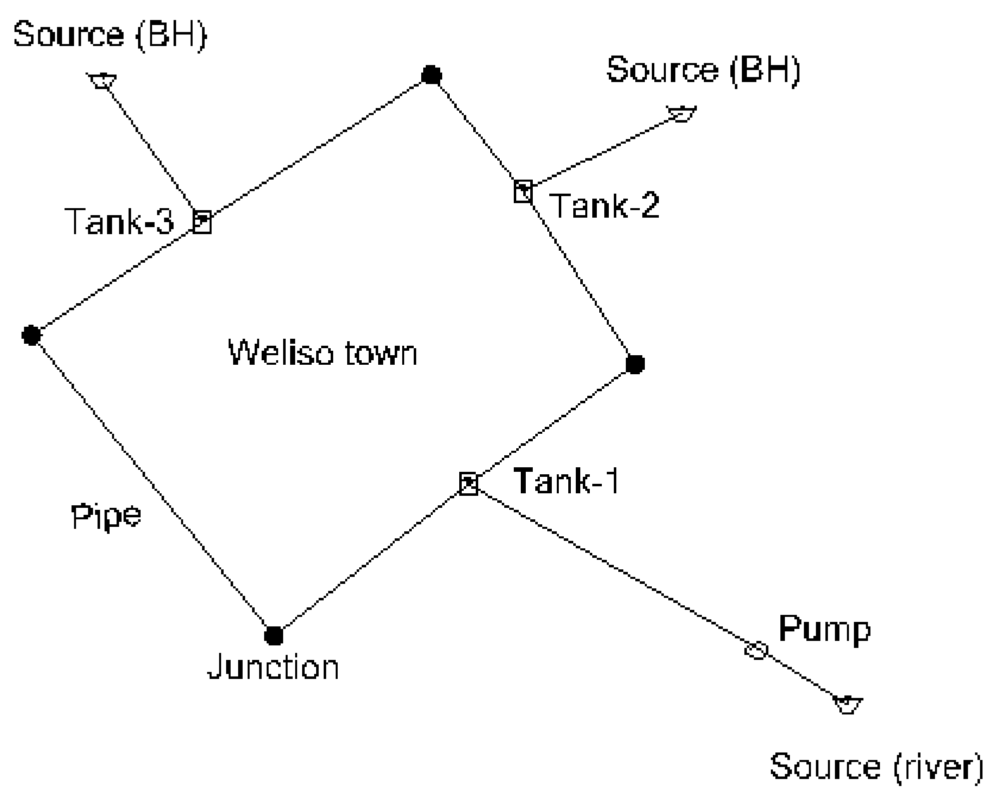

Figure 3-2 Node- link representation of water distribution network

3.8.3.2. WaterCADV8i

WaterCADV8i is a powerful, easy-to-use program that helps hydraulic engineers design and analyses water distribution systems. WaterCADV8i provides intuitive access to the tools you needed to model complex hydraulic situations. It can be used for many different kinds of applications in distribution system analysis.

WaterCADV8i can be analyse complex distribution systems under a variety of conditions for a typical WaterCADV8i project; if one may be interested in determining system pressure, velocity and flow rates under average loading conditions, head loss or under fire flow conditions.

- ❖ Perform steady state and water quality simulation
- ❖ Analyse multiple time variable demands at any junction node

The analysis of the network was carried out using the WaterCADV8i. WaterCADV8i views the water distribution system as a network containing nodes and links, where the nodes are connected by links. In this study, it was used to carry out the hydraulic analysis of the distribution networks in the study area. Data used for WaterCADV8i were:

For nodes/junctions

- ➢ X-Y coordinate
- ➢ Elevation
- ➢ Demand

For pipes

- ➢ Length
- ➢ Diameter
- ➢ Material type

Reservoir:

Reservoirs are a type of storage node. A storage node is a special type of node where a free water surface exists, and the hydraulic head is the elevation of the water surface above sea level. The water surface elevation of a reservoir does not change as water flows into or out of it during an extended period simulation.

Pipes:

Every pipe is connected to two nodes at its ends. In a pipe network system, pipes are the channels used to convey water from one location to another. The physical characteristics of a pipe include the length, inside diameter, roughness coefficient, and miner loss coefficient. The pipe roughness coefficient was associated with the pipe material and age. The miner loss coefficient is due to the fitting along the pipe. Pipe length and diameters are then inputted as well as roughness. A roughness of 150 was selected for the PVC pipes.

Nodes

Nodes are the locations where pipes are connected. Two types of nodes exist in a pipe networks system. All nodes should have their elevation specified above sea level. Nodes, besides representing the connection point between pipes, can represent the following components in a network:

- Points of water consumption (demand nodes)
- Points of water input (Source nodes)
- Location of Tanks or Reservoirs (Storage nodes)

3.9. Materials used

The following materials were used during the study.

- Arc GIS map 9.3
- WaterCADV8i
- SPSS Version 23
- Micro Soft Excel
- Digital camera
- Computer

3.10. Ethical considerations

The data were collected after approval had been given from Hydraulic Engineering Chair, JiT, Jimma University and Weliso town Water supply service office. Before collecting the data through interview and questionnaire, the purpose of the study were clearly described to the organization and to the concerning local communities. Then, data collection had been conducted after obtaining the full consent of the respondents.

3.11. Data quality assurance

To assure the quality of the data the following mechanisms were used:

- The researcher prepared a fieldwork manual to check every day progress.
- All the questions were put in simple and clear ways.

- The selected data collectors were trained to keep the objectives of the study and how to approach households.
- Data collectors were supervised by the researcher throughout the time of data collection.

CHAPTER FOUR

4. Results and discussions

4.1. Introduction

The objective of this study is assessing the water supply coverage and water loss in distribution system of Weliso town. This was in order to assess the water supply coverage, water loss, causes of water loss and water demand and distribution system of the town. This chapter presents the results and discussion of the water supply coverage and loss in distribution system of the town.

4.2. Water supply coverage

Water supply coverage of the town was evaluated using the amount of water consumed and the level of connection. For evaluating the amount of water consumption, the annual water consumption was converted to average daily per capita consumption using the population data of the town. The number of domestic connections per family has been also used for analysing the level of connection as elaborated below.

4.2.1. Average daily per capita consumption

The volume of water consumed for domestic purpose has been aggregated to town level from individual customer meters so as to analyse the water supply coverage. The annual consumption data has been converted to average daily per capita consumption using the number of population.

The average daily per capita consumption of the town for the year 2015 was found as 15.3l/p/d. According to WHO (2008), the minimum quantity of domestic water required in developing countries in urban areas was taken as 20 l/c/d within a radius of 0.5km. Domestic water supply is categorized as basic level of service, which is higher than the average domestic consumption of Weliso town. This result shows that the existing domestic water supply satisfies only 76.5% of the minimum quantity of domestic water required stated by WHO.

4.2.2. Level of connection per family

In order to evaluate the extent of water supply coverage level of water connection is an important element. The total numbers of connections or water meters with in the town for the year 2015 are about 9959 among these, 9403 are for domestic use. The total numbers of connections of the town are converted to connection per family using the population data of the town. According to population census, 2007, the average urban family size of Oromia region was indicated to be 3.8, and thus was used for calculating the average number of connection per family.

The level of connection per family of the town was found to be 0.38. This implies that one water tap is at an average serving more than two and half family (2.63 families) i.e. almost at an average of ten persons are sharing one connection or water tap. In other words the average in-house or yard connection is about 38%. The level of connection is also below the African cities' average of 43%.

4.3. Water loss analysis

Worldwide, water demand is increasing while the resources are diminishing. The reduction and control of water loss is becoming even more vital in this age of increasing demand and changing weather patterns that bring droughts to a considerable number of locations in the world. Many water utilities have been developing new strategies to reduce losses to an economic and acceptable level in order to preserve valuable water resources. In Weliso town, water is supplied by a municipal, Weliso town water and sewerage authority, and this is usually the best assurance of an uninterrupted supply of economical and safe water to our people in towns.

The components of water demand are Domestic like residential, Non Domestic like commercial, industrial, institutional and Fountains like public water uses, and unaccounted system losses and leakages. While all components generate revenue to the utility, the unaccounted system loss and leakages are not associated with total cost revenues, and are a source of wasted production costs. With today's high water production costs and rates, the expense of detecting and mitigating the unaccounted for water and leakages is an attractive option for minimizing operating expenditures. The water utility benefits by: saving the production costs of the water, increasing revenues through sales of water saved, deferring the system expansion and capital expenditures through the capture of lost water, and reducing increases in utility rates, and thus maintaining better consumer relations.

4.3.1. Annual water production, consumption and loss trend

The annual volume of water loss is an important indicator of water distribution system efficiency, both individual years and as a trend over a period of years. High and increasing water losses are an indicator of ineffective planning and construction, and of low operational and maintenance activities. The total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water loss for the town.

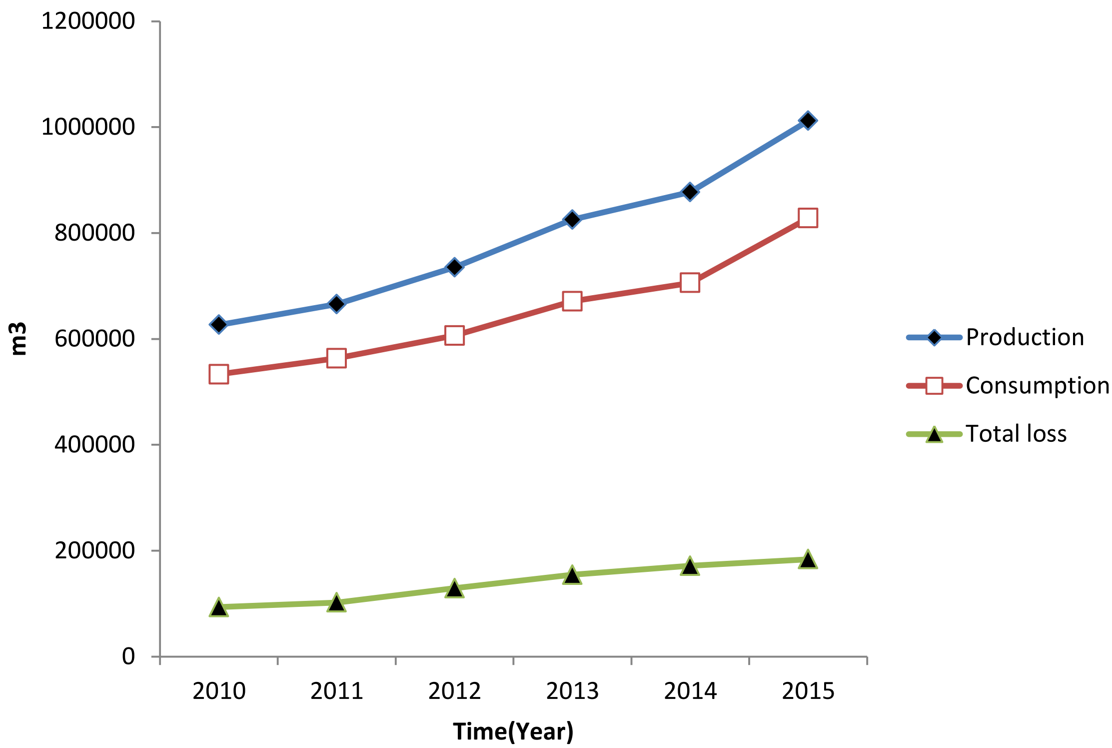

Figure 4-1 Annual water production, consumption and loss trend

4.3.2. Water loss by volume or percentage

The total annual volume of water loss of the town was increased from year to year(2010-2015).This high and increasing water losses were an indicator of ineffective planning and construction, and low operational maintenance activities.

At the end of the year 2015 the annual water produced and distributed to the system with in the specified year was 1011797 cubic meters and annual water consumed was 827972. The loss during this year was 183825 cubic meters which account to 18.2% of the total water production. When this loss was compared with the loss at 2010 it was increased by 97%

i.e. the loss at 2015 was twice of the loss at 2010. Taking the average tariff of water in the town as 5.80 Ethiopian birr, the water loss was estimated to be 1066185 Ethiopian birr.

It is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost of water saved. AWWA leak detection and accountability committee (1996) recommended 10% as a benchmark for UFW. Saroj (2008) gives classification and descriptions of UFW as acceptable, which could be monitored and controlled, when the loss is < 10%, as intermediate, which could be control when the loss is 10-25% and as a matter of concern that reduces the water supply when the loss is > 25%. According to this study, water loss in Weliso town was 18.2% in the year 2015, showing that the loss in the town was intermediate, according to the description given by Saroj (2008). Thus, the loss could be controlled and monitored.

The water loss trend of the town for the year 2010 to 2015 is shown in the figure below.

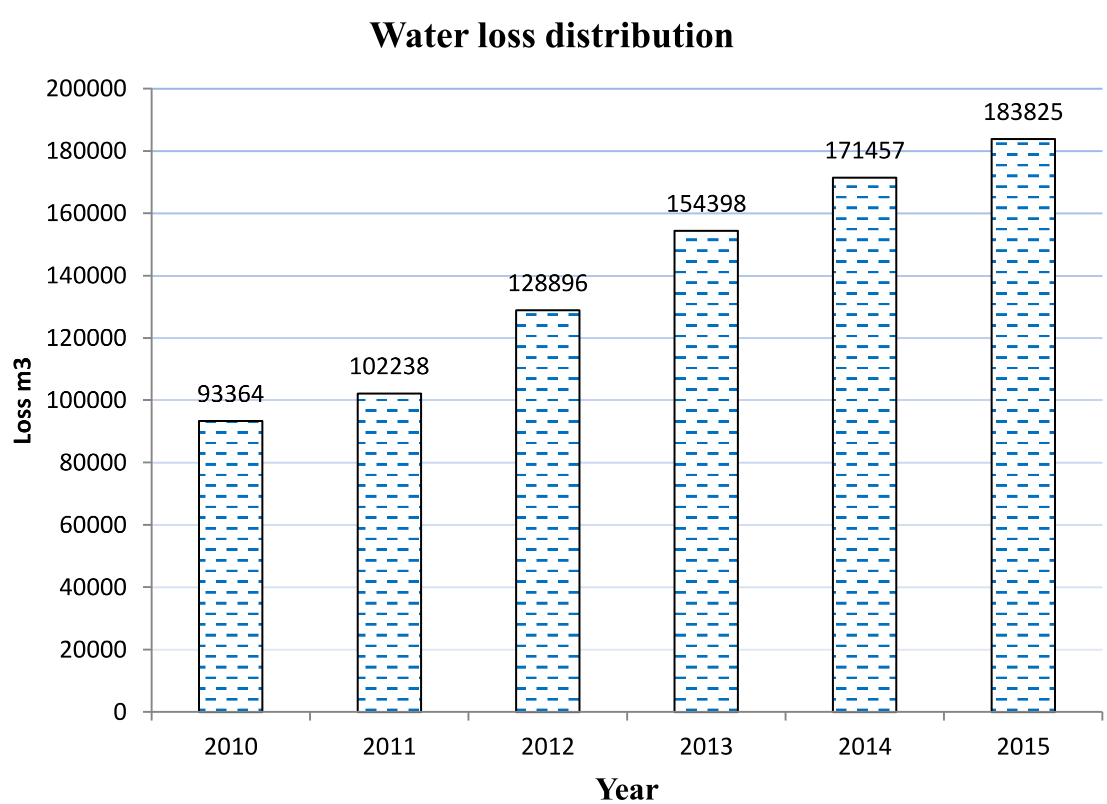

Figure 4-2 Water loss trend

4.3.3. Water loss per number of connection

Water loss expressed as a percentage could be an appropriate means to show the extent of the loss within a given environment, but it is not a good indicator for comparing the loss from one area to another. According to some literature comparison of water loss between different areas is recommended to be done using the water loss per service connection per day. Taking the total number of connection in the town as 9959 WWSSE, the water loss per connection for the year 2015 was derived as, Water loss = 50.57 litre/connection/day.

Water loss trend expressed as per number of connection of Weliso town was shown in the following table.

Table 4-1 trend of loss per connection

Year	Loss(m^3)	Number of connection	Loss per connection (Lit/connection/day)
2010	93364	5874	43.55
2011	102238	5838	47.98
2012	128896	7367	47.94
2013	154398	8099	52.23
2014	171457	9000	52.20
2015	183825	9959	50.57

4.4. Major causes of water losses in distribution system in Weliso town

There are different reasons for the high level of water loss in Weliso town. The major ones are mentioned in detail below.

4.4.1. Different constructions and aged pipe

To identify the causes of water loss a question was presented for respondents that say "have you ever encountered any leakage or loss in your connection?" 47.9% of the respondents answered that they faced a leakage whereas 52.1% said that they don't face leakages. For those respondents who faced a leakages question were extended and they were asked what the reasons were for the leakage. 40.8%, 33.1% and 26.1% responded that the leakages were due to: different construction (road, ditches), technical problems and aged pipes respectively.

Additionally, 70% of the respondents from WWSSE experts answered that aged pipes were the main cause of leakage. Most of the pipes are aged more than 25 years.

4.4.2. Late reporting for leakage

When leakage occurs in different part of the distribution system the way of reporting had a great contribution for loss of water from the system.

For the question in what way the respondents are reporting leakage, their answer was according to this proportion: 75.6% by going to the office, 12.2% by telephone and 12.2% when meter reader comes.

Those who report leakage when a meter reader comes may take 30 days or a month to do so. That means the leakage continuous for a month. In general, the method was passive leakage control way that was reactive to report bursts or a drop in passive and weak manner. Leakage is usually reported by customer or notes taken by the company's own staff while carrying out duties other than leaks detection.

4.4.3. Late respond for maintenance

According to the data obtained from response of respondents after reporting for leakage the respond for maintenance was summarized as below:

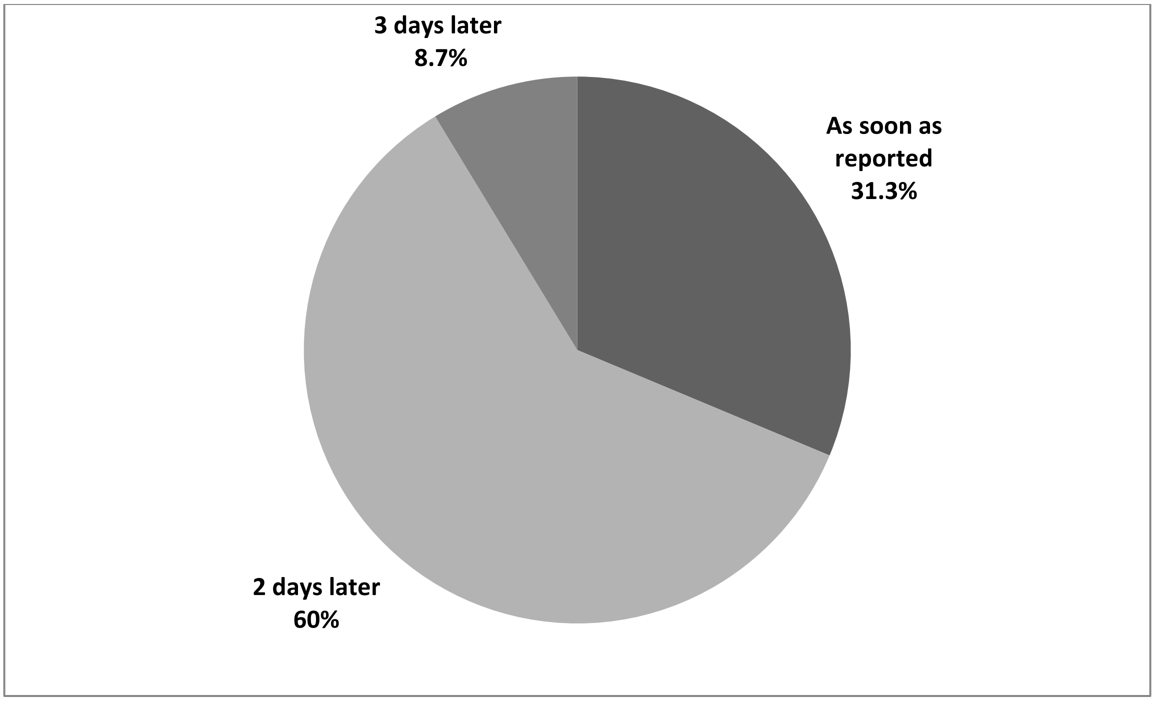

Figure 4-3 responses for maintenance

As observed from the pie chart 31.3%, 60% and 8.7% of the respondents responded that maintenance is undertaken as soon as reported, two days later and three days later respectively.

4.4.4. Quality of materials

According to sample respondents of WWSSE experts the newly installed materials was break frequently, and this was due to low quality of the material.

4.4.5. In proper alignment of pipe lines

Pipe lines crossing a road was frequently break and pipe line that aligned in shower house, near to toilet and animal farming areas were easily deteriorate and cause leakage.

4.4.6. Pressure

The pressure needed to supply water through the pipe network itself causes water loss in several ways through increased leakage because of increased pressure. increased burst frequency as a consequence of increased pressure; pressure cycling from frequent on/off switching by pumps of faulty pressure reducing valves can cause fatigue in plastic pipes. On the other hand, higher pressure will result in more water leaking from holes in the pipeline. All pipes have specific pressure within which they should serve; once the pressure is exceeded, the pipes naturally give way. This is worsened if the fittings were lower pressure rating as well. Excessive pressure should be avoided, if possible serve water under minimum acceptable residual pressures.

4.4.7. Defective meter

A question was presented for WWSSE experts that says how frequent do water meters become defective? 100% of the respondents responded that “most of the time”. As they pointed out, the cause of defectiveness of the meter was due to entering of silt, and reverse installation of meters were the major once. This was caused under registration of the meter.

Additionally, they were asked “how they monitor it and they responded” they do so when costumer reported and when meter readers observe the case. But, customer report was active when the meter was over reading rather than under reading.

With high today’s water production costs and rates, the expense of detecting and mitigating the unaccounted water and leakage is an attractive option for reducing waste. The water utility benefits by:-

- Saving the production costs of the water
- Increasing revenues through the sales of water saved
- Deferring the system expansion and capital expenditures through the capture of lost water
- Reducing increases in utility rates, and thus maintaining better consumer relations

4.5. Water demand and the distribution system

4.5.1. Water demand

Water demand is defined as the volume of water requested by users to satisfy their needs.

4.5.1.1. Supply gap

According to the data obtained from WWSSE archives the total average water demand that had been projected for the year 2015 at 2010 was 5530m^3/day, but the maximum production capacity of the service was 2400 m^3/day. This implies that about 3130 m^3/day gap was existed at the specified year. In other word the supply was only covering 43.4% of the demand.

Moreover, the existing water supply service was weather satisfying the water demand of the town or not the response from respondents was summarized as follows:

Table 4-2 Happiness at existing service

Are you happy at the existing water supply service of the town?			
	Frequency	Percent	Cumulative percent
Yes	89	37.1	37.1
No	151	62.9	100
Total	240	100	

From the above table 62.9% of the respondents were not happy with the existing water supply service. For the question raised what the reason was the response was presented in table below:

Table 4-3 Reason for unhappiness

What is the reason for your unhappiness on the existing service?			
	Frequency	Percent	Cumulative percent
It is Scarce	35	23.2	23.2
Unsafe	7	4.6	27.8
Interruption	108	71.6	99.4
Cost	1	0.6	100
Total	151	100	

From those (62.9%) respondents which are not happy with the existing water supply service; 71.6% of the respondents justified their unhappiness was due to service interruption whereas 23.2% of the respondents responded their unhappiness was due to it was scarce. Service interruption contributes high percentage for unhappiness on the existing service.

4.5.1.2. Distribution of water supply

As discussed at water supply coverage (4.2) the water supply coverage of the town in terms of per capita consumption and level of connection is very low. Areas having better level of connection are expected to consume more water as they can easily get it within their building or compound. A detailed demand study in Africa found that average water carried was about 22 l/d per capita over a long distance rising to about 30 l/d per capita where water was obtained from the consumer own stand pipe. Of course, distance is not a big problem in urban areas as compared to rural areas (ADB, 1993).

To analyse the distribution of water supply the question rose for respondents and their response was summarized in table below:

Table 4-4 Daily taped water access

Do you get daily taped water access for your domestic consumption?			
	Frequency	Percent	Cumulative percent
Yes	70	29.2	29.2
No	170	70.8	100
Total	240	100	

From the total respondents 29.2% got daily taped water while those 70.8% don’t get. For the question how often they get? In the case of those who haven’t daily taped water access their response is presented as below:

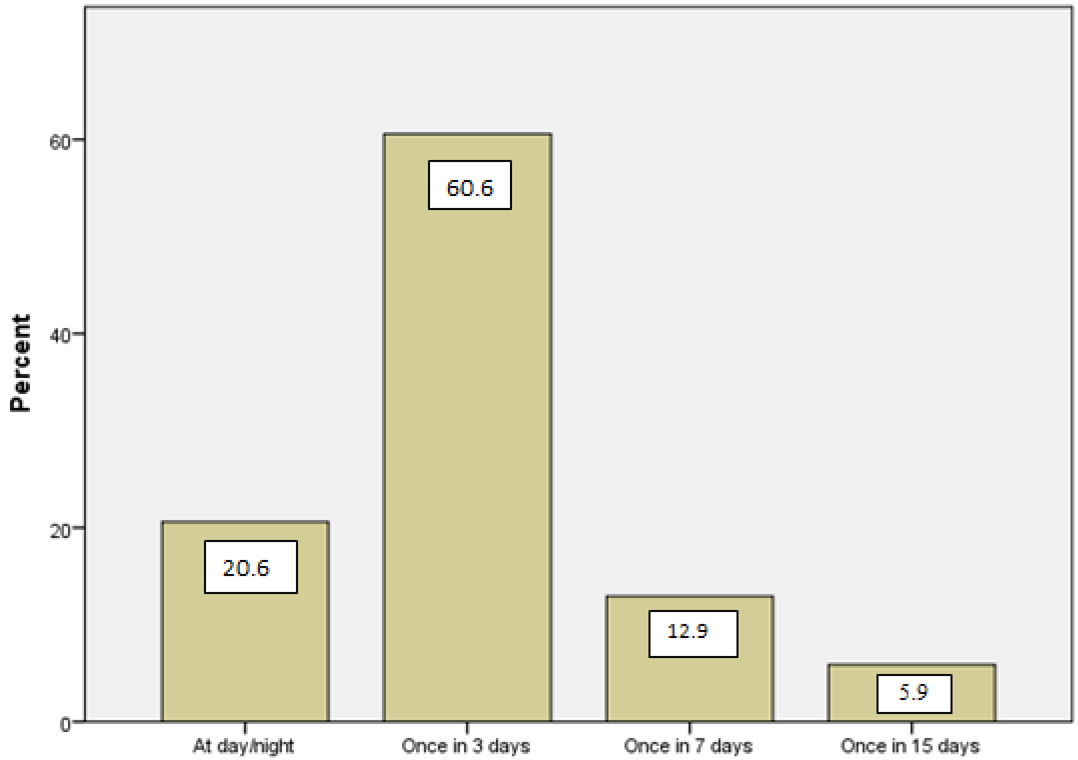

Figure 4-4 Taped water access

As observed from figure 6 above, 60.6% of the respondents get taped water supply once in three days, 20.6% at day or at night time, 12.9 once in seven days and the rest 5.9% once in fifteen days. Large percentage of the respondents get taped water access once in three days; this was mostly due to interruption. But for southern African cities' domestic water supply the supply not interrupted for more than seven days per year (i.e. water should be available 98%of time) is considered as a basic service. (Wallingford HR., 2003).

4.5.1.3. Pending connection

In other hand there were 2400 pending connections i.e. about 2400 applicants requested to have water tap but not yet served.

The existed supply gap, low distribution of water supply and pending connection shows the existing service was not satisfying the demand of the town. This was due to shortage of water.

In order to assess the cause of water shortage in the town a question was raised for WWSSE expert respondents that says what were the causes of water shortage in the town? All respondents (100%) responded that it is due to water shortage at the source.

4.5.2. Water distribution system

4.5.2.1. Water distribution system analysis of the town

Analysis of water distribution network provides the basis for the design of new systems, the extensions, and control of existing systems. The flow and pressure distributions across a network are affected by the arrangement and sizes of the pipes and the distribution of the demand flows. The objective of this analysis was to assess the pressure distribution on nodes and velocity within the pipes. Pressure distribution system on the one hand contributes to the increase of leakage, when it is more, and on the other hand when it is low contributes to the shortage of water that as a result causes for unequal distribution of water among residents. Also, the magnitude of the velocity has an impact on the pressure head as the velocity within the pipe increases beyond the design criteria it results high flow rate which causes head loss.

WaterCADV8i could show pressure, demand, and hydraulic grade in different nodes as well as flows, velocities, head-loss gradient and head-loss in different pipes throughout the distribution system.

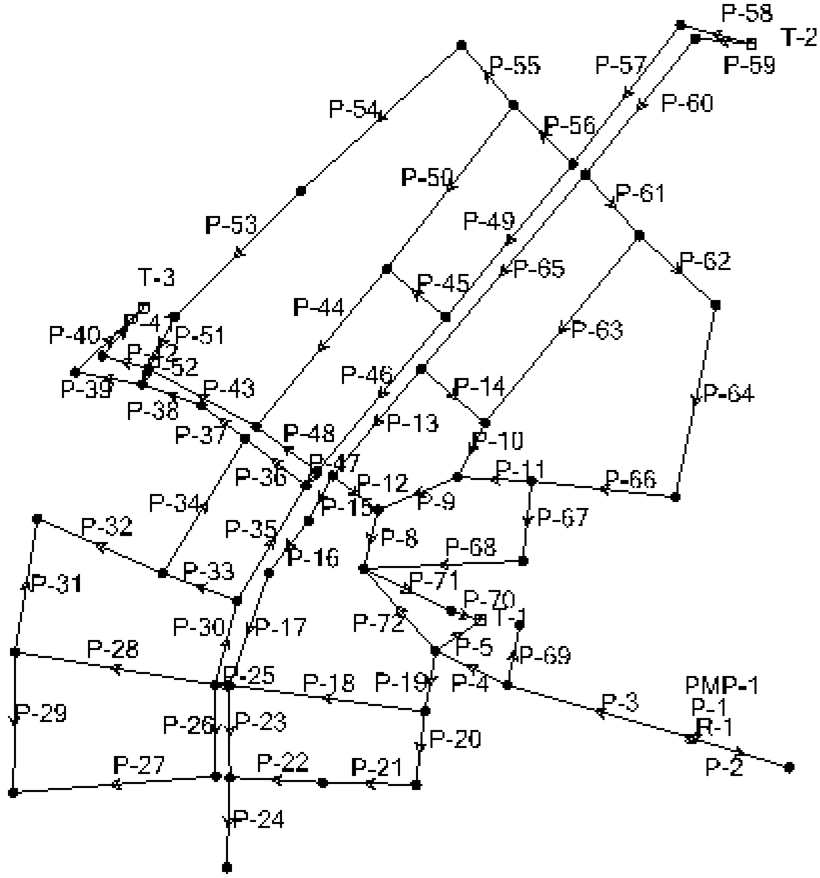

Figure 4-5 Water distribution network of the town

4.5.2.1.1. Pressure

There are low and high pressure throughout the system mainly due to topography of the area and the distance of the service reservoirs from the nodes. All the three reservoirs (T-1, T-2 and T-3) are marked by high elevation. As a result, water was distributed to the system by gravity system. However, Reservoir at treatment plant (R-1) is low pressure and water was distributed to the system using pump system to reach at the higher elevation where the gravity system is not reached. Additionally, the pump at the treatment plant helps to pump the water from R-1 to T-1.

The pressure in water distribution system is at a minimum when the flow and subsequent head losses in the pipes are at peak demand. On the other hand, the pressure is a maximum when the flow is at minimum, normally at night time while most consumers were sleep and institutions were shut down.

Ethiopian guideline criteria for the minimum and maximum operating pressure value in the distribution network were 15m to 70m respectively (MoWR, 2006). Maximum pressure limitation is required to reduce the additional cost of the pipe, strengthening necessary due to the high pressure.

Table 4-5 Pressure range from WaterCADV8i

Pressure range (m)	Count	Count (%)
< 15	9	18
15 - 70	41	82
> 70	-	-
total	50	100

According to this study from fifty (50) junctions/ nods 41 are within the pressure range. But nine (9) junctions/ nods are out of the range i.e. below the minimum operating pressure (15m). The low-pressure nodes were normally those nodes, which are located relatively at high elevations and far from the supply points.

4.5.2.1.2. Velocity

The guideline further states that water velocity shall be maintained at 0.6 to 2m/s. Maximum and minimum velocity limitation was necessary because:

- Velocity should not be lower than 0.6m/s to prevent sedimentation
- Velocity should not be more than 2m/s to prevent high head loss

According to this study, the velocity ranges obtained from the analysis is summarized below:

Table 4-6 Velocity range from WaterCADV8i

Velocity range (m/s)	Count	Count (%)	Effect
0. – 0.6	42	60	sedimentation
0.6 - 2	28	40	acceptable
total	70	100	

As observed from the above table the velocity in 40% (28) pipes was fall at acceptable range. Whereas, velocity in 60% (42) pipes is below the minimum velocity requirement.

Head loss was zero when compared with sedimentation. To solve problem of sedimentation, decreasing the diameter of pipe to increase the velocity and to solve problem of head loss, increase the diameter of pipes to decrease the velocity.

4.5.2.1.3. Pump

The most common input of energy into a system was through pumping. Pumps were crucial to any distribution system that cannot supply acceptable pressure to consumer through the sole use of gravity flow. A pump is an element that adds a head to the system as water passes through it. Pump is an integral of much pressure system and adds energy to head gains to the flow to counteract head losses and hydraulic grade differences within the system.

4.5.2.1.4. Pump curve

A pump curve represents the relationship between the head and flow rate that a pump can deliver at it nominal speed setting. Pump head is the head gain imparted to the water by the pump and plotted on the vertical of the curve in meter. Flow rate is plotted on the horizontal in litter per second. A valid pump curve must have decreasing head with increasing flow. An efficiency curve determines pump efficiency in vertical percent as a function of pump flow rate in horizontal flow. In the graph below the lower curve is a pump curve whereas the upper curve is an efficiency curve.

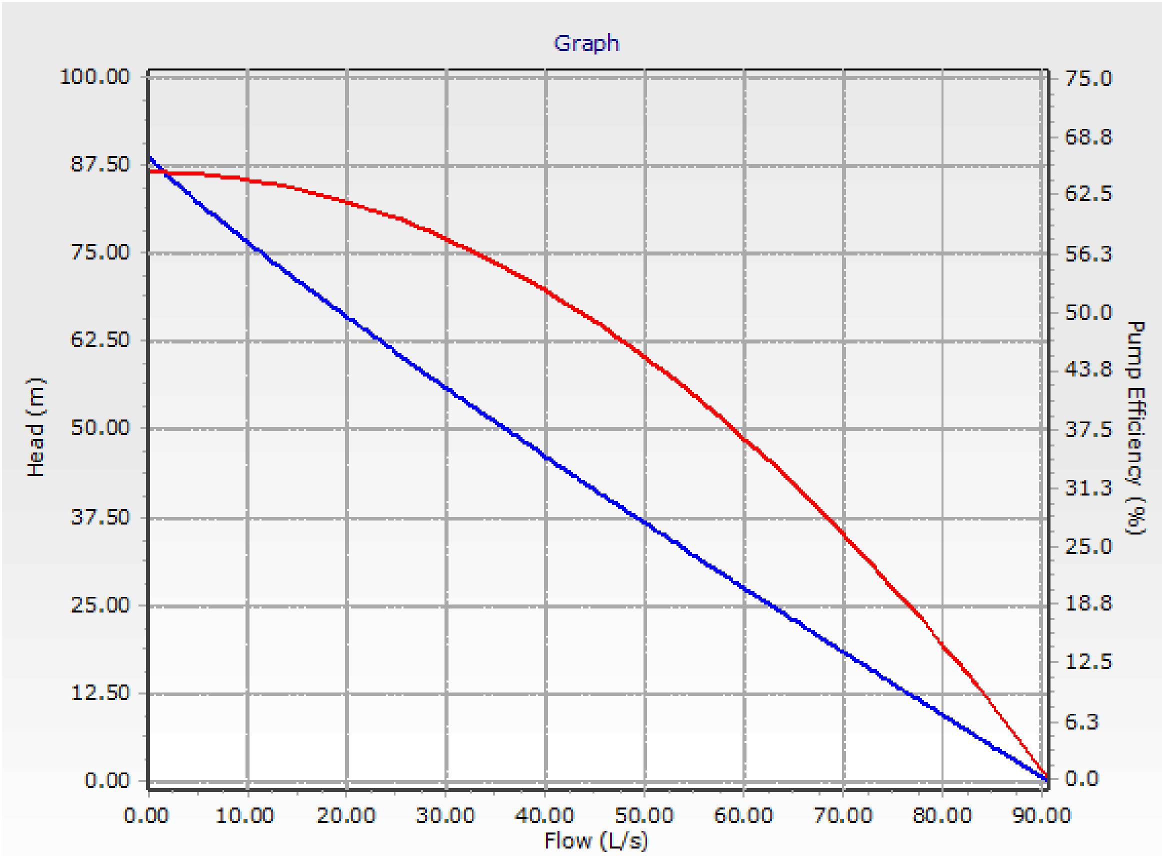

Figure 4-6 Pump curve

4.5.2.1.5. Flow

The flow arrow symbol on the pipe in the plan view always indicates the direction of flow, and the "Start node" and "Stop node" fields in the pipe properties indicate the orientation of the pipe itself. If water is flowing from the "start node" to the "stop node", the flow arrow will point that way and the flow result value will be positive. If water is flowing from the "stop node" to the "start node", the flow arrow will point that way and the flow result value will be negative. A negative flow indicates orientation of flow with regard to the orientation of the pipe itself. The reason why this behaviour occur is because in some system (mainly water distribution), flow can often reverse direction over the course of a day. Showing the negative sign in front of the calculated flow value is one way for the user to distinguish the current direction of flow.

4.5.2.1.6. Demand

As far as distribution of water is concerned, it seems there is more consumption in the afternoon and there is less of it in the morning. However, some areas do not totally get water.

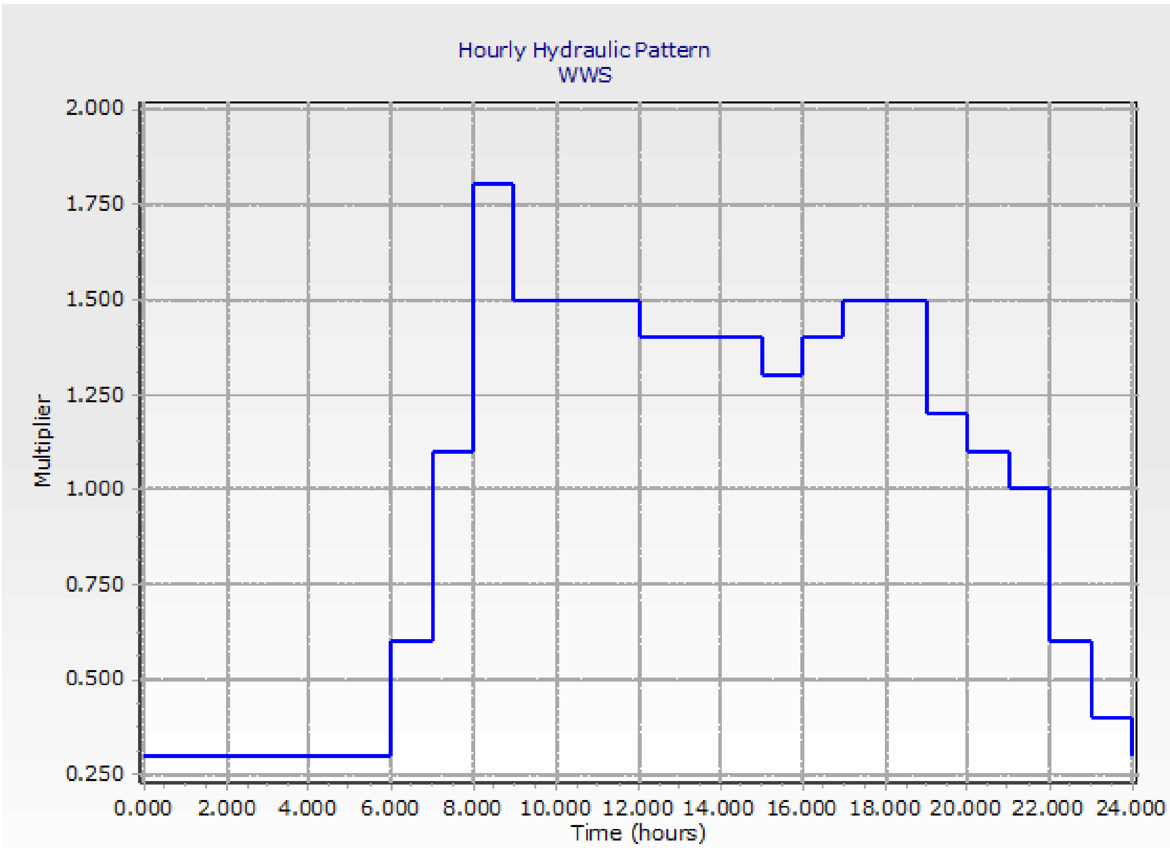

Figure 4-7 Demand pattern

CHAPTER FIVE

5. Conclusions and recommendations

5.1. Conclusions

From the result and discussion part of this study the following conclusion were drawn in order to provide answer for the research questions designed under the title "assessing water supply coverage and water loss in distribution system of Weliso town" and listed below.

1. What is the current status of water supply coverage of Weliso town?
2. How much water will be lost from the distribution system?
3. What are the possible causes and consequences of water losses?
4. In what situation are the water demand and distribution system of Weliso town currently?

- The water supply coverage was evaluated based on the daily per capita consumption and level of connection using the population data of the town for the year 2015. The average water supply coverage of the town was found to be 15.3l/p/d. This average per capita consumption was much lower as compared with some water supply standards set by WHO (2008), the minimum quantity of domestic water required in developing countries urban areas for basic needs is 20 l/c/d within a radius of 0.5 km. In this regard, the town domestic water supply satisfies about 76.5% of the minimum quantity of domestic water required stated by WHO. The level of connection per family of the town was found to be 0.38 connections per family which is equivalent to 38% in-house or yard connection, this is also below the African cities' average of 43%.
- Despite the low water supply coverage of the town, total annual volume of water loss of the town was increased from year to year (2010-2015). High and increasing water losses were an indicator of ineffective planning and construction, and low operational maintenance activities. The water loss was expressed as a percentage and loss per connection. For the year 2015 the water loss evaluated based on percentage was found to be 183825 cubic meters which accounts for 18.2% of the total water production. For the specified year loss per connection was found to be 50.57litre/connection/day. This loss of water from the distribution system was caused the office to lose 1066185 Ethiopian birr.

- The main causes of water loss were found to be leakage and the under-capacity of operation and maintenance of the office due to large area coverage to maintain at time. There are several reasons for the high level of water loss in Weliso town. Major causes of these losses were listed as follows:
  - Different constructions and aged pipe
  - Late reporting for leakage
  - Late respond for maintenance
  - Quality of materials
  - Improper alignment of pipe lines
  - Pressure
  - Defective meters
- The existing water supply was not meeting the demand of the town. The supply gap (about 56.6%), disproportional distribution of water supply (60.6% get water once in three days) and pending connection (there are 2400 applicants that requested to have connection and still they are waiting) of the town were due to shortage of water. This water shortage was found to be due to water shortage at the source.
- From the distribution system analysis of the town, from fifty (50) junctions/ nods 41 were within the pressure range. But 9 junctions/ nods were out of the range i.e. below the minimum operating pressure (15m). And velocity in 40% (28) pipes was within acceptable range. Whereas, velocity in 60% (42) pipes is below the minimum velocity requirement, causes sedimentation.

5.2. Recommendations

To improve the water supply coverage, to reduce water loss from the distribution system and to meet the water demand of the town the following actions should be taken.

- Construct additional borehole in order to increase water supply coverage(that have a capacity to meet the existed water supply gap i.e. 3130m^3/day)
- Increase number of reservoir
- Rehabilitation and replacement of aged pipes program have to be implemented.
- Operation and maintenance strategy in order to decrease leakage
- Updating existing network data, measuring and evaluating water loss
- The leakage control method was found to be passive so, it is necessary to change it to active leakage control method in which company staff itself has to find leaks, where there are no reports. The main active leakage control methods are regular survey and leakage monitoring.
- Awareness creation to the community
- Continuous meter testing repair and replacement in order to reduce loss due to defective meters.
- Proper sized pipes during the implementation of projects.

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Appendix

Appendix I Questionnaire

For resident respondents

1. Do you have access to tap water at short distance?
   A) Yes B) No
2. If your answer is yes for question number one from where do you get?
   A) Tap in side house B) Tap inside private compound C) Tap outside compound D) Youth association vender
3. How many households use this tap (connection pipe)? _______________
4. Are you happy at the existing water supply service of the town?
   A) Yes B) No
5. If your answer for question number four is no, your reason may be?
   A) It is Scarce B) Unsafe C) Interruption D) Cost
6. Do you get daily taped water access for your domestic consumption?
   A) Yes B) No
7. If your answer for question number six is no, how often do you get?
   A) Once in 3 days B) Once in 7 days C) Once in 15 days D) Other_____
8. When drinking water supply is interrupted which water source do you use?
   A) bottled water B) well water C)River D) from other town/kebele
9. How much water do you use on average per day in liter?
   A) <20liters B) 20-50liters C) 51-80liters D)Above 81 liters
   a. For how much person? __________
10. How much amount of water do you use if the supply is as you want?
11. Have you ever encountered any leakage in your connection before?
    A) Yes B) No
    a. If your answer for question number eleven is yes, what is the cause?
       A) Construction B) Aged pipe C) technical problem
       D) Other_______________
    b. If your answer for question number eleven is yes, how you report it?
       A) By going to the office B) When supervisors comes C) By telephone
       D) Other____________

12. After reporting leakage repair is performed?

    A) As soon as reported B) after 12 hrs. C) 2 days later D) Other

For WWSSE experts

1. What are the main sources of water in the city? Are there any water sources that are not included to the distribution system? Where and how much? ____
2. Is there any difference in level of water distribution among different localities? A) Yes B) No. If yes, how do you manage to balance the supply? ____
3. Is there any seasonal difference in amount (volume) of water supplied particularly in rainy season and dry season? If yes what is the cause? ____
4. Are there any non-metered water consumptions? If so for what purpose and how do you estimate the volume of water consumed? ____
5. How do you identify leakage or breakage of water pipes? How do the residents support in reporting leakage or breakage of pipes? ____
6. How frequent do water meters become defective? Do the customers report on time in case of defective water meter? If yes, do they report equally for both in case of the defect causing over readings and under readings? In case they didn’t report how do you monitor it? ____
7. Have you encountered with illegal water connections? If yes how frequent? Do you think that all customers pay for all water they have consumed? If not why? ____
8. From your experience, what are the main causes of water loss from the distribution system? List them in there magnitude (from high to low).____

9. From your experience, does leakage and breakage of pipes have significant relation with age of pipes? ____

10. Do you have any plan regarding operation and management in general and leakage reduction in particular? If so what are the main components? __________________

    ____

11. What is the cause of water shortage in the town? Is it due to shortage at the source?

    ____

Appendix II Water consumption by type for the year 2015

Month	Private(m^3)	Commercial(m^3)	MO&Gov. (m^3)	Industry(m^3)	Total
Sep	38110	5890	5007	3230	52237
Oct	38110	5890	5007	3230	52237
Nov	35790	4450	5429	1201	46870
Dec	39712	4745	7133	285	51875
Jan	44475	5208	8682	267	58632
Feb	64483	5078	7457	462	77480
Mar	45035	5363	7686	391	58475
Apr	51599	6191	9476	791	68057
May	49168	6412	5293	794	61667
Jun	45311	6413	8293	831	60848
Jul	49794	6141	5978	788	62701
Aug	59514	4387	5039	2990	41930
Total	**531101**				

Appendix III Weliso town water production and consumption data from the year 2010 - 2015

Year	Production(m^3)	Consumption(m^3)
2010	626417	533053
2011	665493	563255
2012	735037	606141
2013	825331	670933
2014	877262	705805
2015	1011797	827972

Appendix IV Summary of projected water demand

No	Description	Unit	Year				
			2015	**2017**	**2022**	**2027**	**2032**
1	Population	No	95273	103623	127328	154897	186935
2	Adjusted Domestic Demand	m^3/d	2931	3235	4307	5667	7320
3	Non Domestic Demand	m^3/d	1493	1689	2222	2891	3702
4	Water Loss	m^3/d	1106	1231	1371	1926	2756
5	Total Average Day Demand	m^3/d	5530	6154	7900	10484	13778
		l/s	64	71.2			
6	Max. Day Factor		1.2	1.2	1.2	1.2	1.2
7	Maximum Day Demand	m^3/d	6642	7385	9481	12580	16534
		l/s	76.9	85.5	109.7	145.6	191.4
8	Peak Hour Factor		1.8	1.8	1.8	1.8	1.8
9	Peak Hour Demand	m^3/h	415	462	593	786	1033
		l/s	115.3	128.2	164.6	218.4	287.0

Appendix V Urban population data from different sources

No	**Data source**	**Estimated population (2015)**
1	Town administration	80814
2	Master plan study data	88090
3	CSA 2007 projected to 2015	95273

Appendix VII the three-water distribution reservoir in Weliso town (WWSSE, 2015)

ID	Elevation	X	Y
T-1	2085	387660.84	943629.04
T-2	2145	388822.54	946103.74
T-3	2060	386216.84	944971.85

Distribution pipe network of Weliso town

Appendix VIII Pipe results from WaterCADV8i

Label	Start Node	Stop Node	Length (User Defined) (m)	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Pressure Loss (mH2O)	Headloss Gradient (m/km)	Velocity (m/s)
P-1	R-1	PMP-1	3	150	GI	120	19.18	0	10.27	1.09
P-2	PMP-1	J-1	425	100	GI	120	0.63	0.1	0.13	0.08
P-3	PMP-1	J-2	826	200	DI	130	18.55	1.7	2.05	0.59
P-4	J-2	J-3	346	200	DI	130	17.69	0.6	1.87	0.56
P-5	J-3	T-1	291	200	DI	130	14.12	0.4	1.23	0.45
P-8	J-4	J-5	287	150	GI	130	3	0.1	0.28	0.17
P-9	J-5	J-6	373	100	GI	130	-3.37	0.9	2.54	0.43
P-10	J-6	J-7	262	80	GI	130	-2.92	1.5	5.79	0.58
P-11	J-6	J-8	318	80	GI	130	-0.81	0.2	0.54	0.16
P-12	J-5	J-9	244	100	GI	130	-0.29	0	0.03	0.04
P-13	J-9	J-10	597	80	GI	130	-4.79	8.6	14.47	0.95
P-14	J-10	J-7	356	50	GI	130	1.54	6.2	17.36	0.78
P-15	J-9	J-11	218	80	GI	130	4.1	2.4	10.86	0.82
P-16	J-11	J-12	281	80	GI	130	3.91	2.8	9.93	0.78
P-17	J-12	J-13	511	80	GI	130	3.6	4.3	8.51	0.72
P-18	J-13	J-14	854	50	PVC	150	0.75	3	3.52	0.38
P-19	J-3	J-14	265	50	PVC	150	2.12	6.4	24.24	1.08
P-20	J-14	J-15	316	50	PVC	150	1.01	1.9	6.14	0.51
P-21	J-15	J-16	400	50	PVC	150	0.53	0.7	1.86	0.27
P-22	J-16	J-18	398	50	PVC	150	0.35	0.3	0.85	0.18
P-23	J-13	J-18	395	80	GI	130	0.2	0	0.04	0.04
P-24	J-18	J-19	388	80	GI	130	0.28	0	0.08	0.06
P-25	J-13	J-20	63	80	GI	120	3.91	0.7	11.5	0.78
P-26	J-20	J-17	393	50	GI	130	0.82	2.1	5.38	0.42
P-27	J-21	J-17	874	50	GI	130	-0.44	1.5	1.75	0.23
P-28	J-22	J-20	877	50	GI	130	-0.71	3.6	4.15	0.36
P-29	J-22	J-21	603	50	GI	130	0.02	0	0.01	0.01
P-30	J-20	J-23	375	80	GI	130	1.9	1	2.62	0.38
P-31	J-24	J-22	586	50	GI	130	-0.29	0.5	0.8	0.15
P-32	J-25	J-24	638	50	GI	130	0.15	0.1	0.22	0.07
P-33	J-23	J-25	325	50	GI	130	1.09	3	9.19	0.55
P-34	J-26	J-25	679	50	GI	130	-0.61	2.1	3.12	0.31
P-35	J-27	J-23	575	80	GI	130	-0.39	0.1	0.14	0.08
P-36	J-26	J-27	327	50	GI	130	-1.44	5	15.36	0.73

P-37	J-28	J-26	238	50	GI	130	-1.75	5.3	22.13	0.89
P-38	J-29	J-28	274	50	GI	130	-1.4	4	14.57	0.71
P-39	J-30	J-29	290	80	GI	130	-1.45	0.5	1.58	0.29
P-40	T-3	J-30	350	80	GI	130	-1.22	0.4	1.15	0.24
P-41	T-3	J-31	273	100	GI	130	-2.95	0.5	1.98	0.38
P-42	J-31	J-32	205	100	GI	130	-3.22	0.5	2.33	0.41
P-43	J-32	J-33	525	80	GI	130	-3.31	3.8	7.29	0.66
P-44	J-34	J-33	881	50	PVC	150	1.77	15.2	17.34	0.9
P-45	J-35	J-34	326	50	PVC	150	1.51	4.2	12.96	0.77
P-46	J-36	J-35	860	80	GI	130	-4.04	9.1	10.56	0.8
P-47	J-27	J-36	78	80	GI	130	-1.44	0.1	1.56	0.29
P-48	J-36	J-33	325	50	GI	130	2.14	10.4	32.05	1.09
P-49	J-37	J-35	854	80	GI	130	5.95	18.4	21.58	1.18
P-50	J-38	J-34	884	50	PVC	150	0.76	3.2	3.58	0.38
P-51	J-32	J-39	247	50	PVC	150	-0.67	0.7	2.87	0.34
P-52	J-32	J-29	74	50	PVC	150	0.57	0.2	2.15	0.29
P-53	J-39	J-40	770	50	GI	130	-0.93	5.3	6.92	0.48
P-54	J-40	J-41	930	50	PVC	150	-1.34	9.6	10.3	0.68
P-55	J-38	J-41	343	50	PVC	150	1.88	6.6	19.41	0.96
P-56	J-37	J-38	357	50	GI	130	2.85	19.4	54.59	1.45
P-57	J-42	J-37	754	80	GI	130	9.36	37.6	49.95	1.86
P-58	T-2	J-42	314	100	GI	130	9.61	5.5	17.7	1.22
P-59	T-2	J-43	240	150	GI	130	12.52	1	4.01	0.71
P-60	J-43	J-44	750	100	GI	130	12.16	20.5	27.37	1.55
P-61	J-44	J-45	352	80	GI	130	5.03	5.6	15.81	1
P-62	J-45	J-46	443	80	GI	130	2.65	2.1	4.82	0.53
P-63	J-45	J-7	1,045	50	GI	130	2.02	30	28.76	1.03
P-64	J-46	J-47	843	50	GI	130	2.16	27.5	32.67	1.1
P-65	J-44	J-10	1,091	80	GI	130	6.71	29.4	26.98	1.33
P-66	J-47	J-8	620	80	GI	130	1.97	1.7	2.78	0.39
P-67	J-48	J-8	345	50	PVC	150	-0.72	1.1	3.31	0.37
P-68	J-4	J-48	681	80	PVC	150	-0.35	0.1	0.09	0.07
P-69	J-2	J-49	600	80	GI	130	0.4	0.1	0.14	0.08
P-70	T-1	J-50	108	150	DI	130	-3.82	0	0.45	0.22
P-71	J-50	J-4	665	150	DI	130	-3.82	0.3	0.45	0.22
P-72	J-3	J-4	468	150	DI	130	0.89	0	0.03	0.05

Distribution pipe network of Weliso town

Appendix VIII Junction results from WaterCADV8i

Label	ID	Easting (m)	Northing(m)	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
J-01	35	388,985.77	942,997.10	2,023	0.63	2,023.91	0.911
J-02	36	387,777.06	943,351.58	2,044	0.47	2,089.71	45.615
J-03	37	387,468.90	943,498.70	2,054	0.56	2,089.06	34.988
J-04	38	387,161.84	943,851.84	2,059	0.42	2,089.04	29.984
J-05	39	387,223.06	944,103.67	2,056	0.66	2,089.13	33.06
J-06	40	387,562.78	944,243.82	2,063	0.37	2,090.07	27.019
J-07	41	387,679.03	944,478.33	2,065	0.63	2,091.59	26.537
J-08	42	387,880.62	944,227.14	2,069	0.43	2,090.24	21.202
J-09	43	387,027.95	944,249.83	2,058	0.39	2,089.13	31.071
J-10	44	387,409.14	944,709.81	2,066	0.38	2,097.77	31.707
J-11	45	386,924.57	944,057.88	2,056	0.2	2,086.77	30.703
J-12	46	386,754.69	943,833.80	2,052	0.31	2,083.98	31.912
J-13	47	386,586.70	943,350.88	2,043	0.23	2,079.63	36.555
J-14	48	387,422.32	943,238.26	2,044	0.36	2,082.63	38.556
J-15	49	387,385.72	942,924.56	2,030	0.48	2,080.70	50.593
J-16	50	386,985.96	942,934.75	2,035	0.18	2,079.95	44.86
J-17	51	386,527.22	942,959.90	2,034	0.37	2,076.79	42.701
J-18	52	386,587.96	942,955.65	2,035	0.27	2,079.61	44.522
J-19	53	386,574.44	942,567.88	2,021	0.28	2,079.58	58.464
J-20	54	386,523.53	943,353.30	2,043	0.48	2,078.90	35.831
J-21	55	385,659.80	942,890.23	2,029	0.47	2,075.26	46.169
J-22	56	385,665.38	943,493.60	2,035	0.39	2,075.27	40.186
J-23	57	386,619.65	943,714.62	2,051	0.42	2,077.92	26.868
J-24	58	385,762.00	944,067.01	2,041	0.44	2,074.80	33.728
J-25	59	386,299.56	943,830.64	2,049	0.34	2,074.94	25.884
J-26	60	386,654.01	944,409.56	2,053	0.29	2,072.82	19.78
J-27	61	386,913.64	944,208.30	2,058	0.4	2,077.84	19.802
J-28	62	386,466.85	944,551.37	2,049	0.35	2,067.55	18.515
J-29	63	386,209.97	944,642.11	2,047	0.52	2,063.56	16.527
J-30	64	385,924.55	944,694.94	2,046	0.23	2,063.10	17.068
J-31	65	386,039.93	944,764.17	2,047	0.27	2,063.24	16.209
J-32	66	386,237.86	944,710.47	2,050	0.19	2,063.72	13.692
J-33	67	386,700.03	944,460.94	2,054	0.6	2,067.55	13.52
J-34	68	387,262.03	945,140.07	2,068	0.5	2,082.82	14.794
J-35	69	387,511.68	944,930.78	2,069	0.39	2,087.05	18.011
J-36	70	386,962.65	944,269.05	2,059	0.47	2,077.96	18.925
J-37	71	388,057.18	945,588.10	2,081	0.56	2,105.48	24.429
J-38	72	387,803.41	945,839.32	2,077	0.21	2,085.99	8.971
J-39	73	386,349.86	944,928.67	2,058	0.26	2,064.43	6.416
J-40	74	386,892.49	945,472.06	2,071	0.4	2,069.76	-1.242
J-41	75	387,579.61	946,099.10	2,072	0.55	2,079.33	7.315
J-42	76	388,518.83	946,184.86	2,095	0.25	2,143.14	48.046
J-43	77	388,583.28	946,127.56	2,096	0.36	2,147.74	51.634

J-44	78	388,110.87	945,544.68	2,080	0.42	2,127.21	47.114
J-45	79	388,343.38	945,280.56	2,081	0.36	2,121.64	40.562
J-46	80	388,671.92	944,982.88	2,080	0.49	2,119.51	39.429
J-47	81	388,496.60	944,158.77	2,069	0.2	2,091.97	22.921
J-48	82	387,842.35	943,884.10	2,066	0.38	2,089.10	23.056
J-49	83	387,829.68	943,611.35	2,057	0.4	2,089.62	32.555
J-50	156	387,534.13	943,670.85	2,080	0	2,088.75	8.731