JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULITY OF CIVIL AND ENVIRONMENTAL ENGINEERING

ENVIRONMENTAL ENGINEERING MSc PROGRAM

SUSTAINABILITY ANALYSIS OF URBAN WATER SUPPLY DISTRIBUTION SYSTEM: THE CASE OF JIMMA TOWN, OROMIYA, ETHIOPIA

BY: AZEB KASSAHUN DUNFA

A THESIS SUBMITTED TO JIMMA UNIVERSITY, JIMMA INSTITUTE OF TECHNOLOGY, FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING, AND ENVIRONMENTAL ENGINEERING CHAIR IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING.

DECEMBER, 2021

JIMMA, ETHIOPIA

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MAIN ADVISOR: DR. ZERIHUN ASMELASH (Ass. Professor)

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DECEMBER, 2021
JIMMA, ETHIOPIA

DECLARATION

This thesis is my original work and has not been published for a degree of Master of Science in Environmental Engineering in this university or any other universities.

Azeb Kassahun Signature__________________ Date___________________

This Thesis has been submitted for examination with my approval as university supervisor.

Zerihun Asmelash (PhD) Signature_____________ Date__________________

Dessalegn Geleta (MSc) Signature____________________ Date__________________

ABSTRACT

Sustainable access to water supply is central to social and economic development, improving health and educational achievement, reducing child mortality, and improving livelihoods. The main objective of this study is to analysis sustainability of water supply and distribution system by using sustainability index in Jimma town. The primary data were collected from site visit (like identifying water loss trend of the study area) and allocation of water supply distribution apparaturenances while secondary data were collected from Jimma town water supply and sewerage Authority, Oromiya Water Works and Design Supervision and different journal. ArcGIS version10.4.1 for locating the study area, WaterGEMSV8i tool for simulation of water distribution layout and GPS Garmin72 tool for recording of location of water distribution apparaturenances were used. The source of water supply for the study area was surface water (Boye) with yield of 254.63 l/s but only 72.68 l/s of water used due to less pump delivery capacity to service reservoirs. The Maximum Daily Demand of the study area at design period (2040) is 638.59 l/s but, the source only have capacity to yields 254.63 l/s this implies the existing water distribution were not sustainable. The simulated result of existing extended period simulation showed that the performance of hydraulic parameters were the velocity of pipe at maximum flow (at 8:00 AM) showed that 34.25 % for velocity ($\leq$ 0.6 m/s), 50.46 % for velocity range (0.6-2 m/s) and 15.29 % for velocity $\geq$ 2 m/s. While the existing simulation were also shows the performance of pressure at minimum flow (at 4:00 AM) with 82.25 % for pressure value ($\leq$15 m), 14.71 % for pressure range (15-60 m) and 3.04 % for pressure value ($\geq$ 60 m) head. Based on the existing simulated result, Resiliency value 0.066 and 0.44, Reliability value 0.15 and 0.505, and Vulnerability value 0.076 and 0.48 were obtained for both pressure and velocity respectively. The overall sustainability index was 0.349 but 0.488 for velocity and 0.209 for pressure. Therefore, the existing water supply and distribution system of Jimma town is not sustainable. To increase the sustainability of water supply distribution system finding additional source of water should be mandatory

Key words: *Pressure, Sustainability, Velocity, Water demand, WaterGEMS V8i, Water loss*

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ACRONYMS

ACC	African Centre for Cities
ADD	Average Daily Demand
AWWA	American Water Works Association
CSA	Central Statistics Agency
DCI	Ductile Iron
EPS	Extended Period Simulation
FD	Fire Demand
GEMS	Geospatial Engineering Model System
GIS	Geographical Information system
GPS	Global Positioning System
HC	House Connection
ID	Industrial Demand
JTWSSA	Jimma Town Water Supply and Sewerage Authority
LD	Livestock Demand
Masl	Meter above Sea Level
MDD	Maximum Daily Demand
MDDF	Maximum Daily Demand Factor
MOWR	Ministry of Water Resource
NDD	Non Domestic Demand
NRC	Norweign Refuge Council
NRW	Non-Revenue Water
OWWDSE	Oromiya Water Works Design and Supervision Enterprise
PCD	Public and Commercial Demand
PF	Public Fountain
PHDF	Peak Hour Demand Factor
PHF	Peak Hour Factor
PVC	Polyvinyl Chloride
REL	Reliability
RES	Resiliency

RWH	Rain Water Harvesting
SI	Sustainability Index
UAP	Universal Assess Plan
UFW	Unacounted for water
UN	United Nation
US	Unserved
UTM	Universal Transverse Model
VUL	Vulnerability
WCED	World Commission on Environment and Development
WDN	Water Distribution Networks
WDS	Water Distribution System
WHO	World Health Organization
WUP	Water Utility Partnership
YC	Yard Connection
YSC	Yard Shard Connections

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Water is the most indispensable of all natural resources; it is essential for human beings, economic development and biological diversity. (Brook, 2006) However, many countries have to face the challenge of rapidly growing water demands, driven by an increased population and economic growth, linked to urbanization, industrialization and mechanization (Brook, 2006). Safe and readily available water is important for public health, whether it is used for drinking, domestic use, food production or recreational purposes (WHO, 2011). On the other hand, Kiongo (2005), stated an insufficient access to water is not only bad for health, but also contributes to a poor food security and a lagging social development.

Most water distribution system across the world was built decades ago, and many are reaching their expected life spans within 30 years (NRC, 2006). Accordingly, in developing countries; one of the commonly cited constraints to effective water provisioning is the "aging infrastructure" problem. And these were presents many technical limitations for effective and continues water distribution system to customers (Grady, *et al.,* 2014).

Intermittent piped water networks were found all over the developing world. And it is estimated that one third of urban water supplies in Africa were operated intermittently. As result of; high population growth rate, scarcity of water source, treatment plant size, reservoirs and storage tank capacity, power outages to run water pumps, high leakage problems, or some combination of these conditions were the primary causes for intermittent water distribution in the water system (Renwick, 2013).

In general, water problem is a growing global concern and that has an impact on countries' economic prospects. Rising water stress, large supply variability, and lack of access to safe and adequate drinking water are a frequent problems in many parts of the world. Especially, developing countries face greater challenges of adequate water distribution because of their larger population growth rate, poor infrastructure, lower income levels, and less developed policy and institutional capacity (Kochhar, *et al.*, 2015).

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Similar to the urban water sector, in many developing countries, there are serious constraints in meeting the challenge to provide adequate water sustainably for all urban residents in Ethiopia. Water supply shortages and quality deteriorations are among the problems which require greater attention and action. Various strategies are always being developed to make water accessible to all inhabitants. However, insufficient structures coupled with rapid population growth and urbanization, the gap between demand and supply of water continues to widen (Degnet, 2011). According to Jimma town water supply and sewerage office report, there were inadequate amount of water supply and low coverage in the town. Therefore, this research work was prepared to assess sustainability of Jimma town water distribution system, water loss and leakage management practice.

1.2. Statement of the problem

The world is under transition in water resource development and management (Gleick, 2003). All contemporary societies are under a problem of water system due to an over exploitation of water resources (Kostas and Chrysostomos, 2006). Problems can be particularly acute in urban areas that face ever increasing difficulties in efficiently managing scarcer and less reliable water resources. Worldwide a major challenge is the development of practical tools to measure and enhance urban sustainability especially through the design and management of infrastructure (Sahely and Maclean, 2006).

The issue of sustainability is critical when resource scarcity and equity matters are raised. The sustainability of water supply projects and the benefits they deliver are some of the overriding concerns of the water sector (Wonduante, 2013). The lowest levels of drinking water coverage are in sub-Saharan Africa (50–75 %). In sub-Saharan Africa the proportion of people with access to potable water supply and adequate sanitation is very low (Yitayh, 2011).

To understand the reasons why, how and where water is being lost managers have to carry out an appraisal of the physical characteristics of the network and the current operational practice. In many instances the problem of water loss is caused by age and size of pipe, illegal connection, pressure, poor construction and back filling, data handling error and poor maintenance practice. Although the total loss of water can be easily estimated by comparing billing on water consumption and the total water produced and distribution to the network system, there have been inadequate studies on identifying where and how much water is lost and what are the main cause of water loss in many intermediate towns including Jimma. Thus, this study was contributed to some highlight on the issue of water loss in supply network at Jimma town, Oromiya regional state, Ethiopia.

This research was focused on Jimma town water supply distribution system because of many factors like town expansion, population growth, addition of industrial parks, and expansion of university etc. So, water demand is increasing but the supply system remains the same for few years. Analyzing water loss problems and assuring water sustainability for the future generation is one of the concepts of sustainable developments.

1.3. Objectives

1.3.1. General Objective

The main objective of the study is to analysis sustainability of urban water supply and distribution system of Jimma town by using Water GEMS v8i.

1.3.2. Specific Objectives

The specific objectives of this study were:

- To evaluate water supply and demand of the study area;
- To analyze sustainability of water distribution system; and
- To identify the major factor of water loses in the existing distribution network;

1.4. Research Questions

1. How to evaluate the present water supply and forecast future water demand?
2. How to analyze sustainability of water distribution system of the town?
3. What is the major factor of water loses in the existing water distribution network?

1.5. Significance of the study

Now a day's in developing countries like Ethiopia, there is a problem of safe and adequate water to fulfill the need of the population, research on sustainability analysis is important. Jimma town water shortage problem becomes significant issue and it needs valuable study on sustainability of the water supply system. There have been few studies on sustainability assessment as well as water loss in Ethiopia but none has been focused on Jimma town water supply. In general, the research was significant for Jimma town water supply authority to check the sustainability and to improve the problem of water loss of the distribution system.

1.6. Scope of the study

This study was specifically focused on analyzing sustainability of Jimma town water supply and distribution system by performing hydraulic performance of water supply schemes. The study was limited to Jimma town for analyzing sustainability of water distribution system. It was focused on water demand determination of technical or hydraulic parameter of nodal pressure and velocity. The result and findings of the modeling (WaterGEMS V8i) was the reflections of sustainable water supply and distribution system of the study area.

1.7. Limitation of the study

The limitations of data collection completely depend on the municipality. There were some sorts of limitation while this document was prepared. Shortage of relevant data for the compilation of literature review, data would not organized in computerized system. A municipality must consider how it would collect, store and evaluate the data to allow it to make the most informed decisions.

CHAPTER TWO

2. LITRATURE REVIEW

2.1 General

Water is one of the vital necessity or the need for human being and for all living things. The access of enhanced clean water supply is one of the major factors that greatly contribute to the socio-economic transfer of once county by improving the life style and health thereby escalating life standard and economic productivity of the society (Temesgen. M, 2018)

In developing countries; many water authorities are facing the challenges in providing adequate water supply to the rapidly growing populations'. There by, most of the existing water supply systems are unable to meet the various demands of water. Beside to this; infrastructural aging problem, poor management of the existing system components/assets and utilities capacity shortages were increases the level of water losses in the distribution system (Dawe, 2000)

Ethiopia has 12 river basins with an annual runoff volume of 122 billion meter cube of water and an estimated 2.6 to 6.5 billion meter cube of ground water potential, which makes an average of 1575 meter cube of physically available water per person per year, a relatively large volume. (Kassa, 2017).

2.2 Urban water demand

The amount of water required to meet all the needs of the people, which the system serves is called Demand of water. It was expressed as per capital demand per day (l/c/d). Community growth, the growth of local commerce and industry, and the development of new industries all increases demand for water. Based on Linsley, *et al.*,(1985) water supply system capable of supplying a sufficient quantity of potable water was a necessity for modern city. The components that make up a modern water supply system includes the sources of supply, storage facilities, transmission (to treatment) facilities, transmission (from treatment) and intermediate storage facilities and distribution facilities.

According to Lee, *et al.*, (1994), urbanization and population growth follow a very complex process and affected by a range of economic, political, social, cultural, and environmental factors. They also stated that the design of the water supply project was done based on projected population it was the main factors that affects the water supply project. Future population growth can be influenced by affecting birth, death, or migration rates due to social, economic, political, technological, and scientific developments.

Akbar, *et al.*, (2007) described one of the problems that was related to urban water supply provision which was the lack of a potable water supply, it could be stated that quite often, household connection to a piped water were only available for the higher income group of population. The reasons behind this were because the physical availability of water for many cities in developing countries were in areas of heavy rainfall or were close to major rivers. In other words, because of the limited access to a potable water supply then people may decide to consume water of a doubtful quality from a nearby unprotected river, well or spring.

2.3 The meaning of sustainability

Sustainable water means a nation that can be water self-sufficient: ensuring there is enough water to meet multiple needs, from agriculture to municipal and industrial (WHO, 2011). It also means water supply will remain consistent, despite climate change impacts, such as a lack of rainfall and drought, or too much rain and being flood resilient. Sustainable water also means that the economics stack up in matching supply and demand and the water delivery process is as efficient as possible. Sustainable water supply means to find reliable approaches to various human needs for water for, that does neither exhaust the water sources and the local economy nor have long term negative impact on the environment. Agriculture consumes about 70% of the current world water supply, whereas domestic and industrial use is about 8% and 22% respectively (Roger, 2013). This paper focuses on domestic water supply.

The sustainability issue of water supply schemes disregard of their types, is explained by different institutions and academic researchers in different ways according to International Institute for Sustainable Development. A water supply service is sustainable when the organization believed that sustainability ensures adequate supplies of water of good quality are maintained for the entire population of the planet, and/or preserving the hydrological, biological and chemical functioning of the Ecosystem (ASCE, 2008).

The concepts of sustainability first came from the environmental influence and attempts to protect natural resources and ecological systems from over-extraction, shocks or stresses. However, it has also been extended to integrate other dimensions like economic, social and institutional. In every recent development endeavor, the issue of sustainability is given serious consideration. As a result, sustainable development has been given several definitions by different institutions and researchers. According to WCED (1987) defined that: "Sustainable development is development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs".

2.4 Sustainability of urban water system

For all municipal corporation and organization Sustainability of Urban water management system is a concern and stated objective, but is often ambiguously defined and clear measurement procedure are lacking (Zahraie, *et al.*, 2005). According to Popawala, *et al.*, (2011), not only the functional aspect of urban water management but also environmental, economic, social and engineering aspects of sustainable development concerned with the sustainable urban water. Multi criteria decision analysis is an integrative frame work used in urban water sustainability assessment (Lai, *et al.*, 2008). Lundie, et al., (2008), suggested a framework for evaluating the overall sustainability of urban water systems and adopted a simple scoring multi criteria decision analysis method (MCDM) to implement the proposed framework in a hypothetical case study. Journal of infrastructure systems by Khatri, *et al.*, (2011) proposed a framework for computing a performance index for urban infrastructure systems using a fuzzy multi criteria decision (MCDM) approach. In their framework, the relative importance of performance indicators was determined using analytic hierarchy process (AHP) and a final synthesized performance index was calculated using a simple fuzzy scoring approach. Based on the author Motevallian, *et al.*, (2014), multi criteria decision (MCDM) techniques have received much attention in the context of sustainability assessment of urban water systems in previous studies; however, some remaining issues have been poorly addressed.

2.4.1 Sustainability of water services in Ethiopia

Ethiopia has made significant progress in extending access to improved water sources under its Universal Access Plan (UAP). Although data are contested, all sources confirm the strong upward trajectory. However, the ability of the country to sustain progress is difficult to predict. One key challenge is ensuring that investment translates into sustainable services that continue to meet users' needs in terms of water quantity, quality, ease of access, and reliability. Although data are limited, available evidence suggests that many schemes provide unreliable services or fail completely. Service sustainability is not a new issue in the country, or elsewhere in Sub-Saharan Africa (Roger, 2013).

The Author suggests Periodically Maintenance of the services accessed by individuals over time and space is clearly difficult. This is one reason why planners have focused on systems and the extension of new supplies, with assumptions then made about service levels using government standards to determine water coverage, ensure good governance improving sustainability, effectiveness and efficiency of water supply services (Solomon, 2011).

2.5 Water Supply Source

According to Harry (2012) water supply sources that are surface and ground water is the most common water sources developed for water supply requirement of one's town. Therefore, the selection of appropriate source of water is one of the initial steps in investigating a water supply scheme. Beside to this, the source must be capable of supplying sufficient water of acceptable quality for the scheme.

2.5.1 Ground Water

It is tapped from aquifers through wells, springs and infiltration galleries. The yield depends on the depth, type of aquifer and ground water table gradient. (Harry, 2012)

Good yielding aquifers can be considered as reliable sources of water supply for community purposes. Spring is points at which groundwater comes to surface naturally. It is not always reliable sources of water supply because the shallow water tables that supply the spring are usually subject to rise and fall in elevation during rainy and dry season. Ground water is generally preferred, because usually it is lower in bacterial count, is cleaner, cooler and more uniform. The lower bacterial count and the greater clarity are due to the filtering action of the soil and sand through which the groundwater flows. Also, the required treatment is minimal.

2.5.2 Surface Water

Surface water is perennial streams, lakes, rivers and canals. It also includes stored floods by constructing impoundments. Ground water is generally preferred, because usually it is lower in bacterial count, is cleaner, cooler and more uniform. Here, As the Author states that the lower bacterial count and the greater clarity are due to the filtering action of the soil and sand through which the groundwater flows and the required treatment is minimal (Harry, 2012).

2.6 Water Distribution Systems

A water network system is created or expanded to supply a sufficient volume of water at adequate pressure from the supply source to consumers for domestic, irrigation, industrial, fire-fighting, and sanitary purposes. Water distribution systems can be divided into four main components (Belay, 2012)

A well-intended water distribution network is very crucial in the development of urban areas. A well-intended water distribution network is very crucial in the development of urban areas. The goal of water distribution systems is to deliver drinking water for all areas satisfying design demands and pressure. In the design stage it is of concern to arrive at the least-cost solutions that satisfy a set of limits including demand and pressure requirements. Often it is also of interest to arrive at less expensive solutions that, however, interrupt slightly the constraints. Consequently, research interests have been concentrating on the development of efficient evolutionary algorithms (optimization techniques) to search for the optimal combination of decision variables (e.g. pipe diameters) from a large number of solutions (Thomas,*et al*., 2003).

For efficient distribution it is required that the water should reach to every consumer with required rate of flow. Water supply systems are generally constructed to provide sufficient water to the users with a specified pressure, quantity and quality. These systems consist of various major components like, pipes, valves, junctions, pumps, elevated storage tanks, water treatment plants, etc. The three competing goals for the water supply systems are: reliable delivery of water even in case of emergencies like pipe failures, power outages, efficient and economic operation of the system, and, meeting water quality standards. Therefore, some pressure in pipeline is necessary, which should force the water to reach at every place. Water distribution systems are comprised of three primary components; water source, treatment, and distribution network (Hopkins, 2012).

2.7 Types of water distribution system

According to Thomas,*et al*., (2003), the water distribution system is a part of water supply network with components that carry potable water from a centralized treatment plant or well to water consumers in order to adequately deliver water to satisfy residential, commercial, industrial and firefighting requirements. This water distribution system can be classified as explained below.

2.7.1 Branching systems

This type of distribution networks is the most economical system, and common in the developing countries due to its low cost. In this system, when there is a need for developing the network, new branches follow that development and new dead end will be constructed (Thomas, *et al*., 2003).

2.7.2 Grid systems

There are no dead ends in this type of distribution networks. The maintenance operation did not affect the interruption on the whole area as in the branching system, this type of layout is highly desirable because, for any given area on the grid, water can be supplied from more than one direction. This results in substantially lower head losses than would otherwise occur and, with valves located properly, allows for minimum inconvenience when repairs or maintenance activities are required. The whole area is covered with mains that form the grid system (Thomas, *et al*., 2003).

2.7.3 Ring systems

The supply main is laid all along the peripheral roads and sub mains branch out from the mains. This system also follows the grid iron system with the flow pattern similar in character to that of dead end system. So, determination of the size of pipes is easy (Thomas, *et al*., 2003),

2.7.4 Radial systems

The area under service in the radial system is divided into subareas, and a storage tank is placed in the center of each subarea to supply water to the consumer. The supply pipes are laid radially ending towards the periphery (Thomas, *et al*., 2003).

2.7.5 Water distribution network building and model setup

The concept of a network is fundamental to a water distribution model. The network contains all of the various components of the system, and defines how those elements are interconnected. Networks are comprised of nodes, which represent features at specific locations within the system, and links, which define connections between nodes. Water distribution models have many types of nodal elements, including junction nodes where pipes connect, storage tank and reservoir nodes, pump nodes, and control valve nodes. Models use link elements to describe the pipes connecting these nodes. In addition, elements such as valves and pumps are sometimes classified as links rather than nodes. Intelligent use of element labeling can make it much easier for users to query tabular displays of model data with filtering and sorting commands. Rather than starting pipe labeling at a random node, it is best to start from the water source and number outward along each pipeline (Walski, *et al.*, 2003).

A. Reservoirs

A reservoir represents a boundary node in a model that can supply or accept water with such a large capacity that the hydraulic grade of the reservoir is unaffected and remains constant. It can theoretically handle any in flow or outflow rate, for any length of time, without running dry or overflowing. For modeling purposes, however, there are situations where inflows and out-flows have little or no effect on the hydraulic grade at a node. Reservoirs are used to model any source of water where the hydraulic grade is controlled by factors other than the water usage rate. Lakes, groundwater wells, and clear wells at water treatment plants are often represented as reservoirs in water distribution models. For modeling purposes, a municipal system that purchases water from a bulk water vendor may model the connection to the vendor's supply as a reservoir. For a reservoir, the two pieces of information required are the hydraulic grade line (water surface elevation) and the water quality (Walski, *et al.*, 2003).

B. Tanks

A storage tank is a boundary node and the hydraulic grade line of a tank fluctuates according to the inflow and outflow of water. Tanks have a finite storage volume, and it is possible to completely fill or completely exhaust that storage. For steady-state simulation (SSS), the tank is viewed as a known hydraulic grade elevation, and the model calculates how fast water is flowing into or out of the tank given that Hydraulic gridline (HGL). Given the same HGL setting, the tank is hydraulically identical to a reservoir for a steady-state run. In extended-period simulation (EPS) models, the water level in the tank is allowed to vary over time. For modeling purposes several elevations are important. The maximum elevation represents the highest fill level of the tank. The elevation at which the tank begins to overflow is the overflow elevation, is slightly higher than the maximum elevation. Similarly, the minimum elevation is the lowest water level in the tank should ever be. A base elevation is a datum from which tank levels are measured (Walski, *et al.*, 2003).

C. Junctions

One of the primary uses of a junction node is to provide a location for two or more pipes to meet. The other is to provide a location to withdraw water demand from the system or inject inflows into the system. Junction nodes typically do not directly relate to real-world distribution components, since pipes are usually joined with fittings, and flows are extracted from the system at any number of customer connections along a pipe (Walski, *et al.*, 2003).

***D.* Pipes**

There is flow from one junction node to another in a network through pipes. In practice, pipelines may have various fittings, such as elbows, to handle sudden changes in direction, or isolation valves to close off flow through a particular section of pipe. For modeling purposes, individual segments of pipe and associated fittings can all be combined into a single pipe element. A model pipe should have the same characteristics (size, material, etc.) throughout its length (Walski, *et al.*, 2003).

***E.* Pumps**

A pump is an element that adds energy to the system in the form of an increased hydraulic grade. Since water flows from higher energy to lower energy, pumps are used to boost the head at desired locations to overcome piping head losses and physical elevation differences (Walski, *et al.*, 2003).

***F.* Valves**

A valve is an element that can be opened and closed to different extents (called throttling) to vary its resistance to flow, thereby controlling the movement of water (Walski, *et al.*, 2003).

2.7.6 Water loss

Water losses occur in every water distribution network (WDN) in the world. For economic and technical reasons, it has to be accepted that real water losses cannot be entirely eliminated. Water loss is an issue for most drinking-water utilities. Water can be lost through a range of mechanisms, including leakage, unauthorized connections, metering inaccuracies and failure. If losses are higher than average or if there is evidence of increasing losses, causes should be investigated. Water leakage can lead to impacts on water quality, flows and pressure, whereas unauthorized connections can lead to contamination through poor or missing backflow prevention. Irrespective of the cause, water loss reduces potential revenue (Supply and Programme, 2014).

A. Real loss

In developed countries, real losses usually represent the most important component of water losses. However, in developing and emerging countries losses due to illegal connections, metering and accounting errors may often be of major significance to water utilities (Fallis, *et al.,* 2011).

B. Apparent losses

Apparent losses are losses that are not due to physical leaks in the infrastructure, but are caused by other factors. It comprise all water that is successfully delivered to the customer but which is not metered or recorded accurately and thus causes an error in the amount of customer consumption (Fallis, *et al.,* 2011).

In developing and emerging countries, between 40 and 80 per cent of water fed into drinking water supply networks is lost due to leakages. This loss of the world's most precious resource has considerable financial consequences. Funds are being spent on increasing water production to compensate for water losses when they could be invested in the maintenance or extension of existing infrastructure (Fallis, *et al.,* 2011).

2.7.7 Water loss reduction for sustainable development

Efficient and sustainable water loss management necessitates not only that technical solutions are found and implemented but also financial and managerial aspects are considered. A water balance aims to track and account for every component of water that is added to and subtracted from a water supply system within a defined period of time. When it comes to operating water supply systems, water losses are a clear obstacle to sustainability. A water balance thus seeks to identify all components of consumption and losses in a standardized format (Thornton, *et al.,* 2008).

2.7.8 Acceptable range of water loss

It is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost of water saved (Sonaje, *et al*., 2015). The level of water loss is shown in table 2-1 below.

Table 2-1: Level of water loss

Loss in %	Label
<10%	Acceptable, Monitoring and Control
10-25%	Intermediate, could be reduced
>25%	Matter of concern, reduction

2.8 Water Demand

2.8.1. Domestic water demand

Domestic demand includes water furnished to residential houses for sanitary, drinking, washing, bathing and other purposes. It varies according to living conditions of consumers such as habit, social status, climatic conditions and customs of the people (MoWR, 2006).

2.8.1.1 Population distribution by mode of service

The percentage of population to be served by each mode of service will vary with time. The variation is caused by changes in living standards, improvement of the service level, changes in building standards and capacity of the water supply service to expand. There are different types of modes of services, those are, House connections (HC); Yard connections (YC); Yard Shared Connections (YSC); Public fountains (PT) and other sources. (Sumithra, 2013).

2.8.1.2.Per capita demand

Per capita demand of the town depends on various factors like standard of living of the costumers, number of population and type of commercial places in a town etc.

If ‘Q’ is the total quantity of water required by various purposes by a town per year and ‘p’ is population of town, then per capita demand will be

Precipitate demand = $\frac{Q}{P*365}$ liters/day…………………………………………….……….2.1

2.8.1.3.Adjustment for Climate

Table 2-2: Adjustment due to climatic factor (MoWR, 1997)

Mean annual temp.(^{O}C)	Description	Altitude(m)	Factor
<10	Cool	>3300	0.8
10-15	Cool temperate	2300-3300	0.9
15-20	Temperate	1500-2300	1
20-25	Warm temperate	500-1500	1.3
25 and above	Hot	<500	1.5

2.8.1.4.Adjustment due to Socio-economic conditions

Table 2-3: Adjustment due to Socio-economic factor (MoWR, 1997)

Group	Distribution	Factors
A	Town enjoying high living standard and with high potential for development	1.10
B	Town having high potential for development, but lower living standard at present	1.05
C	Town under normal Ethiopian condition	1.00
D	Advanced rural town	0.9

2.8.2. Public and commercial water demand

This demand category includes the water requirements of all schools, hospitals, public facilities government offices and etc (MoWE, 2006).

Table 2-4: Public and commercial water demand (MoWE, 2006)

Parameter	Restaurants	Boarding schools	Day schools	Public offices	Workshops
Demand	10 l/seat	60 l/pupil	5 l/pupil	5 l/employee	5 l/employee
Parameter	Mosques & churches	Hospitals	Hotels	Public Bath	Railway & Bus station
Demand	5 l/worshiper	50-75 l/bed	25-50 l/bed	30 l/visitor	5 l/user

2.8.3. Industrial water demand

The water demand for small scale cottage industries like edible oil production and other workshops are considered 5% of the domestic water demand. It is also assumed that industrial developments will secure their own sources of water (MoWR, 2006).

2.8.4. Livestock water demand

The livestock water demand is considered where traditional sources such as ponds, rivers and streams are not available within reasonable distances from the project area (MoWR, 2006).

2.8.5. Unaccounted for water

All water leakages in the system and unauthorized connections are categorized under UFW. For urban and complex system, it is usually taken as 15 to 25 % of the total water demands depending on the condition and management of the system (MoWR,2006).

2.9 Variation in water uses

Water requirements in the dry season are more than in wet season. The use of water is also more during weekends than working days. More water is also required at rush hours when people come back from work than on normal working hours. Therefore, to satisfy this variation of demand the average day demand is scaled up by certain factors to get the maximum day demand and peak hour demand. These scaled up water demand figures are used to size or determine the capacities of the water supply system like pump stations, rising main and pipe distribution networks. In fixing the capacities of different components of water supply system, it is vital to consider the daily and hourly fluctuation of demand. Hence, the following conditions of demands are considered (ADSWE, 2016).

2.9.1. Maximum day demand

The maximum day demand is the highest demand of any one 24 hour period over any specific year. It represents the change in demand with season. This demand is used to design source capacity, riser mains, and service reservoir. The maximum day factor utilized to calculate the maximum day demand is dependent on the population of the town.

Table 2-5: Maximum day demand factor (MoWR, 1997)

Population size	Maximum day factor
0-15000	1.3
15000 - 50000	1.25
50000 to Above	1.2

2.9.2. Peak hour demand

The peak hour demand is greatly influenced by the living standard of the population and the size of the town. The peak hour demand is the most prominent figure for the design of the distribution networks.

The peak hour factor (PHF) utilized to calculate the peak hour demand shows similar dependencies as the maximum day factor for the maximum day demand.

Table 2-6: Peak hour demand factor (MoWR, 2006)

Population Range	Peak hour factor
<20000	2
20001 to 50000	1.9
50001 to 100000	1.8
>100000	1.6

2.9.3. Hydraulic models

There are two parts of computer model the first one is the database which contains information that describes the infrastructure, demands, and operational characteristics of the system and the other is the computer program that solves a set of energy, continuity, transport, or optimization equations to solve for pressure flows, tank levels, valve position, pump status, water age or water chemical concentrations. The computer program also used in creating and maintaining the database and presents model results in graphical and tabular forms (AWWC, 2012).

Another author Walski, *et al.,* (2003) described the condition of the consistency of the inter connected of the hydraulic element which is "In networks of interconnected hydraulic elements, every element is influenced by each of its Neighbors; the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other element". According to Hopkins (2012), Network analyses are derived from two basic law of physics, the Law of Conservation of Mass, and the Law of Conservation of Energy. He stated that any control volume of fluid and the energy and mass within that system must be conserved to apply this law.

A. Conservation of mass

The principle of conservation of mass or continuity states that the inflow minus the outflow equals the storage within the control volume. For pipe flow, this means mass entering any pipe will be equal to the mass leaving the pipe (since fluid is typically neither created nor destroyed in hydraulic systems). For this continuity equation to be valid, it is assumed that water is incompressible. In network modeling, all outflows are lumped at the nodes or junctions.

$\sum Qi - QO$ ………………………………………………………………………..2.2

Where; Q = inflow to node in i-the pipe (L^3/T) and QO = water used at node (L^3/T)

B. Conservation of energy

The Principle of Conservation of Energy states energy can neither be created nor be destroyed. Thus, the energy difference between two points is the same regardless of the path taken. The energy in pipe flow is typically described in terms of head. The Energy equation is known as Bernoulli's equation and it is the sum of the pressure head, elevation head, and velocity head.

$$Z1 + \frac{p1}{y} + v12 + \sum hp = z2 + \frac{p2}{y} + \frac{v22}{2g} + \sum hl \text{..} 2.3$$

Where, Z = elevation (L)

P = pressure ($M/L/T^2$);

y = fluid specific weight ($M/L^2/T^2$);

V = velocity (L/T);

g = gravitational acceleration constant (L/T^2);

h.p = head added at pumps (L);

h.l = head loss in pipes (L); and

h.m, = head loss due to minor losses (L)

Thus the difference in energy at any two points connected in a network is equal to the energy gains from pumps and energy losses in pipes and fittings that occur in the path between them. This equation can be written for any open path between any two points. Of particular interest are paths between reservoirs or tanks (where the difference in head is known), or paths around loops since the changes in energy must sum to zero.

2.9.4. Water GEMS *V8i*

WaterGEMS *V8i* is a powerful yet easy-to-use program that helps engineers analyze complex pumping systems and piping networks as they transition from one steady state to another. Hydraulic transients only last from seconds to a few minutes, but they can damage a system or cause significant operational difficulties. For example, WaterGEMS *V8i* name is due to the loud "water hammer" knocking sound that can be heard when sudden hydraulic transients occur. WaterGEMS *V8i* helps engineers understand their pumping and piping networks better, enabling them to design safe and economical surge-control systems (WaterGEMS, 2016).

WaterGEMS *V8i* is based on technology originally created by GENIVAR (formerly Environmental Hydraulics Group Inc.), the water WaterGEMS *V8i* specialists, and backed by a long-term collaboration between GENIVAR and Bentley. Bentley and GENIVAR are committed to continuously improving WaterGEMS V8i. (WaterGEMS, 2016)

2.9.5. Network simulation

Based on Hopkins (2012) the basic types of simulation models are steady state and extended period simulation. Water CAD is capable of performing those types of simulations.

A. Steady state analysis

Steady-state simulation is the simplest simulation type and computes the state of the system (flows, pressures, pump operating attributes, valve position, and so on) assuming that hydraulic demands and boundary conditions do not change with respect to time. It is commonly used to model peak demands or a short time period (Hopkins, 2012). Steady state analysis is a single time period analysis that is practiced to compute the nodal pressures, flow rates, velocities etc. in the pipes (Rossman, *et al*., 2000) .This simulation provides a snapshot of hydraulic conditions in water networks assuming all the nodes have constant water demand. It is mostly used for infrastructure design for example pipe sizing considering a peak demand condition. Another author Walski, *et al*., (2003) states that a steady-state simulation provides information regarding the equilibrium flows, pressures, and other variables defining the state of the network for a unique set of hydraulic demands and boundary conditions. Real water distribution systems are rarely in a true steady state. Therefore, the notion of a steady state is a mathematical construct. Demands and tank water levels are continuously changing, and pumps are routinely cycling on and off. A steady-state hydraulic model is more like a blurred photograph of a moving object than a sharp photo of a still one. However, by enabling designers to predict the response to a unique set of hydraulic conditions (for example, peak hour demands or a fire at a particular node), the mathematical construct of a steady state can be a very useful tool. Steady-state simulations are the building blocks for other types of simulations. Once the steady-state concept is mastered, it is easier to understand more advanced topics such as extended-period simulation, water quality analysis, and fire protection studies (these topics are discussed in later chapters). Steady-state models are generally used to analyze specific worst-case conditions such as peak demand times, fire protection usage, and system component failures in which the effects of time

B. Extended period simulation

Extended-period simulations break up the simulation into time-steps. Each time step may Feature different values for the dynamic variables (tank levels, pump operation, and junction demand). Real distribution systems have variable properties especially demand patterns; the amount of water that is consumed in the morning when everyone is getting ready for work is different at midnight. An extended period simulation models the variability of real water distribution systems (Hopkins, 2012).The results provided by a steady-state analysis can be extremely useful for a wide range of applications in hydraulic modeling. There are many cases, however, for which assumptions of a steady-state simulation are not valid, or a simulation is required that allows the system to change over time. For example, to understand the effects of changing water usage over time, fill and drain cycles of tanks, or the response of pumps and valves to system changes, an extended-period simulation (EPS) is needed. It is important to note that there are many inputs required for an extended-period simulation. Due to the volume of data and the number of possible actions that a modeler can take during calibration, analysis, and design, it is highly recommended that a model be examined under steady-state situations prior to working with extended period simulations. Once satisfactory steady-state performance is achieved, it is much easier to proceed into EPSs (Walski, *et al.*, 2003).

2.9.6. Optimization models

The main objective for designing a WDS regardless of the complexity or simplicity of the water network is to provide secure supply at the lowest cost. For this purpose, the lower cost and higher reliability models are considered while designing the water network. In order to meet the hydraulic requirements (i.e. pressure, velocity, minimum operation cost etc.) and the engineering necessities (i.e. materials, system component configuration such as pump operation etc.) optimization models have been applied to the planning and design of WDSs

(Aydin and Nazli Yonca., 2014). Lansey, (2000) stated that the costs of capital investment (i.e. pipes, pumps, tanks, valves), operation and maintenance (i.e. energy consumption) are the primary objective while designing the water networks. In addition, water demands should be met with adequate nodal pressure. Basic optimization objectives and constraints could be stated as; Minimize investment and energy costs Subject to: Meeting hydraulic constraints, Satisfying water demand and Satisfy nodal pressure requirements.A linear programming approach can be applied to branched water distribution systems (WDSs) using a split-pipe formulation which is based on splitting the pipes into different segments and optimizing the length and diameter of each section. Looped water distribution networks can be optimized via linearization. Non-linear programming can be applied to general system design which is based on integrating hydraulic simulations into the optimization method. This method is specifically useful to optimize the multiple demand conditions and operational problems. There are also stochastic search techniques such as evolutionary optimization, genetic algorithms, simulated annealing which are used to optimize the pipe sizes in the WDSs (Lansey, 2000).

2.10. Sustainability Index of water distribution system

"The sustainability index (SI) summarizes the performance of alternative policies from the perspective of water users and the environment; it is also a measure of a system's adaptive capacity to reduce its vulnerability". The sustainability index will show that the system will have a larger adaptive capacity if a proposed policy makes the system more sustainable (Sandoval, *et al.,* 2011). Reliability, resiliency and vulnerability performance criteria have been used in order to assess different aspects of water resources systems (Aydin and Nazli Yonca., 2014). Sandoval, *et al.,* (2011) analyzed the three criteria which are Reliability, resiliency and vulnerability for evaluating the possible performance of water resource systems. The combination of reliability, resiliency and vulnerability are used to determine SI which is used to determine the integrated performance of the system (Park, *et al*., 2018). A sustainability index (SI) presented by Loucks, (1997) is a term that indicates the performance of a water system with respect to predetermined thresholds of a satisfactory state. Another author Sandoval, *et al.,* (2011) suggested that a modified sustainable index (SI) using the geometric mean of reliability, resilience, and (1-vulnerability (Vul) because the geometric mean can estimate more precise values with scale issue. They adapted sustainability index estimation formula which is $sI = \sqrt[3]{\mathrm{Re} * \mathrm{RS} * (1 - \mathrm{Vul})}$ where SI indicates the sustainability index. The degree of sustainability ranges from 0 to 1 which indicates the lowest and highest degree of sustainability respectively and if one of any performance criteria is zero then the overall performance criteria becomes zero. Mathematically the satisfactory and unsatisfactory states for velocity and nodal pressures scored 1 for satisfactory and 0 for unsatisfactory conditions.

P j; t= unsatisfactory (o) (P j; t < P_{min} $\vee$ p j; t > P_{max} …………………………2.4

Satisfactory (1) P j; t ≥ P_{min} $\wedge$ Pij; t ≤ P_{max}

Where P j, t is the pressure at node j in at time t; P_{min} is the minimum pressure; and P_{max} is the maximum pressure. For velocity the same formula was used by substituting velocity in pressure in the formula.

2.10.1. Reliability

One of the most widely used performance criteria is reliability. It is directly related to the efficiency of the system, and defined as the probability of system availability. The reliability of a system can be described by the frequency or probability that a system is in a satisfactory state. Reliability is sometimes taken to be the opposite of risk. That is, the risk or probability of failure is simply one minus the reliability. Reliability, resiliency and vulnerability performance criteria introduced by Hashimoto, *et al.*, (1982) are used to measure the technical SI of an urban WDS.

2.10.2. Resilience

Park, *et al.*, (2018) illustrates a system's capacity to adapt to changing conditions that is resiliency. Resiliency also described by the system recovers from failure once failure has occurred. If failures are continued events and system recovery is slow, it may have great effects for system design. Mathematically it can be defined as the inverse of the expected value of duration that a system output remains unsatisfactory after a failure (Hashimoto, *et al.*, 1982).

2.10.3. Vulnerability

Vulnerability is defined by Hashimoto, *et al.*, (1982); Sandoval, *et al.*, (2010) as the severity of system failure. High vulnerability (close to 1) means that system performance shows high failure severity, and low vulnerability (close to 0) indicates that system performance has low failure severity Park, *et al*., (2018). Another author Christodoulou, *et al.*, (2014) illustrates the following parameter considered for vulnerability assessment and analysis of water distribution network such as, component analysis (i.e., pipes, valves, reservoirs); topology and connectivity (i.e., the number of arcs/nodes in a network, elevations, arc lengths); and operations (i.e., the operating parameters of a network, such as water pressure and flow).

In water re-sources system design and selection it is important that decision makers be aware of the vulnerability of a system to severe failure should a failure occur. Vulnerability is a statistical measure of the extent or duration of failure, should a failure (i.e. an unsatisfactory value) occur (Loucks, 1997). The vulnerability of water distribution stated by Hashimoto, *et al.* (1982) could be measured by dividing the cumulative extent of unsatisfactory values to the sum of all values in the simulation period.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1. Location

The study area is located in Oromiya regional state of Jimma town, South-western Ethiopia which far ways 356 kilo meter from Addis Ababa. It is located about 7°37′0″ to 7°43′25″ North latitude and 36°47′20″to 36°53′45″east longitude with a total area of about 106 square kilometers, with average elevation of 1850 m amsl. The town has city administration and 23 kebeles.

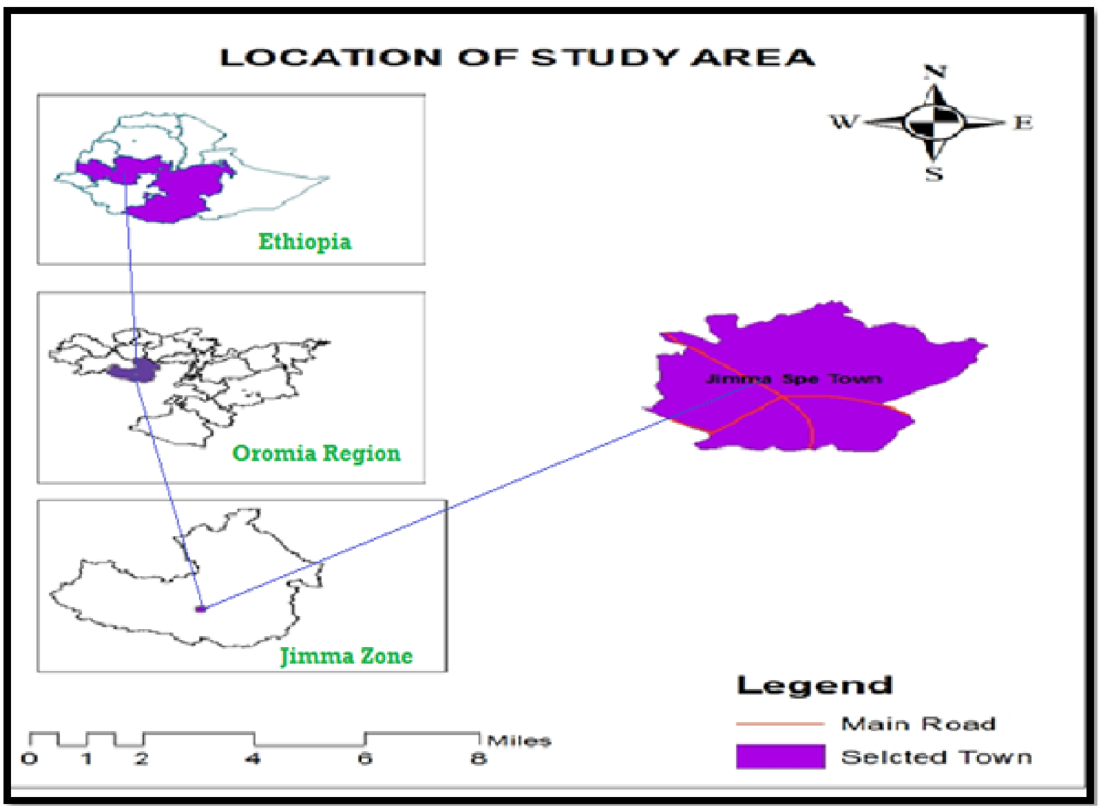

Figure 3-1: Location of the study area

3.1.2. Existing water supply system

The existing water supply system of the town depends on Boye River as a source of raw water and has a weir intake structure, raw water pumping station, raw water rising main, conventional treatment plant, one booster station, distribution systems, clear water collection and pumping system.

3.1.3. Population

According to CSA (2007), the total population of Jimma town has been about 120,960 with an average population density of 1880 people per square kilometer, 60824 male and 60136 female.

3.1.4. Climate

The elevation within the town boundary ranges from around 1700 m amsl in the south to over 2000 m amsl in the northern periphery of the town. The project area is characterized by temperate humid climate that has high precipitation, warm temperature and long wet period. The mean annual rainfall in the area is around 1500 mm and annual potential evaporation is about 1465 mm. The mean temperature is between around 12 ^{O}C and 29 ^{O}C with the mean daily temperature of 19.5 ^{O}C (World-Bank, 2011).

3.2. Study design and period

This study was done by both case study and descriptive design. A study was describe deeply about the sustainability of existing water supply distribution network and experimentally redesign water distribution network by using software package WaterGEMS V8i.The study design flow charts were described in the following figure 3-2 below during the study. The period required collecting data like water source location and yield, tank capacity and location, pipe diameter, leaked pipes and etc. is for one months and a two week. After overall collection of data analysis of data was followed, in order to do such analysis three months was required. Totally the study takes four month and two week to finalize.

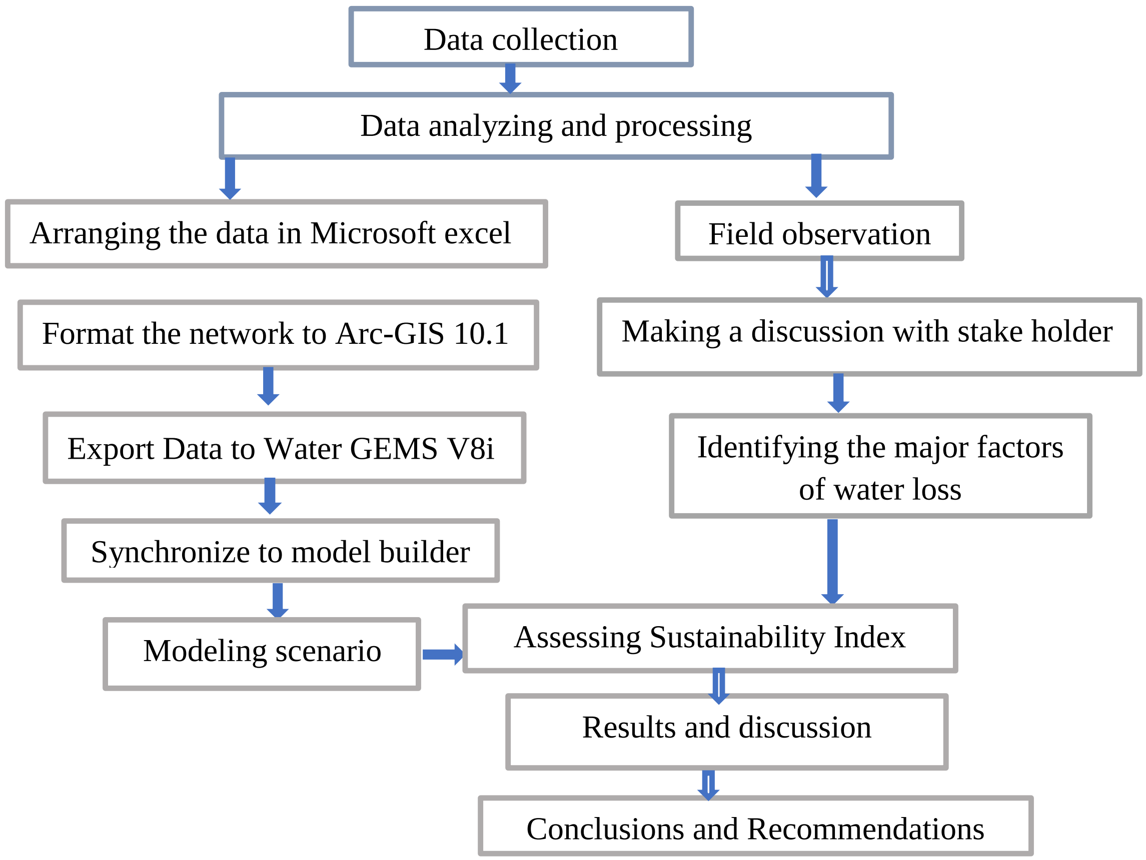

Figure 3-2: Flow chart of study design

3.3. Data Source and method of collection

Both primary and secondary data were used to process the study in the realistic situation and techniques to get the required information.

3.3.1. Primary data collection

Actual field investigation and measurements or survey works including simple observations of town water supply at the sites have been used for required data collection in order to know the present condition of the water supply. For cross checking the water supply data taken from municipality, Elevation, Northing and Easting of junction at each distribution line were collected by using GPS. The water loss trend of the study area has been identified based on interviews with the communities and municipality. Observation of the site or distribution system were conduct for identifying which pipe or distribution line is the reason for the effect of sustainability and cause of water loss of distribution system.

3.3.2. Secondary data collection

Secondary data have been collected from the responsible organization such as Jimma town water supply and Sewerage Authority. The town master plan was taken from Jimma town Municipality office. The town water supply data such as pipe length, diameter, and material used, number and volume of reservoir or tank, number and yield of each borehole or ground water source, number and types of pumps and valves have been collected from the Jimma town water supply and sewerage authority. Water loss analyses were determined based on observation of distribution network and interviews with community. The base population number of the town has been collected from 2007 Ethiopian Central Statistical Agency. For analysis of water demand of study area the standard were based on the Federal Democratic Republic of Ethiopia Ministry of Water Resources and Energy 2006 report.

3.4. Study variables

There are two types of variables, dependent and independent variables. Which variables express about impact of water supply distribution system sustainability and its layout.

3.4.1. Independent variable

It is that factor which is measured, manipulated, or selected by the experimenter to determine its relationship to an observed phenomenon. Independent variable is that factor which is investigated, measured, examined, or selected by the study to determine its relationship to an observed phenomenon. It is highly related with that of specific Objectives. Thus, those variables are: demand, pressure, pump, velocity, pipe diameter and water loss.

3.4.2. Dependent variable

The dependent variable is that factor which is observed and measured to determine the effect of the independent variables. It’s the response variable, output, and a factor which is practically seen and experimented to determine the effect of the independent variable. It characterizes the significance of modification in the situation of study. Since its value depends on the value of independent variable (Sonaje, 2015). Therefore, as it is directly related to general objective the dependent variable of this study is water supply sustainability.

3.5. Materials and tools

3.5.1. WaterGEMS *V8i*

Design of distribution network for continuous water supply can be easily achieved with the help of software WaterGEMS *V8i*, which is used for water distribution modelling and management. WaterGEMS *V8i* is a very useful hydraulic modelling software package with the advancements in the interoperability, optimization of networks in addition to, model building supported with geospatial tools and asset management tools. For this study, the design methodology adapted to analysis and design a distribution network for continuous water supply on software WaterGEMS *V8i* was used.

3.5.2. Tools used

GPS Garmin 72 instrument was used to collect the required elevation data, Northing and Easting of junction, for cross checking the water supply data taken from municipality.

3.5.3. Additional software

AutoCAD 2007 was used to analysis nodal demand of each junction on the water supply distribution system based on the area coved such demand of junction. ArcGIS 10.4.1 was used to delineate the shape file of the study area.

3.6. Data processing and analysis

The data which were important for the analyses were collected from the previous reports and files kept by responsible organizations for further interpretation and analyses. The important data for the study includes GPS reading of the tanker, source of water supply, junctions, pump, valve and reservoir or tank. The data was analyzed by using MS-Excel. The methods of data analysis carried out in two ways. The first method was by comparisons of existing water supply with design period water demand. The other method was based on existing water distribution network WaterGEMS v8i software simulation result of technical parameter like nodal pressure and velocity parameters determination. The standard values of nodal pressure and velocity has been identified based on MoWR, 2006 guide line. There are two ways of technically analyzing the sustainability of water distribution systems; those are water stress index and sustainability index. Water stress index determined the current water availability of the city but sustainability index determined the futurity of water availability. Therefore, sustainability index was selected for analyzing the sustainability of water distribution system. The values which are under standard values were taken as sustainable and below and above standard values were taken as unsustainable. In order to determine the sustainability index (SI) for the water supply, reliability, resiliency, and vulnerability performance indicators have been selected. After checking the sustainability of existing water distribution system identifying major factors of water loss was conduct based on the available yield of water sources and water consumptions.

3.6.1. Population Forecasting

Accurate estimation of water use by particular society is rarely achievable, since water use is practically liable to change. There are different populations forecasting methods. But the result is different from one method to another method. The preference of the method appropriate for particular town needs to consider overall current situations of the targeted town.

For fast growing city, where relatively high economic activity is observed and at the same time continuous expansion of city due to various reasons is experienced, geometric method population forecasting is preferably used.

According to Armstrong, (2001) geometric population forecasting method is expressed as follows;

$$P_n = p_o(1 + r)^n \quad \text{……} \quad 3.1$$

Where, Pn = population at year n;

Po= base year population;

r = population growth rate; and

n =projection year

3.6.2. Domestic water demand

The design of water supply project is necessary to estimate the amount of water that required satisfying and serving up to the end of the design period. This involves determining the number of people who would be served and their per capita water consumption, together with an analysis of the factors that may operate to affect consumption. Water required for drinking, cooking, bathing, gardening, sanitation purpose, depends on the living standard of the consumers. The mode of serves projection (derived from urban model) parameters were used to assess the town domestic water supply coverage by service types connections. Furthermore, it was considered water supply population percentage from House connection, Yard connection, Yard share connection, Public fountain, Unserved mode of service.

Table 3-1: Percentages of population by the mode of services (JTWSSA, 2020)

Mode of services	Percentage of population (2020)
House connection	7.1
Yard connection	33.4
Yard shared connection	53.5
Public fountain	5
Unserved	1

Domestic per capita water demand was estimated taking into consideration of population number of design period and category of the town, expected increase in per capita consumption and population of users with time and domestic water consumption variation based on the mode of service connections and based on litter per capita per day consumption of service connection taken from (MoWR, 2006). This is illustrated in table 3-2. Domestic water consumption varies according to the mode of services, climatic conditions, socio-economic condition and other related factors. After reviewing previous design criteria in the country, projected per capita water consumption was done.

Table 3-2: Percapita demand by mode of services (JTWSSA, 2020)

Mode of services	Litter percapita per day (2020)
House connection	143
Yard connection	39
Yard shared connection	26
Public fountain	16

The number of population used by service type equal to the total population of the study area times the mode of percentage connection service in that year. Average daily demand litter per capita per day is equal to percent of number of population used by service type times litter per capita per day of service type. The same scenarios used for other demands. By considering the capacity of Jimma town the lower limit of range take for domestic demand by mode of service connections types, existing and projected population size in terms of mode of services and domestic water demand analysis by mode of services were done.

3.6.3. Public and commercial water demand

This is the amount of water required by public or institutions like schools, hospitals, public offices, military camps, public parks, dispensaries, day-care centers and so on. While water demands for commercial areas like restaurants, cinema houses, railways, bus stations, shopping centers, local drinks and so on. Based on OWWDSE water demand analysis standard 30 % of total domestic water demand was used for the analysis of public and commercial water demand (OWWDSE, 2010).

3.6.4. Livestock water demand

This is the amount of water required for animals like caw, sheep, goat, and etc. The study area has no perennial water, which is dried during summer time. Currently there is no water supplied for such livestock. Therefore assessment of water for livestock becomes mandatory. Based on the number of livestock present in the study area the amount of water required for livestock were 5% of domestic water demands (OWWDSE, 2010).

3.6.5. Industrial water demand

Normally it is mandatory industrial area can supply water by them. The study area does not have big industry, but there is small industrial area like poultry, which required the supply of water from the towns. Based on OWWDSE water demand determination standard 8% of domestic water demand was used for determination of industrial water demand (OWWDSE, 2010).

3.6.6. Water requirement for fire fighting

Fire hydrants should be installed at public and municipality interest such as schools, shops, hospitals, fuel stations and at salient points of distribution network. Currently the study area does not have supply of water for fire-fighting, but it is mandatory to supply water for fire-fighting. Based on OWWDSE water demand determination standard 12 % of total water demand was used required for fire-fighting (OWWDSE, 2010).

3.6.7. Unaccounted water loss

All water leakages in the system and unauthorized connections are categorized under UFW. Based on OWWDSE water demand determination standard 25 % of total water demand was used for projection of unaccounted for water (OWWDSE, 2010).

3.6.8. Total water demand

This refers to the total water demand required for the study area. The analysis of total water demand was done by summing up of all domestic, non-domestic water demand and unaccounted for water. The water supplied for fire-fighting were mostly used for institution.

Table 3-3: Existing water demand of Jimma town (JTWSSA, 2020)

Water demand	Water consumption (2020)
Daily domestic water demand (l/d)	8601341.024
Public and Commercial demand (l/d)	2580402.307
Industrial demand (l/d)	1032160.923
Livestock demand (l/d)	430067.0512
Fire demand (l/d)	1032160.923
Unaccounted for the water (l/d)	3419033.057
Average daily water demand (l/d)	17095165.28

3.6.9. Source of water supply for Jimma town

The source of municipal water needs to be adequate and reliable, and many municipalities use more than one type of water source. The source of water supply is surface water is from Boye water treatment plant, which is located 267,421.34 m Easting and 845,312.65 m Northing. The supply of water to the town was dependent on electric power. When electric power was available, the sources produce a total volume of discharge 22,000,000 l/d (254.63 l/s), at pump operation hours which is equal to 6,275,320 l/d (72.63 l/s).

3.6.10. Water distribution network pipes

All the elements of distribution system, such as junction (nodes), pumps, reservoirs, valves and tanks are linked to each other by pipes (Melaku, 2015). To deals performances of hydraulic parameters for all pipe networks house hold is difficult and time consume to represent by software. So, skeletonization was needed. Skeletonization is the process of selecting for inclusion in the model for enabling quicker calculation (OWWDSE, 2010). Using skeletonization pipes having diameter greater or equal to 40 mm were selected for modeling the distribution system. The total length of pipes 10461 m Ductile Iron, the remaining length of 142433 m from Polyvinyl Chloride (PVC) pipes has been used in the distribution network (JTWSSA, 2020). Identification of pipe materials and quantification of their length were served for effective analysis of flow velocity and pressure.

Table 3-4: Existing Pipe diameter, materials and corresponding length (JTWSSA, 2020)

Diameter (mm)	Ductile iron (count)	PVC (count)	Percentage of pipe (%)
40	_	22	6.73
50	_	125	38.22
80	_	37	11.32
100	_	35	10.70
150	_	32	9.78
200	_	34	10.40
250	_	21	6.43
300	11	_	3.37
350	10	_	3.05
Total	21	306	100

3.6.11. Storage tank

Storage tank is a structure used to store water and provide water to the system when needed. Storage tank is crucial to continuously supply during a pump turned off and equalize water during peak demand hours. The study area has three storage tanks which functions for storing water and equalizing flow to each service area.

Table 3-5: Storage tank data (JTWSSA, 2020)

Label	Northing (m)	Easting (m)	Elevation (m)	Volume (m^3)
Terara-1	847,979.58	267,155.90	1,946.400	2000
Terara-2	848,052.45	267,161.11	1,946.600	2000
Aba Jifar	851,666.11	266,152.02	2,044.600	200
University	849,853.47	264,294.66	1,871.600	2500
Gebriel	851,170.00	259,289.00	1,825.600	2500

3.6.12. Existing water distribution modeling process by using WaterGEMS v8i

The modeling was performed using the following steps: 1. Input data arrangement and checked; 2. Initial setup (the unit was set to SI unit); 3. Network schematic (connect junction and pump by pipe); 4. Data entering model builder and flex table; 5. Nodal demand calculation; 6. Validate and run process; and 7. Sustainability analysis based on result.

3.6.12.1. Data entering technique

The input data should be entered into the WaterGEMS V8i software using different techniques these were model builder from excel to software, use the properties editor for each element by individually opening the properties editor or used flex table for similar element. However, it is better to enter (X, Y) data used by model builder so that the total data was entered at once and enter pipe parameters, pump variables and other necessary values used by flex table.

3.6.13. Nodal Demand

In this study nodal demand has been calculated using unit line demand allocation method; demand for each node was examined and analyzed based on the number of population point load data selection nearest node based on available load builder methods for each consumption node, And period of supplying water to calculate the peak factor of demand for each node. The population around the node was determined, and the people served by the node were multiplied by per capita demand (Lee, 2007).

Nd = $\sum Pi * dj$ --- 3.2

Where:-

Nd = nodal demand;

Pi = population supplied by the nearest node for the service area;

dj = per capita demand assigned for the study area;

i = subscript referring to the ith node in the service area; and

j= subscript referring to the jth pressure zone in the service area

3.6.14. Sustainability Index Indicators

A sustainability index (SI) is a term that indicates the performance of a water system with respect to predetermined thresholds of a satisfactory state (Sandoval S, 2011). Recently, water resources sustainability has been measured using reliability, resiliency, and vulnerability performance indicators. The SI is a weighted combination of reliability, resiliency, and vulnerability which may change over time and space (Sandoval S, 2011)

Mathematically the satisfactory and unsatisfactory states for velocity and nodal pressures scored 1 for satisfactory and 0 for unsatisfactory conditions.

P j; t= unsatisfactory (0) (P j; t < Pmin∨p j; t > Pmax

Satisfactory (1) P j; t ≥Pmin ∧ Pij; t ≤ Pmax

Where; Pj, t is the pressure at node j in at time t;

Pmin is the minimum pressure; and

Pmax is the maximum pressure.

For velocity the same formula has to be used by substituting velocity in pressure in the formula.

Vulnerability (VUL) is the magnitude or duration of an unacceptable state of WDS in a certain time scale. The vulnerability could be measured by dividing the cumulative extent of unsatisfactory values to the sum of all values in the simulation period. In this study, vulnerability is defined as

$$VUL_k = \frac{\sum \textbf{unsatisfactory values}}{\sum \textbf{all values}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

Where k refers to pressure or velocity

The reliability analysis of existing water supply was done by counting number of pressure and velocity under permissible or satisfactory range to the ratio of total elements which found in the distribution networks with its respective variables.

Reliability (REL) is the probability that the WDS is in a satisfactory state defined as

$$REL_k = \frac{\text{times satisfactory occurs}}{\text{total of time steps}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where k refers to pressure or velocity

Resiliency (RES) The number of satisfactory values of pressure and velocity which were follows unsatisfactory values ratio. RES represents how fast the system recovers from a failure defined as

$$RESk = \frac{\textbf{times of satisfactory follows unsatisfactory}}{\textbf{total of times unsatisfactory occurs}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

Where k refers to pressure or velocity

According to (Sandoval S, 2011) sustainability index then can be calculated by the following formulae

$$SI = [REL * RES * (1 - VUL)]^{1/3} \quad \ldots\ldots 3.6$$

The main feature of the SI is that it ranges from 0 (i.e. the lowest degree of sustainability) to 1 (highest degree of sustainability). Another property is that if any one of the performance criteria is zero then the overall SI will be zero.

In assessing sustainability of water supply distribution system, indicators for technical feasibility, velocity and pressure, have been considered. In the study the performance measurement parameter were evaluated based on the hydraulic efficiency of the distribution system. For analysis of performance indicators of sustainability (i.e. Reliability, Vulnerability and Resiliency) the values of pressure have been taken at low consumption hour (4:00 AM night) while the values of velocity have been taken at high consumption hour (8:00 AM morning).

Table 3.6: Sustainability range based on sustainability index

SI range	State
0-0.25	unacceptable
0.25-0.5	medium but unacceptable
0.5-1	acceptable

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1. Population forecasting

The base population of Jimma town based on 2007 Ethiopian census data was 120960. By using geometric population forecasting methods the population number of Jimma town at 2040 was 456859. The sample calculations for forecasting population were taken on Appendix B.

Table 4.1: Population forecasting of Jimma town

Year	2019	2020	2025	2030	2035	2040
Growth rate	4.362	4.2	4	3.8	3.6	3.4
Population	207250	216204	265278	321758	385482	456859

4.2. Water demand projection

4.2.1. Domestic water demand projection by mode of service

Domestic water demand is the daily water requirement for use by human being for different domestic purposes like drinking, cooking, bathing, gardening, etc. According to second growth transformation plan (GTP-2) of Ethiopian government Goal 1.2 urban water supply access was categorized based on the population number. As which is discussed in table 4.1 the design period (2040) population of Jimma town was 456859, which has been categorized under catogry-1, town with population number greater than 100000.

Table 4.2: Percentage of population distribution by mode of services

Connection	Unit	Year					
		2019	2020	2025	2030	2035	2040
HC	%	6.92	7.10	8.00	9.10	10.2	11.3
YC	%	32.64	33.40	37.90	42.90	48	53.1
YSC	%	49.58	53.50	48.70	42.60	36.3	30.1
PT	%	9.76	5.00	5.00	5.00	5	5
Un-Served	%	1.1	1.00	0.50	0.50	0.5	0.5

Table 4.2 described, from existing percentage of population the future percentage of population distribution by mode of services were projected based on GTP-2 goal urban water supply access category-1. The percentage of population using HC and YC were increased from time to time while YSC were decreased from time to time

Table 4.3: Projected population distribution by mode of services

Connection types	Unit	Year					
		2019	2020	2025	2030	2035	2040
HC	Population	14342	15351	21223	29280	39320	51626
YC	Population	67647	72213	100276	138035	185032	242593
YSC	Population	102755	115670	129192	136748	139931	137515
PT	Population	20228	10811	13264	16088	19275	22843
Unserved	Population	2280	2163	1327	1609	1928	2285

Based on percentage of population distribution described on table 4.2, table 4.3 describes the number of population distribution by each mode of services.

Table 4.4: Percapita consumption by the mode of service

Connection	Unit	Year					
		2019	2020	2025	2030	2035	2040
HC	l/c/d	141.4	143	152	152	152	152
YC	l/c/d	38.6	39	41	41	41	41
YSC	l/c/d	25.8	26	28	28	28	28
Public Tap	l/c/d	15.8	16	17	17	17	17

Table 4.4 described the existing and projected per capita demand of each mode services based on GTP-2 urban water supply access category-1.

Table 4.5: Projected domestic water demand

Connection types	Unit	Year					
		2019	2020	2025	2030	2035	2040
HC	l/d	2027916	2195119	3225780	4450556.7	5976512.9	7847010.2
YC	l/d	2611151	2816273	4111278	5659401.5	7586285.8	9946277.3
YSC	l/d	2651067	3007398	3617331	3828920.2	3918039	3850407.7
PT	l/d	319596.1	172963.2	225486.3	273494.3	327659.7	388330.15
Unserved	l/d	7609731	8191753	11179876	14212373	17808497	22032025
CF	-	1	1	1	1	1	1
SEF	-	1.05	1.05	1.05	1.05	1.05	1.05
ADWD	l/d	7990217	8601341	11738870	14922991	18698922	23133627

Climate condition of the environment affects the quantity of water consumption and the economic or living standard of community can affect the consumption of water. These are adjusted by multiplying climatic and socio-economic adjustment factors with total domestic water demand. Since Jimma town was located at average altitude of 1700 m and 2000 m amsl, therefore take climatic factor 1. Jimma was high potential town for development, but lower living standard at present, therefore take socio-economic factor 1.05. As described on table 4.5, the current (2020) adjusted domestic water demand of Jimma town has been 8,601,341 l/d while design period (2040) water demands of study area were 23,133,627 l/d this indicates the water demand of the down will be increased by 14,532,286 l/d. This is why domestic water demand of the community was increased from time to time.

4.2.2. Projected non- domestic water demand assessment

This refers to the water demand required for non- domestic area like public and commercial, livestock, fire and industrial area.

Table 4.6: Projected non- domestic water demand assessment

Water Demand	unit	Year					
		2019	2020	2025	2030	2035	2040
PCD	l/d	2397065	2580402	3521661	4476897.4	5609676.7	6940088
LD	l/d	399510.9	430067.1	586943.5	746149.56	934946.12	1156681.3
FD	l/d	958826.1	1032161	1408664	1790758.9	2243870.7	2776035.2
ID	l/d	958826.1	1032161	1408664	1790758.9	2243870.7	2776035.2
NDD	l/d	4714228	5074791	6925933	8804564.8	11032364	13648840

Table 4.6 described, water demand for public and commercial area were more than water demand for other non-domestic area, this indicates the area covered by public and commercial were greater than other areas. The design period non-domestic water demand were increased by 8,574,049 l/d as compared to 2020 non-domestic water demand, this can indicates the amount of water supplied for non-domestic area will increase from year to year. Domestic water demand and the percentage contribution of all water demand on the design period were analyzed. Among those categories domestic demand is higher than all other consumption categories. This demand category is followed by public and commercial activities whereas industrial, livestock and fire demand have a lower contribution to total water demand.

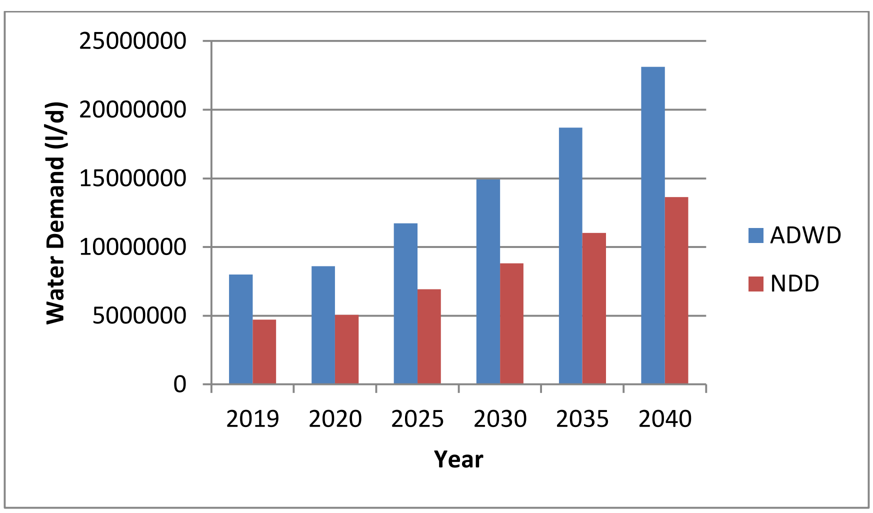

Figure 4.1: Variation of domestic and non- domestic daily water demand

As figure 4.1 described, the domestic demand throughout the year is higher than nondomestic demand categories. Non- domestic demand are found to have a lower to total water demand, all categories has shown increase between 2019 and 2040. Since 2020 the water supplied for domestic was 3,526,550 l/d greater than water supplied for non-domestic area. The reason behind the current water supplied for domestic consumption was greater than non-domestic was, the community of study area were more commonly consumed water for domestic purpose rather than non-domestic purpose.

4.2.3. Projected average, maximum and peak daily water demand

Water demand is a summation of all consumptions given in the preceding sections and it would determine the capacity needed from the sources.

Table 4.7: Projected average, maximum and peak daily water demand

Water Demand	Unit	Year					
		2019	2020	2025	2030	2035	2040
ADWD	l/d	7990217	8601341	11738870	14922991	18698922	23133627
NDD	l/d	4714228	5074791	6925933	8804564.8	11032364	13648840
UFW	l/d	3176111	3419033	4666201	5931889	7432821.6	9195616.5
ADD	l/d	15880557	17095165	23331004	29659445	37164108	45978083
ADD	l/s	183.8027	197.8607	270.0348	343.28061	430.14014	532.15374
MDDF	-	1.2	1.2	1.2	1.2	1.2	1.2
MDD	l/s	220.5633	237.4329	324.0417	411.93674	516.16817	638.58448
PHDF	-	1.6	1.6	1.6	1.6	1.6	1.6
PHD	l/s	294.0844	316.5771	432.0556	549.24898	688.22422	851.44598

Maximum daily demand factor, 1.2, was selected based on the population number of design period. And also the value of peak hourly demand factor, 1.6, was selected based on the population number of design period.

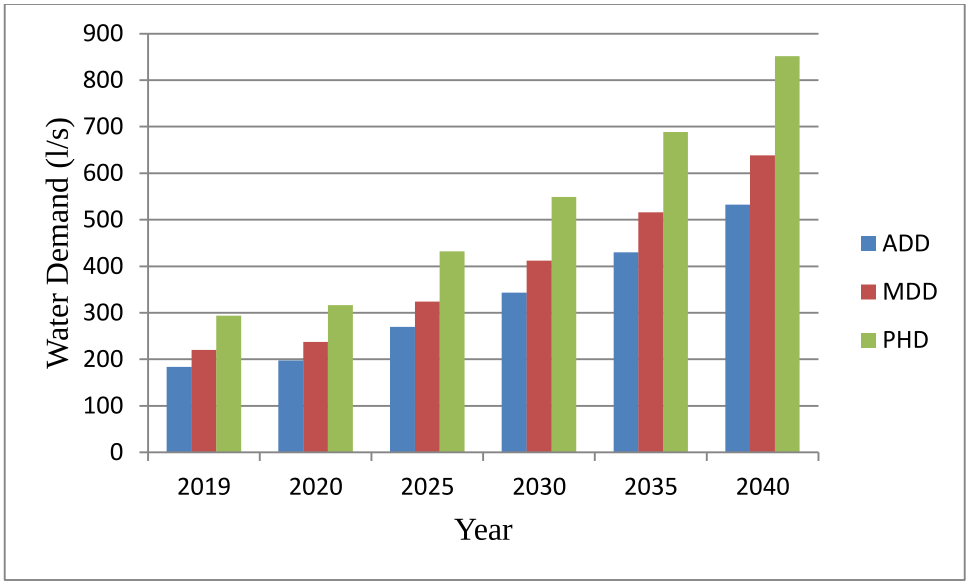

Figure 4.2: Water demand variation

As figure 4.2 described, Average daily demands (ADD), Maximum daily demand and Peak hour demand of the study area for 2025, 2030, 2035 and 2040 were increased by 36.47 %, 73.49 %, 117.39 % and 168.96 % respectively as compared to 2020 average daily water demand.

4.2.4. Water demand and supply analysis

According to the information obtained during discussion with the experts of water supply office the other problem of water supply is the source of power for pump motor or shortage of power supply. That means, the supply of water to the town was dependent on electric power. When electric power was available, the sources produce a total volume of discharge 22,000,000 l/d (254.63 l/s), at pump operation hours which is equal to 6,275,320 l/d (72.63 l/s) in 24 hours. Therefore the total volume of water entered to storage tank within 24 hours is 261,471.7 m^3.

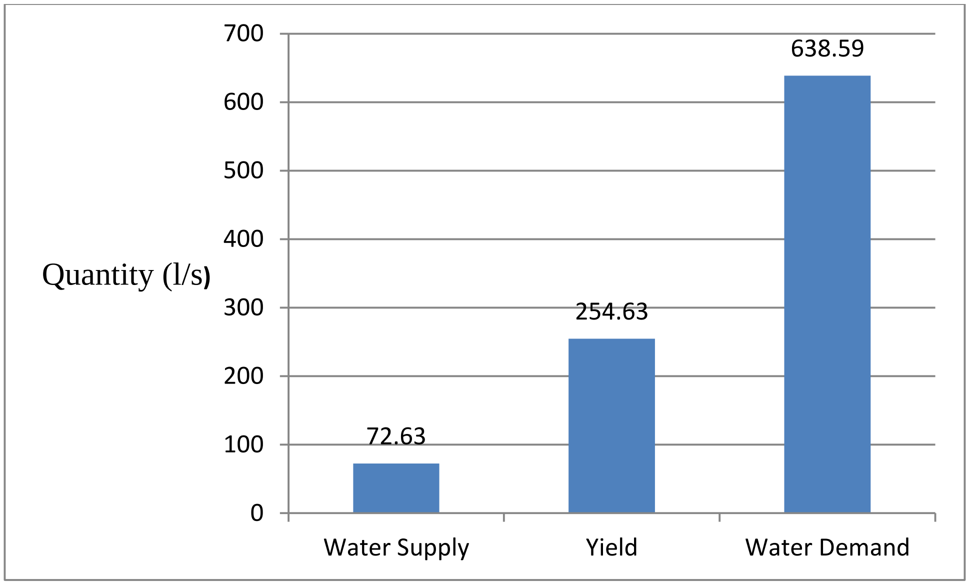

Figure 4.3: Existing water supply and future water demand

As table 4.7 and figure 4.3 discussed, the projected maximum daily demand of the design period (2040) was 638.59 l/s, but existing water supply source (Boye source) of the town supplies only 72.63 l/s. This can indicate that the capacity of water which is supplied for town is less than the design period required amount of water. As discussed on figure 4-3, by comparing the current water supply with the design period water demand the town water supply and distribution system is said to be unsustainable.

4.3. Sustainability Analysis

4.3.1. Existing hourly hydraulic pattern

The system condition have been computed over 24 hours with a specified time increment of an hour and starting model run at time 12:00 AM (Mid night). The model has been simulated for three hour time setup in the twenty- four hour duration. However, for the analysis the peak and minimum hours demand has been simulated to identify the current performance of the system related to system parameter like pressure and velocity. The model has capacity to run 24 hours but to indicate the real performance pattern the simulation of this model was adjusted. The model has been performed 12:00 AM (mid night) to 5:00 AM minimum hour consumption while 6:00 AM (Morning) to 9:00 AM for the peak hour consumption. It is noted that minimum hour model run has been made at 4:00 hour from starting time and peak hour model has been made at 8:00 hour from starting time.

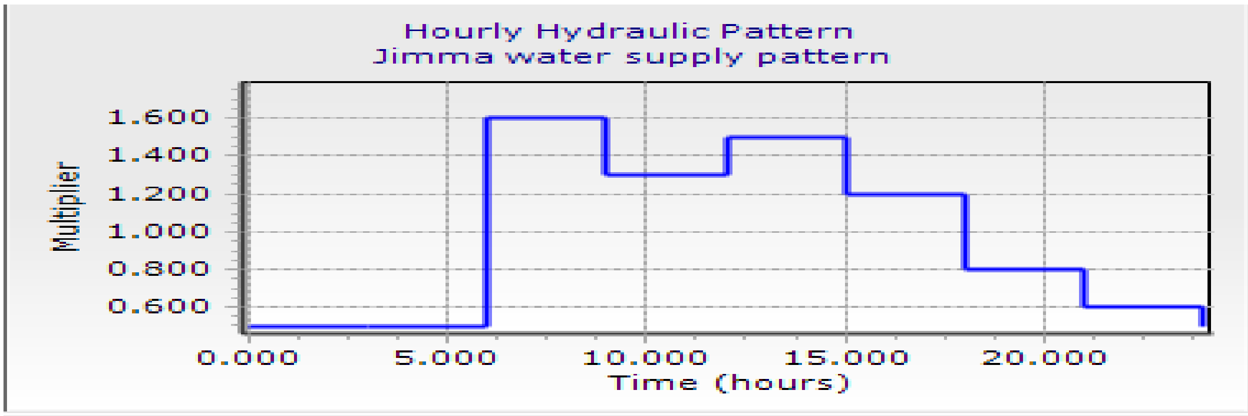

Figure 4.4: Existing hourly pattern of Jimma town within 24 hours

4.3.2. Pressure of existing water supply distribution network

At low peaks through night hours the pressure in the system becomes high and the leakage loses expected to increase whereas at high peaks the pressure becomes small and the leakage losses expected to decrease. High value of pressures affects adversely the hydraulic performance of the distribution network at night time (4:00 AM) during low consumption period, the pressure in the system become high.

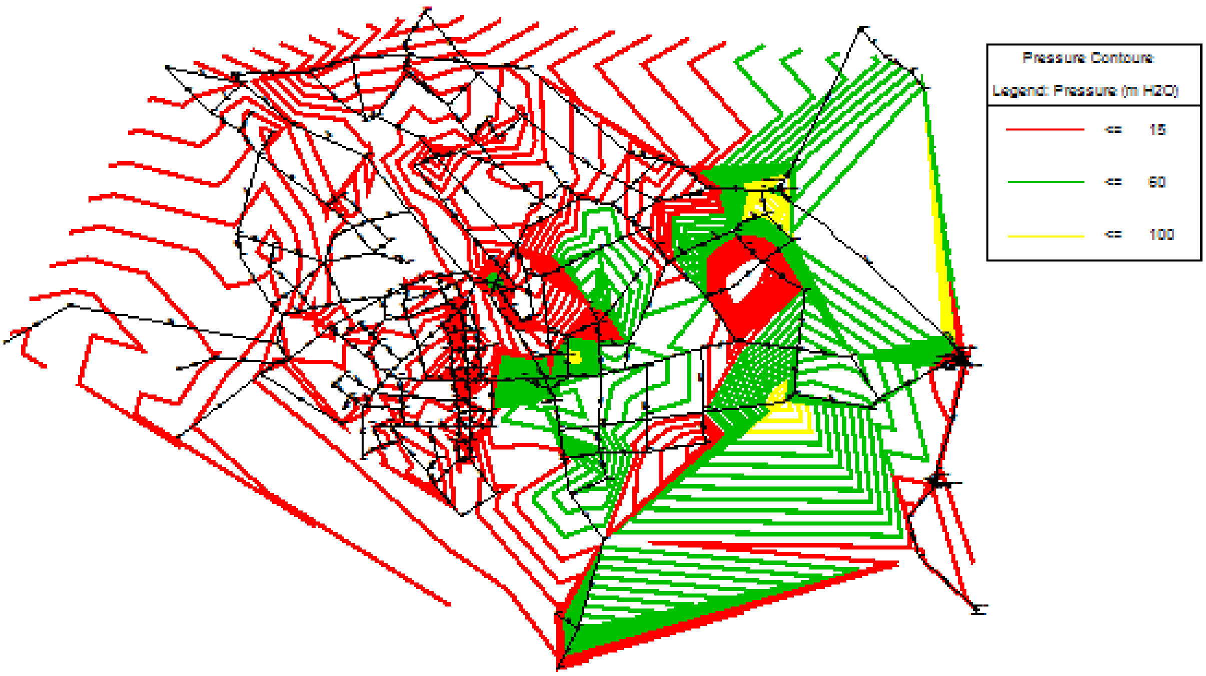

Figure 4.5: Pressure of existing water supply distribution network at 4:00 AM (night)

The red color presented on figure 4.5 indicates pressure less than 15 mH_2O, which implies greater than half of water distribution networks were below 15 mH_2O, which was below permissible range. As described in the figure 4.5, Green color indicates areas around university, koche, yetebaberut and Technic with pressure value between 15-60 mH_2O, which was with in permissible range. The pressure above permissible range indicated by Yellow color on figure 4.4 was areas around Jiren and Mikael church. It is based on the population served, types of dwellings and topography in the area. The pressure at node depends on the adopted minimum and maximum pressure within the network, topographic circumstances, source position, storage elevation and the size of the network.

Table 4.8: Simulated result of pressure at low water consumption hour (4:00 AM)

Pressure range value	$\leq$ 15 mH2O	15-60 mH2O	$\geq$60 mH2O
Number of nodes	190	34	7
Percentage	82.25	14.71	3.04

The result of simulation run was obtained after model constricted from the input of existing data a total node of 231 was reported from the project inventory dialog box software. The number of nodes on each pressure range were counted from the project inventory dialog box software. Table 4.6, show that at low water consumption hour (4:00 AM), 14.71 % nodes have been observed with in recommended serviceable pressure (15 mH_2O to 60 mH_2O) while 82.25 % and 3.04 % were below and above permissible value respectively. According to Yetayal, (2019), existing Finote-Selam town water supply distribution system from the total nodes 2.23 %, nodes have pressure below 15 mH_2O and 97.77 % have permissible pressures between 15 mH_2O and 60 mH_2O. This implies that the percentage of permissible pressure for Jimma town water supply distribution system were lower than Finote-Selam town, the topographical landscape of Jimma town was almost similar to Finote-Selam town. Due to, there is greater demand than the design demand, lack of maintenance, improper function of pump, interruption of electric power in pumped pressure system, inadequate pipe capacity and availability of residences on higher ground of the town. Generally, the high and low pressure were identified in the Jimma water distribution system were lower than Finote-Selam town. Detail pressure result of existing water distribution network was described on Appendix C.

4.3.3. Velocity of water in the existing pipe water distribution network

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 analysis involves the determination of the pipe flows and pressure heads that satisfy the continuity and energy conservation equations (Rossman,*et al*., 2000).

Although the both design guide line have different values on the same idea, the study was conducted using velocity standards given by MoWR water supply design criteria (2006). High consumption of water was occurred at morning time (8:00 AM).

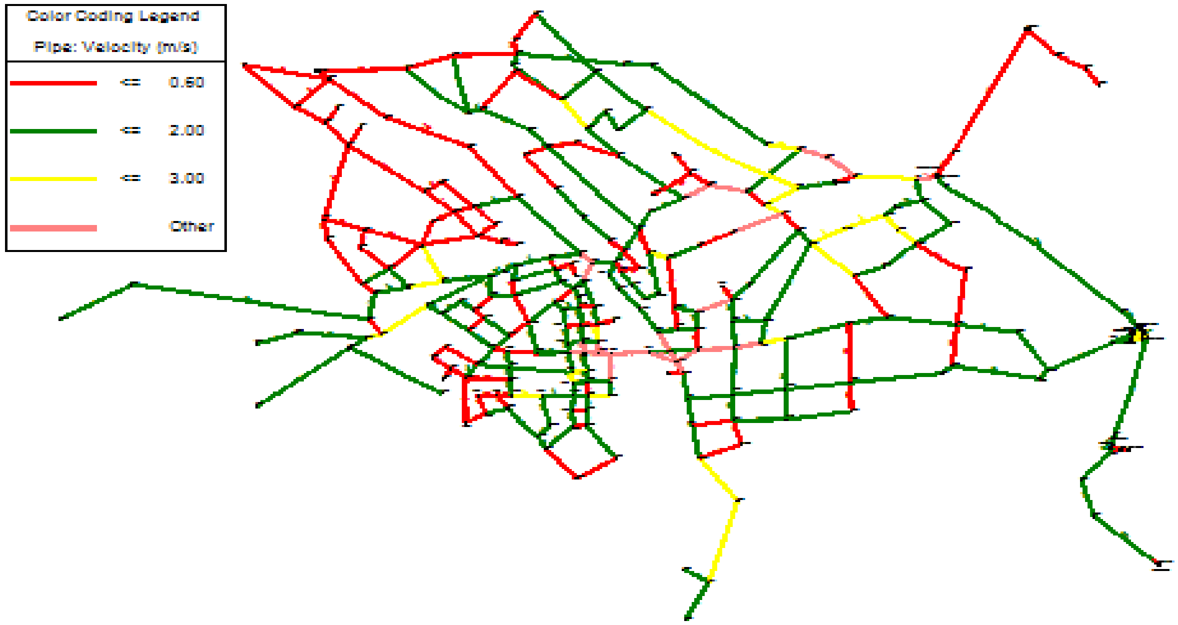

Figure 4.6: Velocity in the existing distribution network at 8:00 AM (Morning)

The red color which have been described on the figure 4.6 with velocity value less than or equal to 0.6 m/s, which indicates below velocity permissible range areas. Almost half of the distribution network described by Green color on figure 4.6 were in different areas like Hospital, Nokie, Yetebaberut, Dipo , Mercato and etc, was with in permissible velocity range (0.6 m/s- 2 m/s). Yellow color presented on figure 4-5 with velocity value range of 2 m/s - 3 m/s were areas around Maremiya and University kollo ber, was above permissible value (2 m/s).

Table 4.9: Simulated results of velocity in the existing distribution network (8:00 AM)

Velocity range (m/s)	Count	Count (%)
≤0.6	112	34.25
0.6-2	165	50.46
≥2	50	15.29
total	327	100

As indicated in table 4.9, 34.25 %, 50.46 % and 15.29 % of the pipes are below, within and above the permissible range of velocity respectively. 29.31 % of the pipes of existing Finote-Selam town water supply distribution system are within the permissible range of velocity

(Yetayal, 2019). It can be concluded that Jimma city water supply distribution system has an indicator of water quality problem because 34.25 % of pipes in the distribution system have velocity that causes to water stagnation which causes sediment deposition in the pipe and head loss happen in low velocity pipe water supply systems. While by comparing the permissible velocity value of Finote-Selam town with Jimma town, the Jimma town velocity value were more permissible. The diameter of pipes distributed in Jimma town half of water supply distribution network was more satisfactory than Finote-Selam town for effective flow of water; this was the reason why Jimma town water supply distribution network velocity values were more permissible. Detail velocity result of existing water distribution network was described on Appendix D.

4.3.4. Sustainability Index indicators

4.3.4.1.Reliability analysis of existing water supply distribution network

Water demand reliability is the probability that the available water supply meets the water demand during the period of simulation. The number of pressure and velocity under permissible or satisfactory range were 34 and 165 respectively. The satisfactory ranges of pressure value were from 15 mH_2O up to 60 mH_2O while the satisfactory range of velocity value were from 0.6 m/s up to 2 m/s. Based on equation 3.4;

$\mathrm{REL_p} = \frac{34}{231} = 0.15$ (Reliability due to pressure)

$\mathrm{REL_V} = \frac{165}{327} = 0.505$ (Reliability due to velocity)

$\text{Average REL} = \frac{0.15+0.505}{2} = 0.33$

This reliability value indicates that the probability of distribution system under satisfactory condition has been 0.33. The reliability values of Bahirdar town water supply system were 0.49 (Abay, 2019). This indicates that the probability of water supply distribution system of Bahirdar city was more satisfactory than Jimma town. The pressure and velocity values of Jimma town water supply distribution system was not satisfactory as compared to Bahirdar city, due to source position and narrow diameter of pipe, this is the reason why reliability value was less.

4.3.4.2.Vulnerability analysis of existing water distribution network

Vulnerability expresses the severity of failures water supply distribution network. The summation of pressure and velocity value which have been below and above satisfactory value were 93 mH_2O and 178.41 m/s respectively. Based on equation 3.3;

$\mathrm{VUL_p} = \frac{93}{1228} = 0.076$ (Vulnerability due to pressure)

$\mathrm{VUL_v} = \frac{178.41}{372.85} = 0.48$ (Vulnerability due to velocity)

$\text{Average VUL} = \frac{0.076+0.48}{2} = 0.278$

This vulnerability value indicates that the magnitude or duration of an unacceptable state of WDS in a certain time scale has been 0.278. The vulnerability value of Bahirdar city was 0.14 (Abay, 2019). This indicates that the probability of failures of Jimma town water supply distribution system was greater than Bahirdar city. This was because existing pressure distribution of Jimma town water supply distribution system were leads the pipes to become failure.

4.3.4.3.Resiliency analysis of existing water supply distribution network

Resilience is the probability that a successful period follows a failure. The number of satisfactory value of pressure and velocity which were follows unsatisfactory values have been 13 and 71 respectively. Whereas the number of pressure and velocity values under unsatisfactory condition have been 197 and 162 respectively. Based on equation 3.5;

$\mathrm{RES_P} = \frac{13}{197} = 0.066$ (Resiliency due to pressure)

$\mathrm{RES_v} = \frac{71}{162} = 0.44$ (Resiliency due to velocity)

$\text{Average resiliency} = \frac{0.066+0.44}{2} = 0.253$

This resiliency value indicates that the probability of how fast the water supply distribution system recovers from a failure has been 0.253. The resiliency values of Bahirdar city water supply distribution system were 0.35 (Abay, 2019). This indicates that the probability of

Bahirdar city water supply distribution system recover from failure was greater than Jimma town, since Bahirdar city was topographically more flat than Jimma town. Due to the topographical position of Jimma town it is difficult to recovery water supply distribution system from failure.

4.3.5. Sustainability index

The sustainability index (SI) represent the aggregate sum of the performance of water supply distribution network based on the values of technical performance indicators especially pressure and velocity. Based on equation 3.6;

$$\mathrm{SI_p} = [0.15 * 0.066 * (1 - 0.076)]^{1/3} = 0.209$$

$$\mathrm{SI_v} = [0.505 * 0.44 * (1 - 0.48)]^{1/3} = 0.488$$

$$\text{Average SI} = \frac{0.209 + 0.488}{2} = 0.349$$

Table 4.10: Performance indicator of existing Jimma city WDS

Performance criteria	Pressure	Velocity	Average
Reliability	0.15	0.505	0.33
Resiliency	0.066	0.44	0.253
Vulnerability	0.076	0.48	0.62
SI	0.209	0.488	0.349

The overall sustainability index was computed by taking average value of velocity sustainability index and pressure sustainability index. Each index was computed by reliability, vulnerability and resilience values. As discussed on table 4.10, sustainability based up on velocity sustainability indicator was medium but unacceptable value which is 0.488 while pressure was in the unacceptable range which is 0.209. The overall sustainability was medium but unacceptable, the value was 0.349. The sustainability index values of Bahirdar city water supply distribution were 0.42 (Abay, 2019). While comparing the sustainability index value of Bahirdar city with Jimma town, Bahirdar city water supply distribution system was more sustainable. Since the growth of population and expansion of city of Bahirdar was almost similar with Jimma town. The sustainability performance indicators of Jimma town water supply distribution system were less, this is the reason behind why the overall sustainability index of Jimma town WDS was less as compared to Bahirdar town WDS. Therefore; the existing water supply distribution system of Jimma town is not sustainable

4.4. Water loss Analysis

4.4.1. Water loss trend of the city

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.

Table 4.11: Water loss trend of Jimma city

Year (E.C)	Total production (m^3/yr)	Total Billed data (m^3/yr)	Total loss (m^3/yr)	% of losses
2007	3,418,778	1,383,668	2035110	59.52
2008	3,392,100	2,051,276	1340824	39,52
2009	4,715,581	2,481,311	2234270	47.38
2010	5,560,235	2,500,498	3059737	55.02
2011	5,791,884	3,601,578	2190306	37.8
2012	6,275,320	4,235,490	2039830	32.5

It is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost of water saved. JWWA leak detection and accountability committee (1996) recommended 10 % as a benchmark for UFW. Sonaje, (2015) 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 Jimma City was 32.5 % in the year 2012 (E.C), showing that the loss in the city was needs concern, according to the description given by (Sonaje, 2015). Thus, the loss must be controlled and monitored.

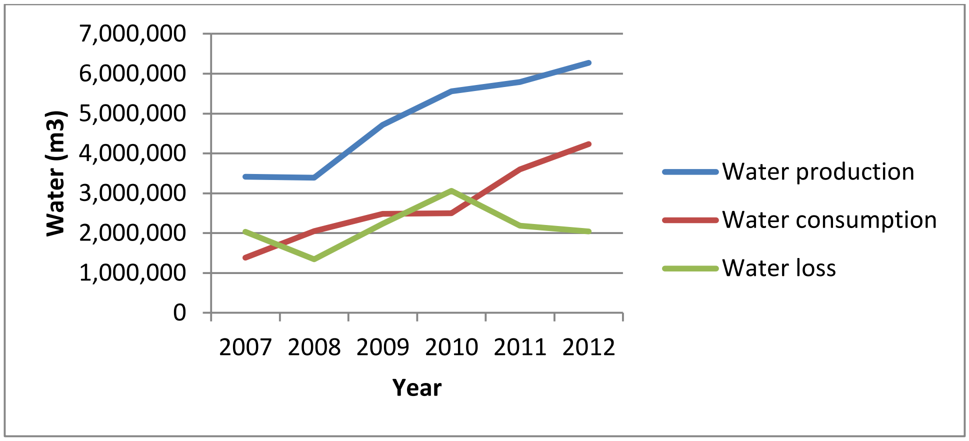

Figure 4.7: Annual water production, consumption, and loss trends

The water loss trend of the city showing that loss was fluctuated from year to year. While conducting observation of the study area in roads, star-hotels construction in Jimma and breakage of pipes was occurred, and this maximized water loss. An interview result showing that, once a leak identified and repairs after 74 hour on the average. This implies that, leak was not a timely response and it maximized water loss. However, both water loss increased and decreased depending on time of construction and awareness creation between people.

Figure 4.7 presents, the amount of water production and water consumption between 2007 and 2012 E.C. This analysis is important to understand the gap between supplied water and water consumption. The results showed that between 2007 and 2012 E.C the amount of water coming to meet with the supply requirement. In the period 2007 the total incoming water to city is lower as compared to other however incoming water amount is still able to meet the supply requirements. In 2012 E.C the gap between supplied water and water consumption is found to the smallest as compared to other year.

4.4.2. Major factors contributing to high levels of water loss in Jimma town

There were several reasons for the high level of water loss in Jimma. Such as illegal connections, age of pipe network, Poor maintenance of networks and unaccounted for water mentioned in detail below.

4.4.2.1.Illegal connections

There are a significant number of illegal uses of water within distribution system in Jimma City. The number of households who do not pay water rates but receive water from its distribution system without knowledge of the authority. Especially areas surrounding Jimma which are not under city administration likes Bocho-Bore and Amenu were illegally connect water distribution lines and they doesn’t pay water tariff. Consequently, they contribute significantly to apparent losses and revenue loss to the authority. These connections were poorly laid just a few meters below the surface and break resulting in real losses taking placed in the form of leakage. Illegal connections are therefore significant concern of water utilities.

4.4.2.2.Age of pipe network

It is estimated that nearly more than 25 % of the pipe network in the city was laid over 25 years ago (JTWSSA, 2020). The main duties which made more than half a month is checking of each customer (door to door water connection) by sounding rod .In this time get so many invisible and visible leakages both on the private connection and also on the main line. Totally up to compile this report identify 9135 m service line, (682 customer connections) from this we get 194 leaked connections, most leakages are easily detectable and the rest are cannot maintain because of its long service age. So it needs to change by new line. These lines are including DCI (Ducktail Cast Iron). The aged pipe is especially in the central part of the city and in densely population areas like in Merkato, Kochi, Agepi and etc. All these materials suffer from degradation over time due to operational measures, environmental conditions and general wear and tear result in increased leakage in the network. It is therefore necessary to replace older mains so that less leakage occurs.

4.4.2.3.Poor maintenance of networks

In some places like expansion areas including Kitto-Furdisa, Furistale, Bocho-Bore and etc., water authorities has performed a maintenance program for distribution system. For partial sub-cities, but in all branches poor maintenance of network and poor man power management for maintenance, it is so difficult to find financial support to renew the water distribution system. Thus, the lack of finance to buy proper materials and poor construction resulted in increased leakage in the system.

4.4.2.4.Unaccounted for water

Not all the water that goes in the distribution pipe reaches the consumers. Some portion of this water wasted in the pipelines due to defective pipe joints, cracked and broken pipes, flood hazard, fault valves, and fittings. There is no enough drainage systems in the city. Besides, to this, some quantity of water was lost due to unutilized and illegal connections. The losses, or uncontrolled for water are expressed as a percentage of the total production.

General speaking, from all the above listed factors contributed for water loss of the study area, illegal connections was the dominant factor, especially around Bocho-bore and Amenu residential areas.

CHAPTER FIVE

5. CONCULUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The future population and water demand of the town has been projected up to the year 2040 using year 2007 as base year. The existing water distribution system of Jimma town was established for an estimated population of 109,000. But as compared with the current population (216,204), it was served beyond the life and low coverage in the town. The current water production of Jimma town was found as 72.63 l/s, besides comparing with the forecasted maximum water demand of design period (638.59 l/s) the water supply of the town was not sustainable.

The pressure in most distribution is below the standard, we were observed high pressure greater than 70 m from the model out in some distribution which probably attributed due to under sized pipe installation. In general, the simulated hydraulic result indicated that the current hydraulic performance of Jimma town distribution system is not satisfactory. But it doesn't mean that the system is not functional.

The average resiliency, reliability and vulnerability value of existing water supply distribution network of sustainability performance indicators were 0.235, 0.33 and 0.62, respectively. The overall sustainability index was 0.349 but 0.488 for velocity and 0.209 for pressure. The simulated hydraulic result indicated that the current hydraulic performance of the water supply system show that velocity based sustainability is higher than pressure based sustainability. It was concluded that the current water distribution network of was in poor performance and were not conducted adequate water pressure to the various demand categories of the town. Therefore; the existing water supply distribution network of Jimma city was not sustainable.

The total water loss has been evaluated on percentage of water production and consumptions. Generally, based on the analysis results the current (2012 E.C) total water loss from the system was 2,039,830 m^3 /year that account 32.5 % from the total water production in the study area. This was due to unauthorized consumption, metering inaccuracies and data handling errors.

5.2 Recommendations

In order to improve the sustainability problems of Jimma town water supply and distribution system the following activity should be required.

- To increase the sustainability of water supply distribution system finding additional source of water should be mandatory.
- It was also observed that large amount of water were lost as result of leakage due to pipe break down. So, it is much advised that; Operation and Maintenance strategy in order to decrease leakage and those pipes were performed in poor status and served for a long period should be replaced by new pipe. In addition to that spare parts and fittings should be applied that can meet appropriate standards.
- In order to achieve permissible pressure range in the distribution systems, it is necessary to provide pressure control valve, establishing boosting station and replacing the old pipes with the new one that has a diameter required size.
- As the current water consumption in the town is much smaller of the recommended per capita consumption so, it is necessary revising the design and rehabilitates water sources supply if financial and environmental conditions allow.
- Generally, due to sustainability assessment is a wide concept and due to limited time and resources, this study is not adequately addressing all sustainability indicators and all areas in the city.so, further study should be conducted on all sustainability indicators including water quality analysis by using different assessment methods.

REFERENCES

Abay, A. (2019). *SUSTAINABILITY ASSESSMENT OF URBAN WATER SUPPLY SYSTEM (A CASE STUDY OF BAHIR DAR CITY, ETHIOPIA).*

ADSWE. (2016). *Wojji multi village water supply project final document.*

Akbar, HM Delwar, Minnery, John R, van Horen, Basil, & Smith, Phil. (2007). Community water supply for the urban poor in developing countries: The case of Dhaka, Bangladesh. *Habitat International,*, 31(1), 24-35.

Armstrong, J. (2001). *Principle of population projection:A Handbook for researcher and practitioners.* Norwell,MA:Klumer Acadamic publisher.

ASCE. (2008). American Society of Civil Engineers and United Nations Educational, Scintific and Cultural Organization. Sustainabilty Criteria for Water Resource Systems.

AWWC. (2012). *Computer modeling of water distribution systems (Vol. 32): American Water Works Association.*

Aydin and Nazli Yonca. (2014). Sustainability Assessment of Urban Water Distribution system. . *Water resources management, v. 28(no. 12), pp. 4373-4384*.

Belay, A. (2012). HYDRAULIC NETWORK MODELING AND UPGRADING OF LEGEDADI SUBSYSTEM WATER SUPPLY .

Bhadbhade, N. (2009). *Performance evaluation of drinking water distribution system, using Hydraulic simulation software for the city of oilton,Oklahome.*

Brook, D. (2006). An operational definition of water demand management. *", International journal of water resources development,,* Vol 22, No 4, pp 521-528.

Christodoulou, Symeon E, & Fragiadakis, Michalis. (2014). Vulnerability assessment of water distribution networks considering performance data. *J ournal of Infrastructure Systems, 21(2), 04014040.* .

CSA. (2007). *Central Statistical Authority.* Addis Ababa, Ethiopia.

Dawe, P. (2000). Workshop on Hydraulic Network Modeling with WaterCAD V8i. Water distribution modeling software.

Degnet, A. (2011). *Access to improved water source and satisfaction with services, evidence from rural Ethiopia development strategy and governance division. Addis Ababa, Ethiopia: International food policy research institute Ethiopia strategy support program ii .*

Dighade, et al. (2014). Challenges in water loss management of water distribution system in developing countries. *International Journal of Innovative Research in Science, Engineering and Technology, 3 (6), 13838 - 13846*.

Fallis, P, Hübschen, K, Oertle, E, Ziegler, D, Klingel, P, Knobloch, A, . . . Laures, C. (2011). *Guidelines for Water Loss Reduction–A Focus on Pressure Management:*.

Gleick, P. H. (2003). *Global freshwater resources: soft-path solutions for the 21st century*.

Grady, C. A. Wing, S . C and Blatchlet, E.R. . (2014). *Global potable water: Current status, critical problems and future perspectives.* Springer international publishing, Switzerland.

Grady, C. W. (2014). Global potable water: Current status, critical problems and future perspectives.

Harry, E. (2012). Harry, E. (2012). Water Supply System Concept. USA, US Fire Adiminstration. .

Hashimoto, Tsuyoshi, Stedinger, Jery R, & Loucks, Daniel P. (1982). Realibility, resiliency, and vulnerability criteria for water resource system performance . *evaluation. Water resources research, 18(1), 14-20.*

Hopkins, M. (2012). *Critical node analysis for water distribution system.*

Howard G and Bartram J. (2003). *Domestic water quantity, service level and health.* Geneva,Switzerland: World Health Organization publication/WHO.

Jimma. (2010). *Socia-economic activity of Jimma town.* Jimma, Ethiopia: Jimma town muncipality.

JTWSSA. (2020). *Jimma Town Water Supply and Sewerage Authority.* Jimma, Ethiopia.

JWWA. (1990). *Design criteria for water work facilities.*

Kassa, M. (2017). Evaluation of water supply and demand: The case of Shambu town, Western Oromia, Ethiopia. *International Journal of Water Resources and Environmental Engineering*.

Khatri, Krishna B, Vairavamoorthy, Kalanithy, & Akinyemi, Edward. (2011). Framework for computing a performance index for urban infrastructure systems using a fuzzy set approach. *Journal of Infrastructure Systems,*, 17(4), 163-175.

Kiongo, J. (2005). *The Millennium Development Goal on Poverty and the Links with Water Supply, Sanitation, Hygiene and HIV/AIDS:A case Study from Kenya. IRC International Water and Sanitation Center,.* Delft, The Netherlands.

Kochhar, k, Pattillo, C., and Sun, Y. (2015). *Issues in managing water challenges and policy instruments. Published by IMF.*

Kostas and Chrysostomos. (2006). Estimating urban residential water demand determinants and forecasting water demand for Athens metropolitan area, 2000-2010. ." *South-Eastern Europe Journal of Economics(Performance-Based Service Contracting", Water Supply and Sanitation Board):* , 47-59.

Lai, E, Lundie, S, & Ashbolt, NJ. (2008). Review of multi-criteria decision aid for integrated sustainability assessment of urban water systems. *Urban water journal,*, 5(4), 315-327.

Lansey, K. (2000). *Optimal Design of Water Distribution Systems, In ―Water Distribution Systems Handbook‖.* Mays, LW: McGraw-Hill, New York.

Lee, Ronald D, & Tuljapurkar, Shripad. (1994). Stochastic population forecasts for the United States: Beyond high, medium, and low. *Journal of the American Statistical Association,*, 89(428), 1175-1189.

Linsley, Ray K, Franzini, Joseph B, Freyberg, David L, & Tchobanoglous, George. (1985). *Water resource engineering.* 1992, McGraw Hill Inc. .

Loucks. (1997). Quantifying trends in system sustainability. . *Hydrological Sciences Journal, 42(4), 513-530.* .

Loucks, D. (1997). Quantifying trends in system sustainability. *Hydrology science journal* , 42(4):513-530.

Lundie, Sven, Ashbolt, Nicholas, Livingston, Daniel, Lai, Elizabeth, Kärrman, Erik, Blaikie, Jennifer, . . . Ashbolt, Nicholas J. (2008). *Sustainability framework. WSAA Occasional Paper(17 PART A).*

Melaku, A. (2015). *Thesis on Assesment of water loss in water supply Net works in case of Debre Markos town.* Addis Ababa Univeristy.

MOIE. (2015). *Second growth and transformation national plan for the water supply and sanitation sub-sector* . 2015/16-2019/20.

Motevallian, Seyed Sajed, Tabesh, Massoud, & Roozbahani, Abbas. (2014). *Sustainability assessment of urban water supply and distribution systems: a case study. Paper presented at the The second Iranian National conference on applied research in water resources.*

MoWE. (2006). *Public and commercial water demand of Ethiopia* .

MoWR. (1997). *Data compilation and analysis project.*

MoWR. (2006). Water supply design guideline.

NRC. (2006). *Drinking water distribution system: Asessing and reducing risks.* The national acadamics press, Washington D.C.

OWWDSE. (2010). *Oromiya Water Works Design and Supervision Enterprise, Water supply design guide line.* Addis Ababa, Ethiopia.

Park, Daeryong, and Um, Myoung-Jin. (2018). Sustainability Index Evaluation of the Rainwater Harvesting System in Six US Urban Cities. *J ournal of Sustainability, 10(1), 280.* .

Popawala, Reena, & Shah, NC. (2011). *Evaluation of sustainability index for urban water management system. Paper presented at the Proceedings of the 2nd international conference on environmental science and development, IPCBEE.*

Renwick, D. (2013). The effects of an intermittent piped water network and storage practices. *For Partial Fulfillment of the Degree of Master in Civil and Environmental Engineering, Massachusetts Institute of Technology.*

Roger, C. (2013). Achieving Water Security, Lessons from Research in Water Supply. Sanitation and Hygiene in Ethiopia.

Rossman, Boulos and Altman. (2000). The discrete volume element method for modeling water quality in pipe networks. . *Journal of water resources planning and management* ., 119: 56-67.

Sahely, P. H and Maclean, L. M. (2006). Comparison of on-site and upstream greenhouse gas emissions from Canadian municipal wastewater treatment facilities. *journal of environmental engineering and science.*

Sandoval S, M. D. (2011). Sustainability index for water resouces planning and management. *Journal of water resources planning and management, 137, 381-390.*

Solomon. B. (2011). An Assessment on the Status of Water Supply and Sanitation in Ethiopia. .

Sonaje. (2015). *A review of modeling and application of water distribution networks software's.*

Sonaje, Nitin P, & Joshi, Mandar G. (2015). A review of modeling and application of water distribution networks (WDN) softwares. *Int. J. of Tech. Research and Appl,,* 3(5), 174-178.

Sumithra, R. (2013). Feasibility Analysis And Design of Water Distribution System For Tiurnelveli Corporation Using Loop And WaterGEMS Software. *International Journal on Applied Bioengineering.* .

Taha, e. a. (2016). Methods of Assessment of Water Losses in Water Supply Systems.

Temesgen M. (2018). Water Supply Distribution System Design Using in Holeta Town Wombera Woreda East Shewa Zone of Oromia region, Ethiopia, Arba Minich university.

Temesgen.M. (2018). Water Supply Distribution System Design Using in Holeta Town Wombera Woreda East Shewa Zone of Oromia region, Ethiopia, Arba Minich university.

Thomas,et al. (2003). Advanced Water Distribution Modeling and Management.

Thornton, Julian, Sturm, Reinhard, & Kunkel, George. (2008). *Water loss control: McGraw Hill Professional.*

Venkateswara, S. (2005). *Water supply engineering for the course of water supply and sanitary engineering.* State institute of vocational education, government of Andrhera predesh.

Walski, Thomas M, Chase, Donald V, Savic, Dragan A, Grayman, Walter, Beckwith,. (2003). *Advanced water distribution modeling and management.* .

WaterGEMS. (2016). *WaterGEMS V8i user guide.*

WCED. (1987). *Report of the world commission on environment and development.* Oxford university press, Oxford,UK.

WHO. (2011). *Progress on sanitation and drinking water -2014 update.* World Health Organization cataloguing in publication date.

Wonduante. (2013). *Assessing the challenges of sustainable water supply in Gondar town, Ethiopia Addis Ababa Addis Ababa University.*

World-Bank. (2011). *Environmental and Social Impact Assessment feasibility study document.* Jimma, Ethiopia.

Yetayal, A. (2019). *ASSESSMENT OF THE HYDRAULIC PERFORMANCE OF EXISTING WATER SUPPLY DISTRIBUTION SYSTEM: A CASE STUDY ON FINOTE-SELAM TOWN, AMHARA REGION, ETHIOPI.*

Yitayh, L. (2011). *Assessment of problems to sustainability of rural water supply and management systems in MachakelWoreda, Amhara region.*

Zahraie, Banafsheh, Karamouz, Mohammad, Kerachian, Reza, & Asadzadeh, Masoud. (2005). In *Evaluation of water sector performance: A case study Impacts of Global Climate Change* . (pp. (pp. 1-12)).

APPENDICES

Appendix A; Existing population distribution and areal consumption of Jimma town

Area	Local Name	Junctions	Population	Areal Demand
A1	SOS School	J-20, J-189, J-13, J-173	1482	0.497952
A2	Bekele	J-173, J-13, J-229, J-6	1397	0.469392
A3	Abedujalali Dabo bet	J-13, J-106, J-228, J-229	1557	0.523152
A4	Hussen Garage	J-106, J-107, J-227, J-228	1597	0.536592
A5	Shinen Gebi Hospital	J-6, J-229, J-8, J-1, J-18, J-209	1374	0.461664
A6	Yetebaberut	J-229, J-228, J-8, J-99, J-191	1907	0.640752
A7	Mikakeal	J-228, J-227, J-16, J-191	2272	0.763392
A8	Agepi	J-10, J-18, J-208, J-1	571	0.191856
A9	Haji yentsa	J-208, J-1, J-14, J-108, J-95	1352	0.454272
A10	Tourist hotel	J-8, J-99, J-94, J-96	2092	0.702912
A11	Nokie	J-1, J-8, J-96, J-14, J-177, J-210	1796	0.603456
A12	Boni Hotel	J-14, J-108, J-98, J-177	818	0.274848
A13	Ferde beti	J-139, J-82, J-83, J-12	1412	0.474432
A14	Fesash	J-139, J-85, J-221, J-220, J-133, J-84, J-83, J-82	2347	0.788592
A15	Depo	J-83, J-84, J-79, J-78, J-72, J-74, J-73	3502	1.176672
A16	Oromiya Bank	J-92, J-119, J-88, J-87	1482	0.497952
A17	Rift valley	J-84, J-133, J-86, J-5, J-4, J-23, J-91, J-19, J-119, J-92, J-116	3587	1.205232
A18	Kollo ber	J-127, J-93, J-94, J-96, J-210	2677	0.899472
A19	Mikael Condominum	J-16, J-227, J-15, J-188, J-192, J-190	2577	0.865872
A20	Addis Ababa exit	J-188, J-226, J-186, J-187, J-192	2518	0.846048
A21	Honey land hotel	J-190, J-192, J-195, J-202, J-203, J-193	3102	1.042272
A22	University	J-193, J-203, J-202, J-201, J-200, J-197, J-93	2407	0.808752
A23	University Jerba	J-202, J-196, J-37, J-35, J-200, J-201	1697	0.570192
A24	Kochi	J-91, J-199, J-19	1480	0.49728
A25	Hospital	J-199, J-17, J-198, J-125	1974	0.663264
A26	Maremiya	J-123, J-121, J-128, J-21, J-120, J-131	982	0.329952

A27	Maremiya jerba	J-122, J-134, J-79, J-80, J-89, J-123, J-131, J-216, J-122	2776	0.932736
A28	Betel church	J-131, J-120, J-124, J-213, J-214, J-215, J-216	2486	0.835296
A29	furistale	J-130, J-129, J-132	574	0.192864
A30	Gebriel	J-29, J-144, J-9	1665	0.55944
A31	Sarise	J-56, J-61, J-218, J-144, J-29, J-55, J-62	2092	0.702912
A32	Kitto furidissa kebele	J-64, J-57, J-33, J-71	1499	0.503664
A33	Agri	J-33, J-67, J-66, J-71	1183	0.397488
A34	Materix	J-33, J-219, J-75, J-67	1798	0.604128
A35	Gerar	J-75, J-81, J-225, J-32	2392	0.803712
A36	Kito	J-30, J-224, J-54, J-32, J-225, J-81	2702	0.907872
A37	Tele	J-75, J-47, J-76, J-81	2784	0.935424
A38	Eyesuse	J-38, J-76, J-28, J-30	2674	0.898464
A39	Gebi Adarash	J-53, J-52, J-68, J-60, J-43, J-103	3012	1.012032
A40	Mariyam hawelt	J-52, J-53, J-45, J-44, J-70, J-69	3482	1.169952
A41	Waliya hotel	J-50, J-44, J-70, J-49	2381	0.800016
A42	Aratu Anbessa	J-50, J-110, J-49, J-46, J-51, J-145	1987	0.667632
A43	Mazegaja	J-51, J-46, J-49, J-48, J-14, J-105	982	0.329952
A44	Ferenji arada	J-49, J-48, J-69, J-70	1480	0.49728
A45	Ferenjii arada warkaw	J-48, J-142, J-141, J-140, J-69	3284	1.103424
A46	Secondary school	J-69, J-140, J-149, J-148, J-68, J-52	3796	1.275456
A47	Poly technic	J-60, J-43, J-59, J-148, J-68	2482	0.833952
A48	Mariyam sefr	J-148, J-59, J-147, J-149	2675	0.8988
A49	Network	J-166, J-41, J-42, J-113, J-40, J-154	4087	1.373232
A50	Metena	J-27, J-154, J-146, J-152, J-230, J-155, J-153	3917	1.316112
A51	Metena	J-154, J-27, J-231, J-166	2983	1.002288
A52	Mtena mesgedi	J-231, J-150, J-147, J-166	3112	1.045632
A53	Merkata mesgedi	J-150, J-171, J-140, J-149, J-147	3749	1.259664
A54	Metena chafi	J-156, J-152, J-230, J-155	1712	0.575232
A55	Tesema hensa	J-155, J-153, J-172, J-159, J-157, J-156	3622	1.216992

A56	Faremide	J-141, J-143, J-137, J-138, J-142	2540	0.85344
A57	Gosaye foto beti	J-137, J-135, J-105, J-142, J-138	2812	0.944832
A58	warekawe	J-143, J-104, J-137, J-179	3499	1.175664
A59	Commercial bank main	J-137, J-135, J-178, J-179	2684	0.901824
A60	Shewa ber hotel	J-104, J-179, J-184, J-164	3007	1.010352
A61	Merkato bank	J-178, J-179, J-184, J-176	3082	1.035552
A62	Merkato oromiya bank	J-164, J-183, J-184, J-163	3503	1.177008
A63	Mehal merkato	J-184, J-183, J-176, J-100	2889	0.970704
A64	Awash Bank	J-163, J-165, J-183, J-162	3385	1.13736
A65	Hiber hensa	J-183, J-100, J-101, J-167, J-174, J-162	2681	0.900816
A66	Aba jifar bank	J-165, J-162, J-174, J-170	2479	0.832944
A67	Besheshi ber	J-170, J-160, J-169, J-174	2374	0.797664
A68	Besheshi	J-167, J-174, J-169, J-168	2232	0.749952
A69	Besheshi chafi	J-160, J-181, J-180, J-169	2194	0.737184
A70	Beherawe lottery	J-181, J-180, J-161, J-182	1681	0.564816
A71	Gulte gebeya	J-182, J-161, J-158, J-151, J-136	3577	1.201872
A72	Dr.chala clinc	J-150, J-171, J-163, J-231, J-165	3900	1.3104
A73	Chat tera	J-231, J-27, J-153, J-172, J-160, J-170, J-165	4112	1.381632
A74	Haji hensa	J-172, J-159, J-157, J-158, J-161, J-181, J-160	3800	1.2768
A75	Police menoriya	J-140, J-171, J-163, J-164, J-104, J-143, J-141	3552	1.193472

Appendix B; Population forecasting

$$P_n = P_o(1 + r)^n$$

Where Pn = Population at any year n;

Po = Base year population

r= Population growth rate (Based on the growth rate of Oromiya region)

Oromiya region population Growth rate for Urban

Year	2000-2005	2005-2010	2010-2015	2015-2020	2020-2025	2025-2030	2030-2035	2035-2040
G.rtae	4.7	4.6	4.4	4.2	4	3.8	3.6	3.4

(Source: GTP:2)

Sample calculation; Po = base year population (population at 2007) = 120,960

$P_{2008} = P_{2007}(1 + 0.482)^1$
$P_{2008} = 120960 \quad (1 + 0.482)^1 = 126762$

$P_{2009} = 126762(1 + 0.792)^1 = 132806$

The rest population were forecasted in this way.

Population forecasting by using Geometric method			
Year	G. rate	population	pop
2007	4.824	120960	120960 (Base)
2008	4.796	126761.2416	126762
2009	4.768	132805.2176	132806
2010	4.74	139100.1849	139101
2011	4.698	145635.1116	145636
2012	4.656	152415.8824	152416
2013	4.614	159448.3512	159449
2014	4.572	166738.3298	166739
2015	4.53	174291.5762	174292
2016	4.488	182113.7821	182114
2017	4.446	190210.5609	190211
2018	4.404	198587.434	198588
2019	4.362	207249.8178	207250
2020	4.32	216203.01	216204
2021	4.272	225439.2025	225440
2022	4.224	234961.7545	234962
2023	4.176	244773.7573	244774
2024	4.128	254878.018	254879
2025	4.08	265277.0412	265278
2026	4.032	275973.0115	275974

2027	3.984	286967.7762	286968
2028	3.936	298262.8279	298263
2029	3.888	309859.2867	309860
2030	3.84	321757.8833	321758
2031	3.76	333855.9797	333856
2032	3.72	346275.4221	346276
2033	3.68	359018.3577	359019
2034	3.64	372086.6259	372087
2035	3.6	385481.7444	385482
2036	3.552	399174.056	399175
2037	3.504	413161.1149	413162
2038	3.456	427439.963	427440
2039	3.408	442007.117	442008
2040	3.36	456858.5561	456859

Appendix C; Jimma town existing water supply distribution network junction result at low flow

FlexTable: Junction Table				
Current Time: 4.000 hours				
Label	Elevation (m)	Pressure (m H2O)	X (m)	Y (m)
J-1	1,690.00	34	262,956.28	847,863.35
J-2	1,750.00	94	265,355.43	849,795.68
J-3	1,735.00	83	265,078.54	849,885.94
J-4	1,701.00	26	263,302.91	849,263.42
J-5	1,698.00	29	262,980.36	849,101.86
J-6	1,703.00	34	262,862.40	847,278.57
J-7	1,705.00	36	263,448.40	848,627.71
J-8	1,705.00	30	263,319.24	847,884.34
J-9	1,702.41	16	258,565.25	851,243.87
J-10	1,665.00	59	262,485.66	847,838.52
J-11	1,652.00	58	263,068.69	845,109.56
J-12	1,668.00	55	262,164.20	848,905.61

J-13	1,698.00	38	263,302.08	847,027.97
J-14	1,640.00	84	262,955.49	848,114.95
J-15	1,665.00	74	265,318.85	847,584.82
J-16	1,726.00	13	264,419.52	848,177.10
J-17	1,783.21	-8	264,484.91	849,924.14
J-18	1,717.00	17	262,758.09	847,724.53
J-19	1,740.80	15	263,436.64	849,740.24
J-20	1,710.00	25	262,973.57	846,586.44
J-21	1,741.10	-15	262,459.52	850,711.10
J-22	1,707.00	-4	259,902.46	848,049.40
J-23	1,740.96	3	263,781.64	849,481.34
J-24	1,705.00	-5	259,760.97	848,008.07
J-25	1,714.00	-26	256,800.17	848,229.86
J-26	1,713.00	-18	258,688.21	847,937.61
J-27	1,718.10	-7	261,150.39	847,517.07
J-28	1,713.00	-6	259,836.58	848,536.98
J-29	1,709.00	8	259,063.47	850,745.96
J-30	1,719.00	-11	259,713.05	848,646.02
J-31	1,703.00	0	259,778.79	848,229.97
J-32	1,719.82	-11	259,739.05	849,290.52
J-33	1,730.24	0	266,974.01	846,680.59
J-34	1,725.00	7	266,794.31	845,888.30
J-35	1,741.00	63	264,866.95	849,568.24
J-36	1,728.00	3	266,670.28	846,324.15
J-37	1,741.00	72	265,122.78	849,635.61
J-38	1,737.00	6	267,301.17	848,009.88
J-39	1,710.00	0	261,215.98	849,113.06
J-40	1,711.00	1	260,506.35	847,517.84
J-41	1,715.00	-3	260,523.93	847,895.42
J-42	1,711.00	1	260,391.45	847,762.03
J-43	1,715.00	-5	260,483.16	848,297.83
J-44	1,716.00	-4	261,202.49	848,870.33
J-45	1,714.00	-2	261,081.17	848,802.08
J-46	1,716.00	-4	261,740.26	848,879.23
J-47	1,714.00	-3	260,496.79	848,678.80
J-48	1,718.00	-6	261,632.07	848,672.71
J-49	1,716.00	-4	261,573.19	848,824.52
J-50	1,718.00	-6	261,532.26	848,961.03

J-51	1,716.00	-4	261,775.72	848,749.12
J-52	1,714.00	-3	260,959.18	848,495.49
J-53	1,714.00	-3	260,948.98	848,741.08
J-54	1,714.00	-5	259,346.52	849,417.56
J-55	1,712.00	2	259,362.27	850,557.53
J-55	1,790.41	60	267,061.56	848,320.03
J-56	1,712.00	-1	259,581.22	850,289.23
J-56	1,730.00	10	266,978.33	847,952.02
J-57	1,704.00	7	260,323.75	849,738.69
J-58	1,712.00	-1	260,607.36	849,498.45
J-59	1,712.00	-1	260,739.37	848,097.53
J-60	1,713.00	-2	260,671.72	848,438.68
J-61	1,718.00	-7	259,704.84	850,507.03
J-61	1,732.41	15	266,991.92	846,848.88
J-62	1,714.00	0	259,478.98	850,733.40
J-63	1,718.00	-2	261,217.87	849,675.93
J-64	1,721.00	-10	260,487.15	849,849.40
J-65	1,713.00	-3	261,061.77	849,145.95
J-66	1,711.00	0	261,005.69	849,352.47
J-67	1,714.00	-4	260,831.87	849,216.17
J-68	1,717.00	-6	260,796.53	848,336.28
J-69	1,716.00	-4	261,183.42	848,512.09
J-70	1,714.00	-2	261,173.62	848,691.13
J-71	1,711.00	0	260,796.45	849,564.50
J-72	1,734.00	-10	261,592.53	849,782.12
J-73	1,747.00	-24	262,112.40	849,158.63
J-74	1,733.00	-9	261,857.89	849,442.14
J-75	1,708.00	2	260,291.52	849,115.17
J-76	1,702.00	7	260,162.06	848,605.85
J-77	1,702.00	-3	259,595.02	847,889.36
J-78	1,740.00	-16	261,284.15	850,169.22
J-79	1,752.00	-28	261,519.38	850,267.06
J-80	1,740.00	-16	261,783.08	850,324.11
J-81	1,713.00	-4	259,977.60	848,829.22
J-82	1,742.00	-19	262,390.05	848,843.25
J-83	1,730.00	-7	262,243.12	849,033.10
J-84	1,738.00	-14	262,390.96	849,300.19
J-85	1,739.00	-16	262,327.12	848,634.17

J-86	1,748.00	-22	262,677.59	848,952.86
J-87	1,742.00	-5	262,527.49	849,705.43
J-88	1,739.00	-2	262,893.53	849,960.40
J-89	1,727.00	-3	262,194.85	850,161.72
J-90	1,740.00	-3	262,731.70	850,200.81
J-91	1,744.00	10	263,613.46	849,584.37
J-92	1,725.00	-1	262,818.59	849,660.39
J-93	1,736.00	7	264,046.77	849,126.73
J-94	1,717.00	20	263,617.27	848,218.18
J-95	1,715.00	11	262,579.26	848,072.07
J-96	1,717.00	19	263,294.54	848,200.75
J-97	1,723.00	13	263,204.00	848,618.77
J-98	1,725.00	1	262,734.42	848,361.71
J-99	1,715.00	22	263,575.08	847,945.89
J-100	1,718.00	1	262,001.92	847,825.76
J-101	1,715.00	7	262,119.61	847,818.23
J-102	1,715.00	10	262,404.64	848,355.80
J-103	1,720.00	-11	260,341.00	848,391.21
J-104	1,718.00	-5	261,686.80	848,144.12
J-105	1,719.00	-7	261,847.55	848,679.95
J-106	1,733.00	4	263,817.66	847,038.96
J-107	1,746.00	-7	264,449.21	847,136.30
J-108	1,717.00	9	262,766.83	848,107.44
J-109	1,710.00	-1	262,825.10	845,264.82
J-110	1,719.00	-5	261,828.48	848,999.11
J-111	1,707.00	-10	258,694.69	847,193.93
J-112	1,701.00	-4	260,487.86	847,349.44
J-113	1,715.00	-3	260,574.43	847,641.83
J-114	1,710.00	12	263,343.90	846,079.70
J-115	1,714.00	-5	262,844.54	844,662.73
J-116	1,725.00	-2	262,499.11	849,500.55
J-117	1,720.00	4	262,209.30	848,579.12
J-118	1,720.00	4	262,101.49	848,757.15
J-119	1,725.00	12	263,075.45	849,817.39
J-120	1,732.00	-6	261,967.84	851,160.66
J-121	1,732.00	-7	262,071.47	850,683.65
J-122	1,727.00	-1	260,863.46	850,715.29
J-123	1,732.00	-7	261,894.50	850,488.76

J-124	1,757.00	-29	261,393.44	851,846.71
J-125	1,743.00	15	263,937.67	850,242.62
J-126	1,746.00	-9	262,253.30	851,251.65
J-127	1,744.00	-1	263,937.45	849,291.35
J-128	1,746.00	-21	262,191.15	850,469.15
J-129	1,727.00	-1	260,740.49	850,692.08
J-130	1,745.00	-21	260,142.71	851,196.95
J-131	1,727.00	-1	261,640.67	850,835.62
J-132	1,745.00	-19	260,598.11	851,355.00
J-133	1,741.00	-17	262,489.70	849,007.42
J-134	1,732.00	-7	261,331.07	850,478.80
J-135	1,717.00	-5	261,963.98	848,376.70
J-136	1,717.00	-3	261,793.29	846,337.60
J-137	1,717.00	-5	261,821.74	848,373.31
J-138	1,717.00	-5	261,817.30	848,500.67
J-139	1,716.00	7	262,217.79	848,792.86
J-140	1,708.00	3	261,324.92	848,192.74
J-141	1,706.00	6	261,578.58	848,425.75
J-142	1,701.00	11	261,765.04	848,588.08
J-143	1,700.00	13	261,649.21	848,350.80
J-144	1,709.00	11	259,396.92	851,074.58
J-145	1,725.00	-2	261,939.62	848,892.83
J-146	1,715.00	-3	260,717.74	847,001.65
J-147	1,706.00	5	260,993.58	847,871.92
J-148	1,706.00	5	260,892.01	848,242.05
J-149	1,708.00	3	261,135.77	848,034.25
J-150	1,706.00	5	261,127.82	847,842.66
J-151	1,709.00	5	262,168.14	846,576.87
J-152	1,716.00	-4	260,912.29	847,108.56
J-153	1,709.00	3	261,162.02	847,323.94
J-154	1,718.00	-6	260,717.71	847,532.80
J-155	1,707.00	5	261,017.22	847,332.16
J-156	1,705.00	7	261,123.34	847,171.01
J-157	1,705.00	9	261,412.81	846,843.20
J-158	1,702.00	12	261,495.24	846,686.65
J-159	1,708.00	6	261,535.42	846,974.98
J-160	1,709.00	7	261,757.46	847,325.80
J-161	1,719.00	-4	261,758.45	846,952.46

J-162	1,707.00	9	261,883.10	847,610.55
J-163	1,719.00	-6	261,715.98	847,828.61
J-164	1,709.00	4	261,700.94	847,940.94
J-165	1,719.00	-5	261,747.94	847,596.31
J-166	1,715.00	-3	260,827.73	847,694.04
J-167	1,709.00	9	262,111.36	847,490.31
J-168	1,704.00	14	262,112.50	847,323.68
J-169	1,712.00	5	261,894.19	847,317.47
J-170	1,718.00	-2	261,757.86	847,466.61
J-171	1,717.00	-5	261,409.77	847,825.35
J-172	1,717.00	-2	261,449.09	847,319.20
J-173	1,727.00	9	262,911.99	846,962.78
J-174	1,719.00	-2	261,890.06	847,484.81
J-175	1,716.00	-3	262,143.00	848,209.05
J-176	1,718.00	-3	261,995.13	847,957.62
J-177	1,713.00	12	262,944.33	848,315.85
J-178	1,707.00	6	261,986.15	848,169.80
J-179	1,705.00	8	261,838.90	848,158.25
J-180	1,703.00	12	261,884.99	847,147.75
J-181	1,720.00	-5	261,750.64	847,145.64
J-182	1,720.00	-5	261,882.20	846,969.79
J-183	1,702.00	15	261,866.40	847,834.12
J-184	1,704.00	10	261,852.80	847,962.85
J-186	1,710.00	29	266,349.63	847,622.73
J-187	1,706.00	33	266,052.73	848,076.44
J-188	1,717.00	22	265,422.41	847,672.62
J-189	1,707.00	29	263,384.08	846,750.68
J-190	1,735.00	4	264,793.79	848,247.62
J-191	1,712.00	26	263,817.50	847,996.20
J-192	1,698.00	41	265,466.11	848,162.55
J-193	1,731.00	16	264,470.87	848,742.32
J-194	1,728.00	18	265,547.34	848,801.91
J-195	1,725.00	58	265,409.05	849,361.53
J-196	1,729.00	40	264,379.91	849,300.40
J-198	1,765.00	1	264,215.79	850,145.19
J-199	1,765.00	0	263,934.69	849,784.80
J-200	1,770.00	29	264,773.15	849,457.50
J-201	1,791.00	-14	264,896.28	849,288.62

J-202	1,790.00	-37	265,072.24	849,124.66
J-203	1,801.00	-51	264,762.57	848,849.44
J-204	1,985.00	57	266,844.64	851,000.64
J-205	1,996.00	46	266,710.14	851,201.77
J-206	2,010.00	32	266,432.68	851,354.25
J-207	1,998.00	44	265,429.08	850,202.44
J-208	1,714.00	23	262,679.06	847,590.21
J-209	1,714.00	23	262,818.57	847,599.63
J-210	1,745.00	-9	263,289.54	848,460.51
J-211	1,743.47	11	263,622.55	850,305.15
J-212	1,745.61	-6	262,514.70	851,241.77
J-213	1,748.14	-20	261,181.15	851,526.53
J-214	1,744.58	-17	261,208.73	851,375.58
J-215	1,741.07	-13	261,170.99	851,227.54
J-216	1,727.00	-1	261,192.09	851,160.10
J-217	1,715.10	2	260,749.91	850,268.66
J-218	1,711.72	7	259,944.82	850,622.44
J-219	1,710.19	0	260,394.86	849,386.34
J-220	1,739.83	-16	262,579.99	848,531.79
J-221	1,739.50	-16	262,456.10	848,474.13
J-222	1,710.02	-14	259,077.57	848,065.34
J-223	1,711.24	-22	257,490.07	848,632.30
J-224	1,715.41	-7	259,379.65	849,174.25
J-225	1,717.27	-9	259,699.42	849,074.46
J-226	1,715.00	24	266,259.54	847,523.20
J-227	1,726.00	13	264,437.00	847,472.76
J-228	1,724.00	15	263,810.50	847,396.22
J-229	1,708.03	27	263,294.56	847,333.85
J-230	1,710.97	1	260,837.82	847,319.44
J-231	1,713.16	-2	261,142.69	847,650.05
Pressure Result.wtg		Bentley Systems, Inc. Haestad Methods Solution Center		
18/12/2020		27 Siemon Company Drive Suite 200 W Watertown, CT 06795 USA +1-203-755-1666		

Appendix D; Jimma town existing water supply distribution network pipe result at maximum flow

FlexTable: Pipe Table					
Current Time: 8.000 hours					
Label	Start Node	Stop Node	Material	Velocity (m/s)	Diameter (mm)
P-1	J-2	Jiren motor biet	Ductile Iron	0.84	250.0
P-2	Jiren motor biet	J-3	Ductile Iron	4.21	112.0
P-3	J-4	J-5	PVC	0.18	200.0
P-4	J-1	J-14	PVC	0.31	200.0
P-5	J-1	J-10	PVC	1.41	200.0
P-6	J-6	J-209	PVC	0.83	200.0
P-7	J-191	J-16	PVC	1.44	150.0
P-8	J-6	J-20	PVC	1.43	50.0
P-9	J-29	J-9	PVC	0.14	50.0
P-10	J-28	J-31	PVC	1.72	50.0
P-11	J-171	J-163	PVC	1.76	50.0
P-12	J-35	J-37	PVC	1.97	80.0
P-13	J-44	J-45	PVC	1.33	100.0
P-14	J-50	J-49	PVC	0.01	50.0
P-15	J-105	J-145	PVC	4.8	50.0
P-16	J-49	J-48	PVC	0.79	100.0
P-17	J-49	J-70	PVC	0.62	100.0
P-18	J-142	J-48	PVC	1.65	100.0
P-19	J-50	J-44	PVC	0.94	100.0
P-20	J-48	J-69	PVC	0.78	100.0
P-21	J-47	J-53	PVC	1.2	100.0
P-22	J-61	J-56	PVC	0.08	50.0
P-23	J-56	J-54	PVC	0.19	50.0
P-24	J-144	J-29	PVC	0.45	50.0
P-25	J-55	J-29	PVC	0.36	50.0
P-26	J-56	J-57	PVC	0.33	50.0
P-27	J-57	J-58	PVC	0.28	50.0
P-28	J-62	J-55	PVC	0.08	50.0
P-29	J-71	J-64	PVC	0.26	50.0
P-30	J-71	J-63	PVC	0.76	50.0
P-31	J-65	J-67	PVC	0.31	50.0

P-32	J-63	J-110	PVC	1.83	50.0
P-33	J-69	J-70	PVC	0.19	50.0
P-34	J-66	J-67	PVC	0.08	50.0
P-35	J-66	J-71	PVC	0.17	50.0
P-36	J-93	J-94	PVC	0.68	80.0
P-37	J-94	J-96	PVC	1.37	80.0
P-38	J-100	J-101	PVC	5.01	80.0
P-39	J-104	J-143	PVC	1.24	80.0
P-40	J-104	J-164	PVC	1.34	80.0
P-41	J-106	J-107	PVC	1.48	80.0
P-42	J-114	J-20	PVC	2.77	50.0
P-43	J-116	J-12	PVC	0.8	150.0
P-44	J-117	J-118	PVC	1.4	50.0
P-45	J-116	J-92	PVC	0.81	150.0
P-46	J-92	J-119	PVC	3.26	50.0
P-47	J-121	J-123	PVC	0.88	100.0
P-48	J-129	J-130	PVC	0.67	50.0
P-49	J-129	J-122	PVC	1.35	50.0
P-50	J-129	J-132	PVC	0.73	50.0
P-51	J-84	J-134	PVC	1.02	50.0
P-52	J-122	J-134	PVC	1.1	50.0
P-53	J-137	J-138	PVC	1.32	50.0
P-54	J-64	J-57	PVC	0.16	50.0
P-55	J-141	J-142	PVC	0.54	50.0
P-56	J-147	J-149	PVC	0.66	50.0
P-57	J-155	J-156	PVC	0.43	50.0
P-58	J-158	J-157	PVC	0.81	50.0
P-59	J-169	J-174	PVC	0.44	50.0
P-60	J-168	J-169	PVC	2.2	100.0
P-61	J-168	J-167	PVC	1	150.0
P-62	J-186	J-187	PVC	1.27	200.0
P-63	J-192	J-190	PVC	1.81	150.0
P-64	J-187	J-192	PVC	1.26	200.0
P-65	J-204	J-205	PVC	0.05	150.0
P-66	J-205	J-206	PVC	0.09	150.0
P-67	J-201	J-202	PVC	2.1	50.0

P-68	J-202	J-203	PVC	0.98	100.0
P-69	J-200	J-201	PVC	2.27	50.0
P-70	J-137	J-143	PVC	0.74	50.0
P-71	J-144	J-9	PVC	0.3	50.0
P-72	J-110	J-50	PVC	1.57	80.0
P-73	J-77	J-111	PVC	0.69	50.0
P-74	J-160	J-172	PVC	1.52	80.0
P-75	J-206	Aba jifar	PVC	0.14	150.0
P-76	J-114	J-11	PVC	2.08	50.0
P-77	J-11	J-115	PVC	0.69	50.0
P-78	J-109	J-11	PVC	0.69	50.0
P-79	J-189	J-20	PVC	0.56	80.0
P-80	J-13	J-189	PVC	0.39	100.0
P-81	J-106	J-13	PVC	1.49	100.0
P-82	J-13	J-173	PVC	0.08	80.0
P-83	J-188	J-15	PVC	0.96	200.0
P-84	J-188	J-192	PVC	0.35	150.0
P-85	J-195	J-202	PVC	0.24	50.0
P-86	J-37	J-3	PVC	1.77	100.0
P-87	J-37	J-196	PVC	1.97	50.0
P-88	J-196	J-202	PVC	1.89	50.0
P-89	J-200	J-197	PVC	2.51	50.0
P-90	J-35	J-200	PVC	1.94	80.0
P-91	J-193	J-203	PVC	0.92	100.0
P-92	J-197	J-93	PVC	2.42	50.0
P-93	J-192	J-195	PVC	0.38	50.0
P-94	J-193	J-93	PVC	2	50.0
P-95	J-3	J-17	PVC	2.9	110.0
P-96	J-17	University	PVC	0.38	100.0
P-97	J-198	J-17	PVC	3.09	100.0
P-98	J-125	J-198	PVC	3.06	100.0
P-99	University	J-199	PVC	1.3	100.0
P-100	J-199	J-91	PVC	2.68	50.0
P-101	J-91	J-19	PVC	0.22	50.0
P-102	J-19	J-119	PVC	3.65	50.0
P-103	J-125	J-19	PVC	1.02	100.0

P-104	J-120	J-124	PVC	0.94	50.0
P-105	J-131	J-120	PVC	0.66	50.0
P-106	J-131	J-123	PVC	2.22	50.0
P-107	J-121	J-128	PVC	0.89	100.0
P-108	J-92	J-89	PVC	1.06	100.0
P-109	J-89	J-123	PVC	1.41	100.0
P-110	J-199	J-21	PVC	2.28	50.0
P-111	J-21	J-120	PVC	1.46	50.0
P-112	J-128	J-21	PVC	0.9	100.0
P-113	J-119	J-88	PVC	0.2	50.0
P-114	J-88	J-90	PVC	0	50.0
P-115	J-88	J-87	PVC	0.1	50.0
P-116	J-89	J-80	PVC	0.34	100.0
P-117	J-80	J-79	PVC	0.32	100.0
P-118	J-79	J-78	PVC	0.26	100.0
P-119	J-78	J-72	PVC	0.23	100.0
P-120	J-84	J-133	PVC	0.28	80.0
P-121	J-98	J-86	PVC	0.24	80.0
P-122	J-86	J-5	PVC	1.12	80.0
P-123	J-127	J-23	PVC	0.41	50.0
P-124	J-23	J-91	PVC	2.69	50.0
P-125	J-4	J-23	PVC	3.02	50.0
P-126	J-127	J-93	PVC	0.99	80.0
P-127	J-127	J-7	PVC	0.77	80.0
P-128	J-190	J-193	PVC	0.57	80.0
P-129	J-190	J-16	PVC	1.94	150.0
P-130	J-8	J-96	PVC	1.61	80.0
P-131	J-8	J-1	PVC	5.03	80.0
P-132	J-99	J-8	PVC	3.19	80.0
P-133	J-106	J-191	PVC	0.93	80.0
P-134	J-209	J-208	PVC	0.11	50.0
P-135	J-209	J-18	PVC	5.1	80.0
P-136	J-18	J-95	PVC	3.44	50.0
P-137	J-1	J-18	PVC	4.97	50.0
P-138	J-18	J-10	PVC	4.55	50.0
P-139	J-95	J-102	PVC	1.4	50.0

P-140	J-99	J-191	PVC	2.57	100.0
P-141	J-99	J-94	PVC	1.89	50.0
P-142	J-96	J-210	PVC	1.56	50.0
P-143	J-7	J-210	PVC	1.96	50.0
P-144	J-210	J-97	PVC	0	50.0
P-145	J-102	J-117	PVC	1.4	50.0
P-146	J-14	J-177	PVC	1.5	80.0
P-147	J-177	J-210	PVC	3.3	50.0
P-148	J-14	J-108	PVC	1.42	50.0
P-149	J-108	J-95	PVC	1.67	50.0
P-150	J-108	J-98	PVC	0.12	50.0
P-151	J-177	J-98	PVC	0.69	50.0
P-152	J-86	J-133	PVC	2.15	50.0
P-153	J-12	J-118	PVC	1.4	50.0
P-154	J-72	J-74	PVC	0.78	50.0
P-155	J-74	J-73	PVC	0.64	50.0
P-156	J-73	J-83	PVC	0.51	50.0
P-157	J-83	J-82	PVC	0.19	50.0
P-158	J-12	J-139	PVC	0.58	100.0
P-159	J-10	J-101	PVC	3.01	150.0
P-160	J-101	J-167	PVC	3.54	100.0
P-161	J-160	J-169	PVC	1.77	100.0
P-162	J-174	J-162	PVC	1.97	50.0
P-163	J-162	J-183	PVC	1.17	50.0
P-164	J-160	J-170	PVC	1.29	50.0
P-165	J-170	J-165	PVC	2.69	50.0
P-166	J-165	J-163	PVC	1.34	50.0
P-167	J-167	J-174	PVC	1.92	80.0
P-168	J-174	J-170	PVC	1.9	50.0
P-169	J-183	J-100	PVC	3.37	80.0
P-170	J-163	J-164	PVC	0.87	80.0
P-171	J-162	J-165	PVC	2.62	50.0
P-172	J-165	J-166	PVC	1.25	80.0
P-173	J-183	J-163	PVC	3.48	50.0
P-174	J-100	J-176	PVC	3.86	50.0
P-175	J-176	J-178	PVC	2.11	50.0

P-176	J-178	J-135	PVC	1.27	50.0
P-177	J-178	J-175	PVC	0	50.0
P-178	J-183	J-184	PVC	3.19	50.0
P-179	J-184	J-179	PVC	1.89	50.0
P-180	J-179	J-137	PVC	1.19	50.0
P-181	J-164	J-184	PVC	1.79	50.0
P-182	J-184	J-176	PVC	1.34	50.0
P-183	J-104	J-179	PVC	0.31	50.0
P-184	J-179	J-178	PVC	0.44	50.0
P-185	J-169	J-180	PVC	1.7	50.0
P-186	J-180	J-182	PVC	1.18	50.0
P-187	J-160	J-181	PVC	1.29	40
P-188	J-181	J-161	PVC	1.13	40
P-189	J-182	J-151	PVC	0.63	40
P-190	J-151	J-136	PVC	0.43	40
P-191	J-136	J-158	PVC	0.23	50.0
P-192	J-158	J-161	PVC	0.92	50.0
P-193	J-76	J-28	PVC	1.26	50.0
P-194	J-181	J-180	PVC	0.25	50.0
P-195	J-161	J-182	PVC	0.25	50.0
P-196	J-159	J-172	PVC	1.14	50.0
P-197	J-157	J-159	PVC	0.83	50.0
P-198	J-157	J-156	PVC	1.33	50.0
P-199	J-152	J-146	PVC	0.53	50.0
P-200	J-152	J-156	PVC	0.62	40
P-201	J-172	J-153	PVC	2.28	40
P-202	J-153	J-155	PVC	0.46	50.0
P-203	J-146	J-154	PVC	0.37	50.0
P-204	J-154	J-166	PVC	0.72	50.0
P-205	J-166	J-147	PVC	1.63	50.0
P-206	J-153	J-27	PVC	1.35	50.0
P-207	J-154	J-27	PVC	0.45	50.0
P-208	J-147	J-150	PVC	0.55	50.0
P-209	J-166	J-41	PVC	0.49	50.0
P-210	J-41	J-42	PVC	0.3	40
P-211	J-42	J-113	PVC	0.11	40

P-212	J-113	J-154	PVC	0.26	40
P-213	J-113	J-40	PVC	0.19	40
P-214	J-77	J-112	PVC	0.69	40
P-215	J-147	J-59	PVC	0.92	50.0
P-216	J-171	J-150	PVC	0.52	50.0
P-217	J-140	J-141	PVC	0.91	50.0
P-218	J-171	J-140	PVC	0.69	50.0
P-219	J-149	J-140	PVC	0.39	50.0
P-220	J-59	J-43	PVC	1.03	50.0
P-221	J-149	J-148	PVC	0.66	50.0
P-222	J-68	J-60	PVC	1.14	50.0
P-223	J-60	J-43	PVC	0.87	50.0
P-224	J-59	J-148	PVC	0.43	40
P-225	J-103	J-22	PVC	2.43	40
P-226	J-43	J-103	PVC	1.62	40
P-227	J-53	J-103	PVC	0.95	50.0
P-228	J-135	J-105	PVC	0.82	50.0
P-229	J-137	J-135	PVC	0.12	50.0
P-230	J-143	J-141	PVC	1.91	50.0
P-231	J-138	J-142	PVC	1.03	50.0
P-232	J-142	J-105	PVC	1.38	100.0
P-233	J-140	J-69	PVC	0.51	50.0
P-234	J-148	J-68	PVC	0.1	80.0
P-235	J-53	J-52	PVC	0.88	50.0
P-236	J-52	J-69	PVC	0.8	100.0
P-237	J-52	J-68	PVC	0.46	100.0
P-238	J-45	J-53	PVC	1.29	100.0
P-239	J-70	J-44	PVC	0.73	80.0
P-240	J-139	J-82	PVC	0.01	80.0
P-241	J-85	J-139	PVC	0.62	100.0
P-242	J-49	J-46	PVC	0.27	40
P-243	J-46	J-51	PVC	0.14	40
P-244	J-12	J-145	PVC	1.2	150.0
P-245	J-145	J-110	PVC	4.94	50.0
P-246	J-55	J-56	PVC	0.11	50.0
P-247	J-71	J-58	PVC	0.16	50.0

P-248	J-24	J-22	PVC	2.77	50.0
P-249	J-31	J-22	PVC	0.34	40
P-250	J-77	J-24	PVC	1.39	40
P-251	J-30	J-28	PVC	0.57	40
P-252	J-30	J-81	PVC	0.67	50.0
P-253	J-58	J-67	PVC	0.11	50.0
P-254	J-47	J-76	PVC	2.48	50.0
P-255	J-47	J-75	PVC	2.14	50.0
P-256	J-81	J-75	PVC	0.6	40
P-257	J-75	J-67	PVC	0.32	40
P-258	J-76	J-81	PVC	1.01	40
P-259	J-54	J-32	PVC	0.34	50.0
P-260	J-32	J-75	PVC	0.56	50.0
P-261	J-65	J-39	PVC	0.31	50.0
P-262	J-33	CV-1	Ductile Iron	0	400.0
P-263	J-33	Clear Water	Ductile Iron	1.03	300.0
P-264	J-34	J-36	Ductile Iron	0.69	365.0
P-265	J-36	J-33	Ductile Iron	0.69	365.0
P-266	Boye source	Boye pump	PVC	0.58	400.0
P-267	Boye pump	J-34	Ductile Iron	0.69	365.0
P-268	J-207	Aba jifar	Ductile Iron	0.08	150.0
P-269	Clear Water	Boosting pump	Ductile Iron	0.74	350.0
P-270	Boosting pump-3	J-207	Ductile Iron	0.08	150.0
P-271	Jiren motor biet	Boosting pump-3	Ductile Iron	0.03	250.0
P-272	J-125	J-211	PVC	2.01	100.0
P-273	J-211	J-212	PVC	1.84	100.0
P-274	J-212	J-126	PVC	1.66	100.0
P-275	J-124	J-213	PVC	0.41	80.0
P-276	J-213	J-214	PVC	0.44	80.0
P-277	J-214	J-215	PVC	1.26	80.0
P-278	J-215	J-131	PVC	1.22	80.0
P-279	J-122	J-216	PVC	0.07	80.0
P-280	J-216	J-131	PVC	0	80.0

P-281	J-63	J-217	PVC	0.42	80.0
P-282	J-217	J-218	PVC	0.42	80.0
P-283	J-218	J-144	PVC	0.38	80.0
P-284	J-75	J-219	PVC	0.36	50.0
P-285	J-219	J-58	PVC	0.23	50.0
P-286	J-133	J-220	PVC	1.06	80.0
P-287	J-26	J-222	PVC	0.69	50.0
P-288	J-222	J-24	PVC	1.39	50.0
P-289	J-31	J-223	PVC	1.39	50.0
P-290	J-223	J-25	PVC	0.69	50.0
P-291	J-81	J-225	PVC	0.27	50.0
P-292	J-225	J-32	PVC	0.01	50.0
P-293	J-54	J-224	PVC	0.33	50.0
P-294	J-224	J-30	PVC	0.2	50.0
P-295	J-226	J-188	PVC	0.78	200.0
P-296	J-16	J-227	PVC	0.47	150.0
P-297	J-227	J-107	PVC	0.43	150.0
P-298	J-15	J-228	PVC	0.96	200.0
P-299	J-228	J-6	PVC	1.65	150.0
P-300	J-8	J-229	PVC	1.38	80.0
P-301	J-229	J-13	PVC	1.53	80.0
P-302	J-152	J-230	PVC	0.18	50.0
P-303	J-230	J-155	PVC	0.45	50.0
P-304	J-27	J-231	PVC	1.45	50.0
P-305	J-231	J-150	PVC	0.66	50.0
P-306	J-220	J-221	PVC	1.03	80.0
P-307	J-221	J-85	PVC	1	80.0
P-308	J-126	J-214	PVC	1.49	100.0
P-309	J-214	J-132	PVC	0.38	100.0
P-310	J-132	J-130	PVC	0.18	100.0
P-311	J-130	Gebriel	PVC	0	100.0
P-312	Gebriel	J-144	PVC	0	100.0
P-313	J-38	Chaka	Ductile Iron	0.87	250.0
P-314	CV-1	Back wash	Ductile Iron	0	400.0
P-315	J-186	J-226	PVC	0.79	200.0
P-316	Chaka	Boosting	Ductile Iron	0.84	250.0

		pump-2			
P-317	Boosting pump-2	J-55	Ductile Iron	0.84	250.0
P-318	J-55	J-2	Ductile Iron	0.84	250.0
P-319	Terara-2	J-56	Ductile Iron	1.01	200.0
P-320	Terara-1	J-56	Ductile Iron	1.06	200.0
P-321	Boosting pump	J-61	Ductile Iron	1.01	300.0
P-322	J-61	J-38	Ductile Iron	1.01	300.0
P-323	J-56	J-186	Ductile Iron	0.68	350.0
P-324	J-38	Boosting pump-4	Ductile Iron	2.03	300.0
P-325	Boosting pump-4	Terara-2	Ductile Iron	2.03	300.0
P-326	J-38	Boosting pump-5	Ductile Iron	2.04	300.0
P-327	Boosting pump-5	Terara-1	Ductile Iron	2.04	300.0

Questionnaires for Local Administrative and Local Community Survey

Hello! My name is ________________. I am assisting an on-going research by **Azeb Kassahun**, in partial fulfillment of her MSc degree at Jimma University. We are talking to selected sample households in Jimma City about the water supply coverage and water loss in distribution system. The information collected from this questionnaires survey will be used for research purpose only. Please be frank and open-minded in your evaluations and opinions. All information obtained will be kept strictly confidential. Your kind cooperation is highly appreciated.

I. Personal Information of Respondents

1. Name of Kebele_____ 2. House No: _____ 3. Sex: (1) Male (2) Female

4. Age: (1) Under 14 years (2) 15-39 years (3) 40-64 years (4) above 65 years

5. Educational attainment

(1) None (2) Read- Write (3) Elementary school (4) Secondary school

(5) High School (6) College (7) Graduated (8) Higher education (9) Others_____

6. Occupation: (1) Government Sector (2) Retired (3) Private Sector (4) Housekeeper

(5) Other (specify) ___________

7. How many persons live in your household? _________________

Infants (less than 1 year old) ( ) persons

Children (1-18 years old) ( ) persons

Adults (more than 18 year old) ( ) persons

8. House holding: (1) Private (2) Rent (3) Government (4) private (5) other (specify)

II. Local Administrative (JTWSSA)

9. Is your Unaccounted-for-Water below 10%?

A) Yes

B) No

10. Are there problems with the water source (s)?

A) Yes

B) No

11. Is water available year round?

A) Yes

B) No

12. What causes water loss in distribution system?

A) Pipe damage

B) Heavy track

C) Illegal connection

D) Ageing pipe

E) I don’t know

13. Do you conduct an annual water audit of your system?

A) Yes

B) No

14. Do you think that poor connection causes leakage on distribution system?

A) Yes

B) No

C) I don’t know

15. Are the type of material used and leakage on distribution system related?

A) Yes

B) No

C) I don’t know

16. Do think your current method of calculating water loss fairly and accurately reflects the amount of water loss in the system?

A) Yes B) No C) I don’t know

17. Do you conduct a full leak detection program for your distribution system every two years?

A) Yes

B) No

C) I don’t know

18. Is your system 100% metered?

A) Yes

B) No

C) I don’t know

19. Do you use an automatic or radio-read meter reading system?

A) Yes

B) No

C) I don’t know

20. Are all public-sector facilities billed for their water use?

A) Yes

B) No

21. Are any accounts not billed?

A) Yes

B) No

22. Do you bill based on actual meter readings, not estimated use?

A) Yes

B) No

C) I don't know

23. Is the volume of water used stated in gallons on the bill?

A) Yes

B) No

24. Do you have a meter repair/replacement program that services meters based on the AWWA (American Water Work Association) standards?

A) Yes

B) No

25. Is your meter repair/replacement program funded through an annual budget appropriation?

A) Yes

B) No

26. Are water supply system operations fully funded by water supply system revenues?

A) Yes

B) No

27. Was your rate structure developed to promote water conservation and/or control demand (that is, do you charge more for water when demand is higher – for example, in the summer)?

A) Yes

B) No

28. Do any of your customers have a second meter for outdoor water use?

A) Yes

B) No

29. How much water is consumed by consumer?

A) Once a day

B) 24 hr

C) In a week

30. Does your water supply system provide assistance to your public-sector users in conducting water-use audits?

A) Yes

B) No

C) I don’t know

31. Do you have a public education plan on water conservation?

A) Yes

B) No

32. Does your utility have any specific programs or procedures where you fix leaks on the customer service?

A) Yes

B) No

III. Local Community

33. Do you have secondary source of water for drinking?

A) Yes

B) No

C) I don’t know

34. Are there any leaks in the household pipes?

A) Yes

B) No

35. Is water point secure?

A) Yes

B) No

36. During dry season distance of water source from your home

A) Meter

B) Kilometre

37. Time required to the nearest alternative source of water

A) Minutes

B) Hours

38. How much water get in a month?

A) Once in a day

B) Once a week

C) Twice a week

D) Monthly

E) Never through a year

39. Does the water line distribute in your home?

A) Yes

B) No

40. Where do you get water?

A) Borehole

B) Public tap/ stand pipe

C) Water point

41. Do you think shortage of water occur in Jimma?

A) Yes

B) No

C) I don’t know

42. What causes shortage of water?

A) There is no enough source of water

B) Problem of distribution

C) I don’t know

43. Do you think pipe damage causes water loss?

A) Yes

B) No

C) I don’t know

44. Do you think illegal connection occur in your area?

A) Yes

B) No

C) I don’t know

IV) Open ended questionnaires towards local community

45. How frequent are water losses in the distribution network?
46. How speedily the water service office responds to these losses?
47. How do you evaluate the residents feeling to pay for water?
48. What are the major causes of water supply shortage in the town?
49. What measures do you recommend to alleviate the water supply shortage problem?

V) Open ended questionnaires towards local administration (JTWSSA)

50. How frequent are fittings, pump and generator failures?
51. How clear are the water system details for the technicians?
52. Are there illegal connections?
53. Have there been pipeline destructions in the case of other infrastructure developments?
54. If yes, how do you manage it?
55. What do you think are the major causes the water supply shortage?
56. Is there improper use of water by the public?
57. If yes, what techniques do you use to raise awareness of the public in water use?