JIMMA UNIVERSITY

SCHOOL OF POSTGRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Assessment of the performance of existed water distribution system: a case of Jimma Town, by using water GEMS V8i model

A Thesis submitted to the School of Graduat0e Studies of Jimma University, Jimma Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering

By: Munawer Husien

November, 2019

Jimma, Ethiopia

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By: Munawer Husien

Main Advisor: Dr. Zeinu Ahmed (Phd)
Co-Advisor: Andualem Shigute (MSc)

DECLARATION

I hereby declare that this thesis titled "**Assessment of the performance of existed water distribution system: a case of Jimma Town, by using water GEMS V8i model**" has been carried out by me under the guidance and supervision of my Advisors Dr. Zeinu Ahmed (Phd) And Andualem Shigute.The thesis is original and has not been submitted by others and for any university or institutions.

Researcher's Name	Signature	Date
Munawer Husien	______________________	November, 2019

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CERTIFICATION

As members of the Board of Examiners of the MSc Thesis Open Defense Examination, we Certify that we have read, evaluated the thesis prepared by Munawer Husien and examined the candidate. We recommended that the Thesis be accepted as fulfilling the requirement for the degree of Master of Science in Hydraulic Engineering.

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Chairperson	Signature	Date
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Internal Examiner	Signature	Date
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External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon the submission of final copy of the thesis to council of graduate studies (CGS) through the departmental or school graduate committee (DGC or SGC) of the candidate.

ACKNOWLEDGMENT

Above all I thank the almighty of ALLAH for his guidance and grace upon me during all my works and in all my life.

I would like to express my sincere gratitude and special thanks to my supervisor ***Dr.-Zeynu Ahmad (PhD)*** for his valuable guidance, encouragement, suggestions and constructive comments from the inception to the completion of this proposal work. I am deeply grateful to my co-supervisors

Mr.Andualem Shigute (MSc.) for his comments and correction throughout this work.

Last, but not indeed least, I would like to forward the largest thanks to my helpful Brothers for their never ending concern, support and encouragement.

ABSTRACT

Water is one of the prime requirements for life, and the Water supply systems are one of the most important and expensive core public infrastructures. In urban area of Ethiopia, water demand is increasing day to day due to urbanization. During operations of water supply systems in many towns of the Country, the common problems are pressure drops, Leakages, contamination and lack of a simple tool to accurately predict low and high pressure zones areas. Hence, the aim of this study is to assess the performance of the water supply system in terms of pressure and velocity variation using Water GEMS V8i software and to evaluate the amount of annual water loss in the system. Sample kebeles and sample population were selected to distribute questionnaires in order to collect information about current daily water supply amount and the level of customer satisfaction with current supply. And the distribution network data like; pipes data, junctions' data, reservoirs data and other appurtenance elements of the network data were collected from Jimma Town Water Supply, Sanitation Service Enterprise(JTWSSSE) office. Based on the result of the study, the current average water supply coverage is found to be low (10 l/c/ dy).In Jimma town, the annual average water loss for the consecutive eleven years (2008 – 2018) is founded to be 39.14 % out of the total yearly production. This amount is 13,796,488 m^3 out of the total water production of 35,312,888 m^3in the last 11 years. This annual percent loss of water is more than the tolerable percent loss value of water for developing countries.The pressure and velocity distribution along the current distribution system is also found to be far from the recommended range. Water GEMS software was used to optimize the system by modifying and re-arranging the network elements for further improvement towards the pressure and velocity distribution and demand satisfaction. The result shows that, the system performance was increased ie. The number of junctions and pipes that have pressure and velocity in the recommended range was increased. Therefore, JWSSSE should modify and re arrange to improve the system according to the recommended modification in this study to maintain the system safe and customer satisfaction.

Key words: Jimma Town , JWSSSE, Water GEMS V8i, water loss

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ACRONYMSAND ABREVIATIONS

AMSL	Above mean sea level
AWWA	American Water Works Association
DCI	Ductile Iron
EEA	European Environmental Association
EPS	extended period simulation
FCV	Flow control Valve
GMS	Galvanized Mild steel
IWA	International water association
MoH	Ministry of Health
NRW	None revenue Water
PI	Performance Indicator
PIs	Performance indicators
PRV	Pressure reducing valve
SSS	Steady state simulation
UN	United Nation

CHAPTER ONE

INTRODUCTION

1.1. Background

Nowadays, the population of the planet is growing dramatically. Today's world population of 7.5 billion is expected to reach about 8.5 billion by 2030 (UN, 2011).Ethiopia's population is estimated to be 94 million CSA (2016), and is the second most populous country in Africa next to Nigeria. Hence, such growing of population will result in considerable additional demand of Water.

Throughout the developing world, the provision of water supply is marred by inefficiencies due to low coverage, high non-revenue water (NRW) levels, intermittent supply, and poor water quality. According to the World Bank report of 2016, 45 million cubic meters of water is lost each day globally, with an economic value of US$ 3billion per year. Also, annual report shows that, 46% of under-five mortalities are due to diarrhea (Hong et al., 2009).The best way to overcome this problem is by managing water supply system and reducing the NRW.

In many developing countries water distribution systems, there is a significant pressure variation which leads to water losses as leakage at some area and unable to reach on other area while transmitting from treatment to customers. Many water supply distribution systems in Ethiopian town shares common problems of water shortage due to poor installation during construction and poor management during operation. Most of the town's residents get water intermittently with a gap of days (Mukand, 2015).

Water loss is not only amounts to less usable water, but also in potential increased charges due to additional treatment and distribution costs. The extra costs due to lost water are passed on to consumers, who are required to pay higher tariffs to offset these losses. High rates of NRW decrease the capacity of a country's water utilities service provider. There are a number of direct and indirect benefits from embarking on a program to minimize water loss: Economic benefits through savings in pumping and treatment costs when delivering less lost water; Appropriately sized infrastructure which does not have to accommodate downstream lost volumes; Future infrastructure investment costs can be delayed to later years; Spare resource capacity is made available for residential and industrial growth; A better understanding and knowledge of the water supply system is achieved by undertaking an audit of the system and future monitoring of the data; and the image of the corporation is improved, especially where customers are encouraged to reduce their consumption.

Reducing total water loss or NRW to an economically optimal level is fundamental for improving the urban drinking water supply, and for effectively responding to rapid urbanization and growing concerns of water security.

Access to safe and adequate water supply is a universally recognized human right, which has special significance to the survival of humanity(WHO, 2011). The existing problems of inadequate service provision is exacerbated by the fact that population growth and mounting pressure of increasing urbanization have offset much of the gains in service coverage. Service coverage can be one of the indicators of accessibility of water supply that can have an effect on the performance of water utilities. Apart from service coverage, there are other problems that affect the performance of the public water utilities. Moreover, the public utilities often face financial challenges due to a combination of low tariffs, poor services, poor consumer records and inefficient billing and collection practices (WHO, 2011).

The development of Jimma town is becoming faster and faster more than expected. This faster growth of the town is calling for the improvement and management of basic infrastructures including water supply system.Even though, there have been an expansion of the distribution system to address the fast growing population, there is a problem regarding to water loss. To save the amount of water loss that is caused by both physical and commercial losses. Now a days, the high level of water loss or "non-revenue water" (NRW) in distribution networks is one of the major challenges facing the Jimma water supply system service enterprise (JTWSSSE). A high level of NRW is often the main reason that a water utility is unable to improve its performance, especially for those with water supply systems that have unsatisfied demand and limited coverage. A high rate of NRW is also a cause of poor energy efficiency because part of the energy used in the production and distribution processes is embedded in the lost water. Reducing NRW is important to overall efficiency and financial sustainability, because it provides additional revenues and reduces costs.

1.2. Statements of the problem

Safe drinking water is one of the basic necessities for human beings. However, billions of people in the world have not access to it today. Of this, significant number of the population is from the developing countries especially in sub Saharan countries. Problems in provision of adequate and safe water to the rapidly growing urban population are increasing dramatically.

Water demand for domestic and non-domestic purpose of the towns of developing countries increases time to time due to urbanization. These, increase in demand results, the requirements of additional water sources and infrastructures. Despite increasing the population in the cities, the financial capacity of the cities is low to satisfy the growing demand. The low financial capacity, leads to poor operation and management of the existing water supply systems (Mukand, 2015 2).

Ethiopia is one of the countries with a challenge on inadequate water supply and sanitation system in urban areas due to rapid urbanization. Jimma town is also one of the old age towns in Ethiopia whose population of the town is growing rapidly from time to time. Therefore, now days, supplying an adequate drinking water in standard level are very difficult. In addition to the population growth, water losses also have a great contribution for the un-satisfaction of the demand. Jimma town water supply system, gives a service for a decade with major expansion completed in 2014. Most of the components of the distribution system in the town are too old that cannot sustain burden on the system due to rapid population growth. Now it is facing many problems regarding to management of the system. The municipality and water supply authority of the town manage the system poorly that results high pressure at some areas and very low pressure at other areas. Therefore, the aim of this study is to assess the water supply coverage in terms of areal coverage and demand coverage/satisfaction with modeling the system.

The water supply system in Jimma has a number of challenges in terms of operational management and service delivery. Among these problems are; low coverage, low service level, high non-revenue water, high rate of cut-offs (some areas get supply once or twice a week with still others getting no water for weeks) and intermittent water supply. There are also frequent pipelines bursts (because of the pipelines been very old, some laid as far back as1970s and leakages, which also affect the quality of the water supplied. Therefore, the aim of this study is to check the performance of the existed water distribution system in terms of demand satisfaction and amount of water losses in the system. In addition, optimization of the system for further improvement is done using water GEMS V8i model.

1.3. Objectives

1.3.1. General objective

The general objective of this study is to check the performance of the existed water distribution system for Jimma Town and to optimize the system for further improvement using water GEMS V8i model.

1.3.2. Specific objectives

The specific objectives of the study are:-

1. To assess the existing water supply and demand of the town and the level of Customer's Satisfaction towards the water supply service.
2. To determine the amount of water loss and the consequent economic loss of JTWSSE
3. To check the hydraulic performance of the existed distribution system
4. To model and optimize the network for improvement of the system

1.4. Research question

2. How much water is produced by the JTWSSE and how much water consumed by the customers?
3. How much water is considered as a loss out of the total annual production and how much will be the corresponding economic loss?
4. How is the performance of the exited water distribution system towards hydraulic parameters?
5. What will be the possible measure and improvement in the system to address problems related to unbalanced pressure, velocity and water flow in the system?

1.5. Significance of the study

This study is expected to increase the knowledge and up to date information on the city water demand satisfaction and its undesirable impacts on the urban community due to shortage of water supply. It will serve as a working document to policy makers in the water sector and the non-governmental Organizations in the town. It will also help for the stakeholders specifically for JTWSSE to use the result as information for action done for solution. In addition, the optimized or the simulated network map will be used for further improvement in the distribution system.

By accounting for the water, municipalities can make operations, maintenance, and capital improvement decisions in the best interests of their local Administrative and the community they serve. This best practice helps municipalities prioritize their capital and operating decisions and better safeguard their systems from water loss. Moreover, the finding will serve as reference data and it opens avenue for any further investigation in the areas, and as a useful material for academic purposes.

1.6. Scope of the study

The scope of this work is limited to evaluating the water supply and demand coverage of Jimma town, assessing the amount of water loss in annual basis and the corresponding cost of water loss in distribution system. The study considered four representative kebeles in Jimma town (namely Mentina, Bosa Adis, Bochobore, Ginjo Guduru) for data collection.

The evaluation of the performance of the system is limited to evaluate in terms of demand satisfaction, the pressure and velocity distribution variation along the whole distribution network. That means the system performance was checked by a hydraulic performance indicators, namely, Velocity and pressure.

The optimization of the network system was considered only pipe diameter greater than and equal to 50 mm as it is time consuming and un manageable to consider all the detail small diameter pipes.

1.7. Organization of the research

This thesis consists of five chapters structured as follow :Chapter one; contain the introduction, problem statement general and specific objective of the thesis, scope and significance of the study. Chapter two; literature on water demand and supply, water loss and the corresponding economic loss. Chapter three; discussion on the methodology, data collection and presentation. Chapter four; Result and Discussion. Chapter five; conclusion and recommendation

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Water distribution system

Water distribution systems are water utilities which deliver water of the required quantity to individual customers under sufficient pressure through a distribution network(Darshan et al., 2017).Hydraulic infrastructure of Water distribution system, include elements such as pipes, tanks, reservoirs, pumps, meters valves and etc. The integration of all those elements is needed for efficient and effective water delivery to the required area. Hence, the primary task for water utilities is to deliver water of the required quantity to individual customers under sufficient pressure through a distribution network.

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 relationships 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 (Abera, 2018). In addition, just as pipe elements were not laid randomly, a pipe-labeling scheme should be developed to reflect that order.

2.2. Water demand

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (EEA, 1999).In most developing countries, that theoretical water demand considerably exceeds the actual consumptive water use. In many African cities urban water demands are often homogeneous owing to a range of levels of services occurring within the same urban area Levels of service can vary from household connections to standpipes or to no service at all (Melaku Abebaw,2014).Amount of water required for the user mainly affected by climate, geographic location, population size, economic condition of the community, extent of industrialization, cost of water and etc.

2.2.1. Type of water demand

The produced water from the treatment plant delivers to different type of demand/ purpose. Water demand is will be categorized in different category for easy allocation of water.

2.2.1.1. Domestic water demand

The quantity of water required in the houses for drinking, bathing, cooking, washing etc.is called domestic water demand and mainly depends upon the habits, social status, climatic conditions and customs of the people (Rao et al, 2005). Domestic water consumption varies according to the mode of services, climatic conditions, socio-economic condition and other related factors. According to Ethiopia ministry of urban water supply design criteria, the following per capita water consumption is recommended. Table 2.1 shows the recommended daily water demand for Ethiopian towns.

Table 2.1Recommended domestic water demand

Demand	Stage one (l/c/day)	Stage two (l/c/day)	No. of representative houses
House connection(HC)	50	70	105
Yard connection, own(YCC)	25	30	110
Yard connection, shared(YCS)	30	40	120
Public top supplies(PT)	20	25	100

Source; FDRE ministry of water resource urban water supply design criteria January, 2006

2.2.1.2. Non-domestic water demand

The non-domestic water demand includes, water demand other than for domestic purpose. These includes; institutions, commercials, industrial, public use and fire demand.

Institution and commercial demand refers to the water demand for Universities, schools hospital and etc. Whereas commercial demand includes demand for commercial buildings like; commercial centers, office buildings, warehouses, stores, hotels, shopping centers, health centers, schools, temple, cinema houses, railway and bus stations etc. (Sengupta, 2014).The review will assess the extent and development of the institutional and commercial base in each town and vary the likely daily demand, if necessary, based on the following consummations:

Institutions	Daily demand
Restaurants	10 $l/_{seat}$
Boarding school	60 $l/_{pupil}$
Day schools	5 $l/_{pupil}$
Public offices	5 $l/_{employee}$
Workshop/shops	5 $l/_{employee}$
Cinema house	4 $l/_{seat}$
Mosques & Church	5l/ $_{worshiper}$
Public latrines (with water facility connection)	20 l/seat
Hospitals	50 - 75 l/bed
Abattoir	150 l/cow
Hotels	l/bed 25-50
Railway & Bus station	5 l/user
Public Bath	30 l/visitor
Military Camps	60 l/person

Table 2.2Recommended institutional water demand

Source; FDRE ministry of water resource urban water supply design criteria January, (2006)

Industrial water demand is the water required in the industries which is mainly depends on the type of industries. The water required by factories, paper mills, cloth mills, cotton mills, breweries, sugar refineries etc. comes under industrial use. The quantity of water demand for industrial purpose is around 20 to 25% of the total demand of the city (Rao, 2005).

Public water demand is a quantity of water required for public utility purposes such as for washing and sprinkling on roads, cleaning of sewers, watering of public parks, gardens, public fountains etc. comes under public demand. To meet the water demand for public use, provision of 5% of the total consumption is made designing the water works for a city (Rao, 2005).

Fire may take place due to faulty electric wires by short circuiting, fire catching materials, explosions, bad intension of criminal people or any other unforeseen miss-happenings. If fires are not properly controlled and extinguished in minimum possible time, they lead to serious damage and may burn cities (Rao, 2005). Hence, demand for fire-fighting should be included during the design of distribution system. In the cities fire hydrants are provided on the water mains at 100 to 150 m apart for fire demand. The quantity of water required for firefighting is generally calculated by using different empirical formulae Water demand for firefighting purposes shall be assessed on a town-by-town basis, depending on the existence of equipment and the capacity of any firefighting service. Fire hydrants shall be installed at public and municipality interest such as schools, shops, hospitals, fuel station sand at salient points of distribution network. This demand is taken off by increasing the volume of the storage tanks by 10 %.

2.3. Water loss in distribution system

The term "water loss" is generally adopted to indicate the difference between the overall amount of water supplied in the network and the sum of the water volumes corresponding to the customer consumption recorded by the flow-meters (Lambert et al., 2009).

Water losses occur in all water distribution networks, even new one and it is only the volume that varies. Thereby, the volume of this loss reflects the capacity of water authorities to manage their distribution networks (Mutikanga, 2011).

On average 26 % treated water has been lost from water distribution networks from around the globe due to pipe - breaks, damages / failure, poorly designed infrastructure and illegal line connections or consumptions every year. This has resulted in loss of $14 billion in profit from the non-revenue water. However, reducing or controlling water loss not only enhances revenue but also conserving water and energy, limiting carbon footprints, and supplying safe drinking water to the world population (Zheng et al., 2011).

Different studies have been made on urban water supply problems and challenges around the world with special emphasis on developing countries. According to study by (Wegelin, W. 2012) the problem of water shortage in most of the nations in developing countries is not only due to limitation on the sources but also as a result of inefficiency on distribution networks of cities. High rate of water losses from the distribution systems is one the significant factors for such inefficiency in the water utility performance. According to studies conducted in the world, water losses in cities of developing countries is estimated to be 40- 60% out of the treated amount or the difference between water produced and water consumed (AWWA, 2007).

Accordingly, the International Water Association (IWA), by studying the best practice from several water supply enterprises around the world has designed an international best practice standard approach for water balance calculations. According to German National Report on Water Loss Management and Techniques produced by (Wegelin, W. 2012) water loss is classified as minimal (8% and below), medium (8%-15%), and highest (more than 15%).

2.3.1. Causes of water loss

Produced and delivered water to the distribution system is intend to be sold to the customer without loss or siphon from the distribution system. Not long ago, water companies sell water at a flat rate without metering. As water has become more valuable and metering technology has improved, more and more water system in the U.S. meters their customers. Although all customers may be meter in a given utility, a fairly sizable portion of the water most utilities produce does not pass through customer meters. Unmetered water includes unauthorized users, including losses from accounting errors, malfunctioning distribution system controls, thefts, inaccurate meters, or leaks (Mutikanga, 2011). Leakage is usually the major component of water loss in developing countries, but this is not the only case in developing or partially developed countries, where illegal connections and meter error are often more significant (Mutikanga, 2019).The largest portion of unaccounted for water is loss through leaks in the main pipes. There are many possible causes of leaks and often a combination of factors leads to their occurrence. The material, composition, age and joining methods of the distribution system components can influence leaks occurrence (AWWA, 2007).

2.3.2. Sources of water loss

International Water Associations (IWA) Water Audit/ balance, defined the components of water losses in a supply network in order to set internationally recognized and consistent standards. This makes it possible to accurately compare performance across national boundaries. The IWA has defined three key water loss components within water supply networks. According to (Farley, 2003),the major source of water loss are categorizes as; un authorized consumption, apparent losses and real losses.

2.3.2.1. Real loss

Physical (real) losses are losses that are caused by large damages that may have occurred to the network pipes or by the deterioration of the pipe junctions or the hydraulic devices. Such losses comprise leakage from all parts of the system and overflows at the utility's reservoirs. They are caused by poor operations and maintenance, the lack of active leakage control, and poor quality of underground assets.

2.3.2.2. Apparent loss

The Commercial (apparent) losses, which consist of water volumes actually consumed but not accounted. Such losses are caused by customer meter under registration, data handling errors, and theft of water in various forms.

2.3.2.3. Unbilled authorized consumption

Includes water used by the utility for operational purposes, water used for firefighting, and water provided for free to certain consumer groups.

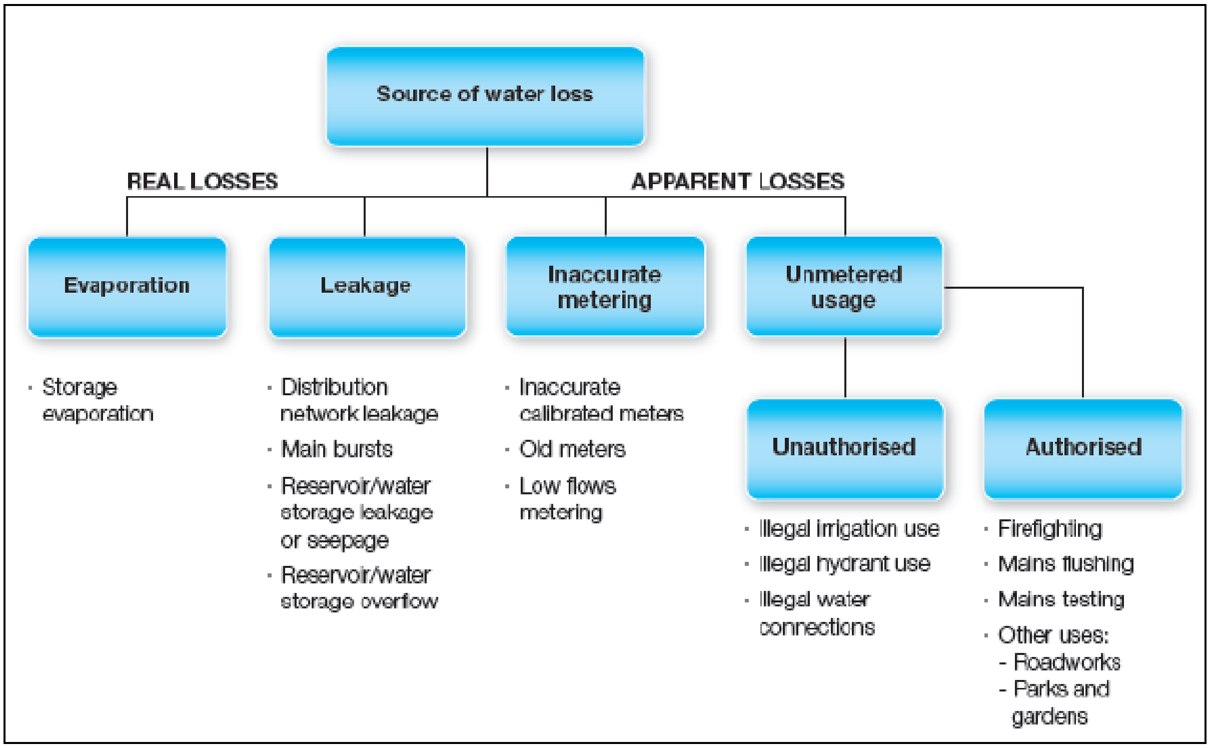

Figure 2.1Classification of water loss type

2.3.3. Water Losses Control and Management strategy

Water losses control is necessary part of water supply management in water supply systems and part of the life of the system as long as there have been organizations operating this urban utility.

It is important to note the Chinese proverb to clearly understand the importance of water management in today's world scenario, "We will not know the worth of water, 'til the well is dry".

On average 26% treated water has been lost from water distribution networks from around the globe due to pipe - breaks, damages / failure, poorly designed infrastructure design, and illegal line connections or consumptions every year(Zheng et al., 2011).This has resulted in loss of $14 billion in profit from the non-revenue water. However, reducing or controlling water loss not only enhances revenue but also conserving water and energy, limiting carbon footprints, and supplying safe drinking water to the world population (Zheng et al., 2011).

The strategy to be framed for any water losses reduction requires proper understanding about the action to be taken including technical, operational, institutional, planning, financial, administrative, and above all leadership commitment issues (WHO, 2008).

According to the news release by Ethiopian News Agency 2011, an official figure tells that 30-35 percent of water in the Addis Ababa city would be misused, wasted or non-accounted for charge. A strategy has been designed to address significantly the wastage to 20 percent. As part of the efforts, old pipelines are being replaced by new ones (ENA, 2011).

The study further described that the source of water losses are not all the results of poor infrastructure and leakages from pipes in the networks. There have been always apparent losses or water misuses from the networks because of local customs, not well developed tariff structures, and absence of proper metering policies.

The model developed by United Kingdom National Leakage Initiative (1991-1994) provided the concept for understanding losses and developing solutions. This experience could help the international water industry to develop strategies customized to local characteristics and infrastructure conditions, in any urban in the world; in addition to this, water supply enterprises would be able to introduced programmers to encourage urban citizens or water users to use economically optimal water.

Now days, water supply enterprises in the world, are taking active water loss management as their primary interest. It has been recognized as significant saves. As a result, further investments in new water resources holdings can be justified only if appropriate action is done to minimize loss from the water supply networks. In the last decade, IWA Task Force has made great efforts to develop new way of performance measuring and benchmarking in this regard. The study paper by the task force, presents the basic principles, methodology and the results of the first step in attempt to approach Serbian water mains tothe new standards (Technical Performance Indicators, IWA Best Practices for Water Mains (IWA, 2007).

2.4. Existing Water Supply System

The water distribution system in Jimma has been classified into four distribution pressure zones. The first zone, Zone 1 of the system, covers the southwestern part of the town and is supplied from hospital reservoir. The far northern part of the town is classified as Zone 2 and it is supplied from Aba Jifar reservoir, and the northern part of the town is classified as Zone 3 and it is supplied from Ginjo reservoir. The rest part of the town, i.e. central and western parts are classified at Zone 4 and supplied from JirenKella and St. Gabriel reservoirs. The Gabriel reservoir has a capacity of 2,500m3. The water distribution network mainly consists of three types of pipe materials: Ductile Cast Iron (DCI), Galvanized Mild Steel (GMS) and un-plasticized Polyvinyl Chloride (uPVC). The diameter of the pipe types listed above ranges from 50mm to 600 mm and the total length is about 40.5 km.

2.4.1. Water Sources

Jimma town water supply system uses surface water (Gilgel Gibe River) as a source of water for three decades. Major expansion following population growth is completed before 5 years using the same water source. The water from Gilgal Gibe River is treated at treatment plants located nearby Boye wetland about 8km from the Jimma town center.

2.4.2. Boye Treatment Plants

There are two treatment plants at Boye. The old treatment plant which was commissioned in 1995 with a daily production capacity of 13,248m3/day and the new treatment plant which was commissioned in 2015 with daily production capacity of 20,324m3/day. The treated water is in turn pumped to service reservoirs from which the water is distributed to the customers by gravity via the distribution network.

2.4.3. Transmission Mains and components

Jimma town's water supply system is currently subdivided into four operating sub-systems, i.e. pressure zones (Figure2.2). The network map for this study was thus developed in accordance to the sub divisions. As per the design study of Jimma town's water supply system of 2012, the topographical layout of the town and the configuration of the existing water supply facilities served as basis for the delineation. Accordingly, the first three zones were supplied from two of the reservoirs, Hospital and Ginjo, while the fourth pressure zone, Aba Jifar, is relatively newly developed and hasits own service reservoir and distribution network.

2.4.3.1. Jiren Kella Pressure Zone (Zone 01)

JirenKella pressure zone covers an area of 20.4 km². It comprises of new residential area such as Becho Bore, the central part, South and West of Saint Gabriel reservoir. From the total water demand of the town, about 58.7%is consumed in this pressure zone. The elevation of the area in the zone ranges from 1707.00 AMSL to 1719.55 AMSL.The pressure zone is supplied from JirenKella Service Reservoir, which is situated at an elevation of 1879.40 AMSL. Gabriel Reservoir is also found in this pressure zone and it is located at an elevation of 1768AMSL. This reservoir is also used to balance the water demand fluctuation of the town by storing extra water during night-time, during which demand is minimal.

2.4.3.2. Hospital Pressure Zone (Zone 02)

Hospital pressure zone supplies areas nearby the hospital, Kochie and Seto villages and it encompasses about 5.3 km² of the town. The pressure zone is supplied with water from the existing 2,500m^3 Hospital Reservoir located at an elevation of 1786.64 AMSL. The reservoir is in turn supplied from JirenKella Reservoir via gravity main. About 22.74% of the total water demand of the town is consumed in this zone. The altitude of areas situated in the zone ranges from 1726.43 AMSL to 1780.20 AMSL.

2.4.3.3. Ginjo Pressure Zone (Zone 03)

This zone covers nearly 1.66 km² area and about 14.36% of the total water produced is consumed in this pressure zone. Jimma University, Teachers' Training College, Ginjo Mendera and areas west of the teachers' training college are encompassed within Ginjo pressure zone. The pressure zone is supplied by Ginjo Reservoir, which has a 500m^3capacity and is situated at an elevation of 1834.90AMSL. The reservoir is itself supplied from Jiren Kella Reservoir. Areas encompassed within this pressure zone have an elevation range of 1,758.08AMSL to 1,831.72 AMSL.

2.4.3.4. Aba Jifar Pressure Zone (Zone 04)

Aba Jifar pressure zone is relatively newly developed to serve the area surrounding Aba Jifar Palace, which had no access to piped water supply system until around year 2015. The reservoir, located at an elevation of 2,018.12AMSL, is supplied from Ginjo Reservoir after being lifted by a pump (Ginjo Booster Station). The zone approximately covers an area of 1.13km² and the water from the reservoir is consumed within the pressure zone, which accounts to about 4.21% of the total water exiting the treatment plants. The area within this zone has an elevation range of 1,835.08 AMSL and 2,004.61 AMSL.

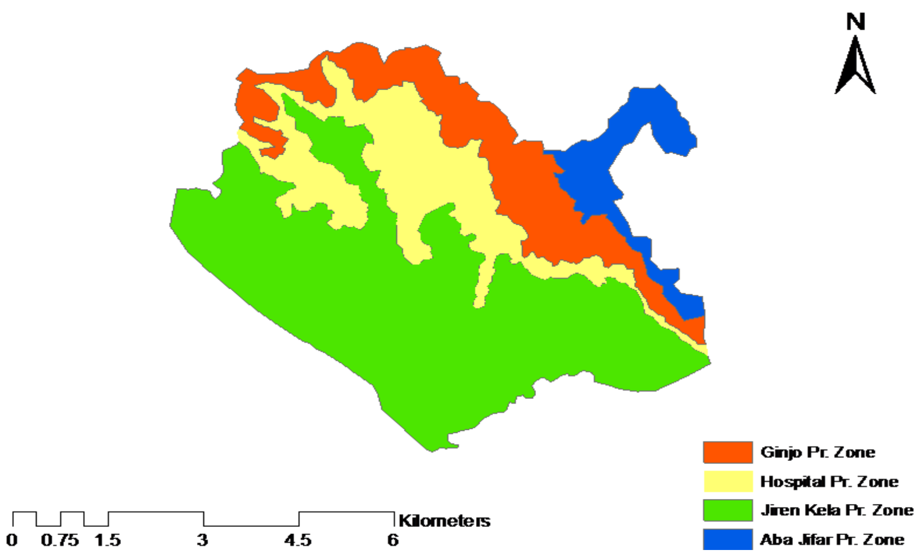

Figure 2.2The four pressure zones of the existing water supply system

The data in Table 2.3 shows the length and dimer of each distribution pipe size in existed system.

Table 2.3Total JTWSSSE network length

Sn.	Diameters(mm)	Length(m)
1	50	4,046
2	80	9,864
3	100	13,330

4	150	12,159
5	200	15,216
6	250	7,931
7	300	5,268
8	350	791
9	400	8,170
10	500	5,627
11	600	1,681
	All Diameters	**84,083.00**

2.5. Performance indicators of urban water supply systems

The use of standardized Performance Indicators (PIs) is necessary in order to measure changes in a utility's Non-Revenue Water control performance and in order to compare the performance of different utilities.

The International Water Association (IWA) has worked for a number of years on the development and utilization of Performance Indicators for many aspects of the water industry. Table2.4 shows Performance Indicators recommended by the IWA for Non-Revenue Water and Real Losses.

Table 2.4Performance indicators recommended by IWA

Component	**Type**	**Level**	**Performance Indicator**
Non-Revenue Water	Financial	Basic	Volume of NRW as % of System Input Volume
Non-Revenue Water	Financial	Detailed	Value of NRW as % of annual cost of running system
Real Losses	Water Resources	Basic	Real losses as % of System Input Volume

Real Losses	Operational	Basic	Real losses as liters/service connection/day when system pressurized
Real Losses	Operational	Detailed	Infrastructure Leakage Index (ILI)
Apparent Losses	Operational	Detailed	Apparent losses as m^3/service connection/year

It must be noted that the Basic Operational Performance Indicator for Real Losses is expressed in terms of the number of service connections because it has been the experience of IWA Task Force members and other practitioners that in well run systems the majority of leaks and bursts (and of the annual volume of Real Losses) occurs on service connections rather than mains. Systems with low density of service connections are an exception. The above Basic Operational Performance Indicator for Real Losses is therefore recommended for systems with more than 20 service connections per km of pipes, as in the case with Jimma. If the density of service connections were smaller, the recommended Performance Indicator for Real Losses would have been liters/km of mains/day when system pressurized.In the following Sections, the above recommended Performance Indicators are evaluated for the JTWSSSE water distribution system at utility level.

2.6. Over view of Water GEMS V8i

Water GEMS V8i is a multi-platform hydraulic and water quality modeling solution for water distribution systems with advanced interoperability, geospatial model-building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, Water GEMS V8i provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems (Darshan et al., 2017).

WaterGEMS was originally developed by the Company Haestad Methods, Inc. based in Watertown, CT (USA). This company was acquired by Bentley Systems in mid-2004, acquisition from which the product began to be known commercially as Bentley Water GEMS V8i. It is a product whose launch was given early twenty - first century and later software product Water CAD the same software house launched in the 90s.

For many experts, Water GEMS V8i more than an evolution of Water CAD is essentially a 'super (Which is already included in Water CAD), adds seamless integration with GIS environments and includes in a single commercial version all the advanced analysis modules which can only acquires separately in Water CAD. In this sense, it is software whose target user is the company that operates supplies, regulators and or important consulting projects. In terms of basic and intermediate tasks Hydraulic Modeling, Water CAD and WaterGEMS are similar products (in fact share the same engine hydraulic calculation) and the same structure data model, so a model created in Water CAD can be read in Water GEMS V8i and vice versa. While Water CAD, supports an autonomous platform (Stand Alone), Micro Station and Auto CAD (as an addition to the product), Water GEMS V8i adds support for ArcGIS to previous environments(Darshan et al., 2017).

In recent years the software has had a great evolution especially in features such as interoperability, ease of use, productivity tools, connection to external data; consultation processes multi-criteria, operations of spatial analysis, graphics capabilities, integration with Systems Geographic information (GIS), etc. Within the most recent developments include the following features like Data Exchange with other Information Systems, Electronic Devices and or other management programs, Using Genetic Algorithms for automated processes hydraulic calibration, optimal design and energy optimization, Analytical Leakage Detection, Vulnerability Plans to Pollution Events, Systems integration with SCADA, Multi-parameter Quality Analysis, Network Renewal Planning, Integration with Analysis of Hydraulic Transients and Waterfall (Paul, 2005).

2.7. Water distribution network simulation

The term simulation generally refers to the process of imitating the behavior of one system through the functions of another. It can be used to predict system responses to events under a wide range of conditions without disrupting the actual system. Using simulations, problems can be anticipated in proposed or existing systems, and can be evaluated before time, money, and materials are invested in a real-world project (Melaku, 2015).

As per (Melaku, 2015), in water distribution networks the most basic type of model simulations are either steady-state or extended-period simulation. Steady-state simulations; represent a particular view of point in time and are used to determine the operating behavior of a system under static conditions. It computes the hydraulic parameters such as flows, pressures, pump operating characteristics and others by assuming that demands and boundary conditions were not change with respect to time. In general, this type of analysis was used to determining the short-term effect of demand conditions on the system. Extended period simulations:-are determine the dynamic behavior of a system over a period of time, and it analyze the system on assumption that the hydraulic demands and boundary conditions were change with respect to time. Hence, ‘extended period analysis used to evaluate system performance over time and allows the user to model pressures and flow rates changing, tanks filling and draining, and regulating valves opening and closing throughout the system in response to varying demand conditions and automatic control strategies formulated by the modeler. Therefore, regardless of project size, model-based simulation can provide valuable information to assist an engineer in making well-informed decisions.

Water GEMS is a hydraulic modeling application for water distribution systems with advanced interoperability, geospatial model building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, Water GEMS provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems. This model uses an assortment of data, input, and output files. It is important to understand which essential, temporary holding places for results are and which must be transmitted when sending a model to another user. In general, the model is contained in a file with the wtg.mdb extension. This file contains essentially all of the information needed to run the model. This model gives the choice between performing a steady state analysis of the system and performing an extended-period simulation over any time period (Bentley Water GEMS V8i, 2014).

2.8. Hydraulic Performance of Distribution Networks

Hydraulic analysis of flows and pressures in a distribution system has been a standard form of engineering analysis since its development by Hardy Cross in 1936. The demand usually reaches a peak in the morning when people are at home and preparing their Meal and its second peak in the evening Maximum water use and minimum water use, usually related to average water use by multiplication of peaking factors (Melaku, 2015).Water CAD views the water distribution system as a network link.

According to WHO (1995), the measurements of the hydraulic performance of the distribution network can be undertake by checking whether (a) can supply safe and wholesome water to the users, whether these constitute a family, a group of families, or a community; (b) can supply water in adequate quantity; and (c) can make water readily available to the users, in order to encourage personal and household hygiene. However, all the above criteria are directly or indirectly affects by the pressure and velocity distribution in the system. To maintain the system in optimum and safe condition, the pressure and velocity distribution variation should range from 0.3 -2.5 m/s and 15 - 60 m respectively. According to Water pipeline design guideline (2004), the following tables, Table 2.5 shows the recommended values of velocity and pressure in large towns water supply system.

Table 2.5Velocity and pressure variation with corresponding effects

S.No.	Velocity(m/s)	Status	Pressure(m)	Status
1	< 0.3	Sedimentation will occurs	< 0	No flow due to negative pressure
2	0.3-2.5	Safe condition	0-15	Low pressure to satisfy the demand
3	>2.5	Scouring will occurs	15-60	Safe water pressure
4			>160	Pipe break due to high pressure

2.9. Water Distribution Simulation

Simulation refers to the process of imitating the behavior of one system through the functions another. In our case, the term simulation refers to the process of using a representation or real system, called a model. Simulation can be used to predict system responses to under a wide range of conditions without disrupting the actual system, and solutions can be evaluated before time, money, and materials are invested in a real-world project (Bentley Water GEM V8i, 2014). There are two most basic types of simulations that a model may perform, depending on what the modeler is trying to observe or predict. These are: Steady state simulation (SSS) and extended period simulation (EPS).

2.9.1. ***Steady State Simulation***

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. 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 are not particularly significant.

2.9.2. Extended Period Simulation

Extended period simulation tracks a system over time, and it is a serious of linked steady state run. The need to run extended period simulation is because the system operations change over time. This simulation is important as demand varies over the course of the day, pumps and wells go on and off, valves open and close and tanks fill and draw.

2.10. Application of Water GEMS V8i to check the performance of existed water distribution system

Water GEM V8i is a hydraulic modeling application for water distribution system with advanced interoperability, geo spatial model building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management. WATERGEMS V8i also provides an easy-to-use environment for engineers to analyze, design, and optimize water distribution systems. WATERGEMS V8i is a multi-platform hydraulic and water quality modeling solution for water distribution systems with advanced interoperability, geospatial model-building, optimization, and asset management tools.

A number of studies and simulations of water supply system were performed by using Water GEMS V8i model in order to simulate the hydraulic performance of the system. For instance, Darshan et al., (2017), were used this software to design optimal water distribution systems for surat city. In this study, the obtained result verified that the pressures at all junctions at all pipes are feasible enough to provide adequate water to the network of the study area. Some of the works related to this work including Mukand (2015), Udhane (2018), Dipali (2017) shows that the model performs well.

CHAPTER THEREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study area (Jimma town) is the largest city in the south-western part of Ethiopia, which is located about 347 km to south west of capital of the country (Addis Abeba). It is found in region of Oromia regional state, Jimma zone. Geographically, Jimma town is located between of 7º37' to 7^0 41’ N and 36º48' to 36^0 52’ E. The town is found in *Manna wereda*.

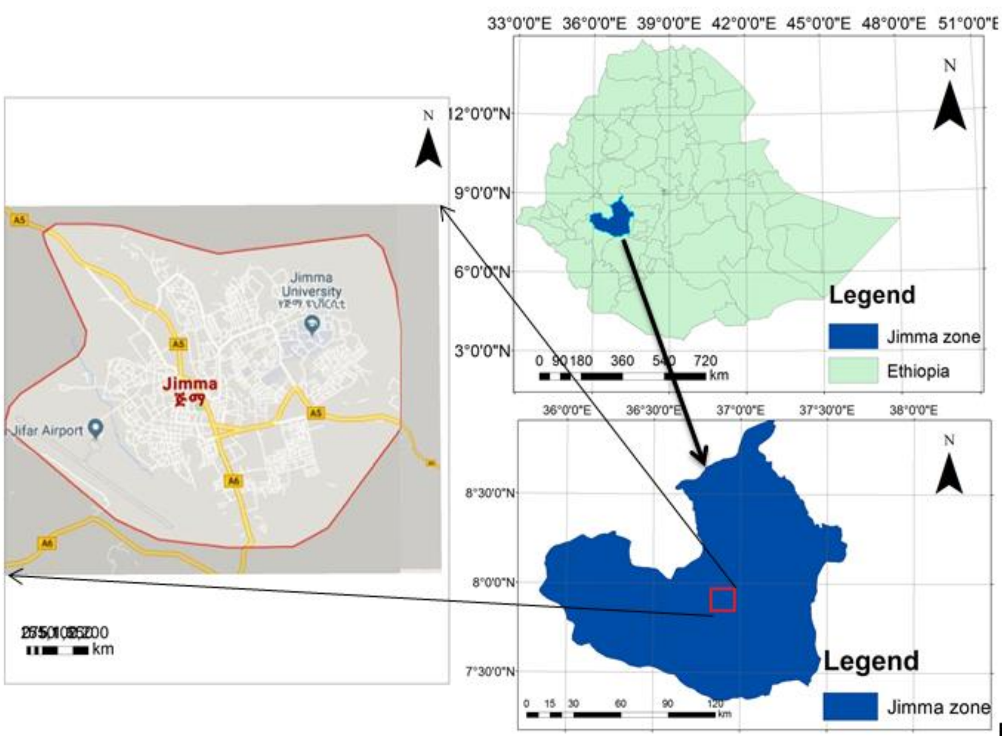

Figure 3.1Location map of the study area

3.1.2. Climate and topography

Jimma town lies in the climatic zone of locally known as *Woyn*a *Dag*awhich is considered ideal for agriculture as well as human settlement. It has features of a long annual wet season from March to October with annual precipitation of 131.8 mm. The temperatures of Jimma town is in a comfortable range, with the daily mean staying between 20 °C and 25 °C year-round.

Jimma town is found in an area of average altitude of about 1780 m above sea level. The major part of Jimma town, including the central, southern and western parts, is characterized by flat to gently sloping/undulating topography, while the northern and eastern parts of the town and its peripheries are characterized by hilly/ sloping landscape.

3.1.3. Demography

According to the information from Jimma town administration and statistics office, the town is divided into thirteen kebeles. With those kebeles, the current population is estimated to be about 263,000, of whom 127,824 are men and 135,176 women. With an area of 64 square kilometers, Jimma has a population density of 4109per square kilometer area with a total of 65750 households, which results in an average of 4 persons to a household, and 30,016 housing units. The three largest ethnic groups reported in Jimma were the Oromo (46.71%), the Amhara (17.14%) and the Dawro (10.05%); all other ethnic groups made up 26.1% of the population.

Table 3.1 Demographic data of Jimma town

Geographical area	Population				
	Both sexes	Male	Female	Number of house holders	Number of housing unit
Bosa Addis ketema	15,202	7,574	7,628	3962	5,852
Seto semero	14,888	7124	7764	3548	3414
Mendera kochi	20,232	10770	9566	5660	2,7415482
Ginjo Ketema kebele	31,900	17302	14578	7908	7570
Jiren	4,366	2108	2258	918	896
Bosa kito ketema	22,000	10242	11758	6286	5988
Mentina	15,320	7258	8062	4210	4032
Hermata	12,674	6264	6410	2196	3304
Hermata mentina	19,104	9546	9558	4432	4138
Hermata merkato	12,320	6236	6084	3064	2958

Awetu mendera	18,788	8892	9896	5196	5010
Guduru	16,124	8308	7796	5066	4560
Bicho Bore	42,160	21,200	20960	10,782	10,298
Total	**263,000**	**134,500**	**128,500**	**62,156**	**61,320**

Source; Jimma town population house hold and housing unit for urban kebeles, (2013)

3.2. Data collection

3.2.1. Primary data (data from customer)

The required primary data for the analysis were collected from the sample customers of the selected kebeles. The information collected by the interview from the customers were, the amount of current water supply per a day and the level of satisfaction.

3.2.2. Secondary data (Data from JTWSSS)

The required secondary data for the analysis were collected from JTWSSSE during the data collection. The network elements consisting of points and polylines representing the physical component42160s of the water network: pipes, junctions, service reservoirs, customer-meters and network appurtenances were given in different file format (PDF, excel and GIS shape files format). The network elements category consists of a geo-referenced information organized in the following layers.

3.2.2.1. Pipes data

The information includes data of all pipe elements in the network. The table has the following fields:

ID label of pipe, pipe category (primary transmission, primary ground source supplied, secondary - distribution), nominal diameter (mm), material type (DCI, GI, GS, PVC), Year of Installation, Start junction ID, Stop junction ID, Zone, Description Notes and Length (m).

3.2.2.2. Junction data

The junction data includes all the information of junction nodes in the. The junctions information has the following fields:

ID label of junctions (unique identification), elevation (m), category (primary - Supply to secondary network, primary - supply to special consumer, secondary), zone, description botes and X and Coordinates (m).

3.2.2.3. Service reservoir

Reservoir data includes all the information about the service reservoir, nodes and has the following fields:

ID label of service reservoirs (unique identification), reservoir name, location (X and Y coordinate),status, description notes, volume (m^3), year of construction, material, remarks, cross sectional shape (circular, rectangular, hexagonal), DTM elevation (bottom, inlet, outlet, overflow, drain) (m) and pressure zone.

3.2.2.4. Pump data

The collected pump data includes the following information

ID label of surface pumps (unique identification), Location (Xand Y coordinate), pump status, description notes, elevation (m) , pump manufacturer, pump model, pump capacity Q (m^3/h), pump H (m), pump inlet D (mm), pump outlet D (mm), pump remarks, motor manufacturer, motor model and motor power (KW).

3.2.2.5. Flow meter

The flow meter data for all existing Flow Meters in the network is given as follows:

ID label of bulk flow meters (unique identification), location (X AND Y coordinate),installation year,category (A, B, C), status (functional, not functional, unknown), status remarks, inlet pipe diameter (mm), Meter diameter (mm), Meter type (electromagnetic, mechanical) and remarks notes.

3.2.2.6. *Appurtenance*

The appurtenance infrastructure of the network includes the following:

ID label (unique identification), Type of appurtenance (Gate Valve, Pressure Reduction Valve, Public Fountain, Flow Control Valve), Diameter (mm), Pipe diameter (mm), Status (Open, Closed, Not Functional), Description note and location coordinate.

3.2.2.7. *Water production and billed data*

In order to evaluate the approximate yearly water loss amount and the consequent economic loss, eleven years recorded annual billed water and annual water production were collected from JTWSSSE. This data is given in table 3.2.

Table 3.2Yearly water production and billed amount of water

Sn.	Year	Yearly system input Volume (m^3)	Yearly billed water Consumption (m^3)
1	2000	2,047,800	1,254,272
2	2001	2,230,800	1,335,940
3	2002	2,316,800	1,428,655
4	2003	2,426,500	1,465,002
5	2004	2,691,210	1,511,416
6	2005	2,744,590	1,585,678
7	2006	2,821,384	1,680,591
8	2007	3,418,778	2,126,865
9	2008	4,339,210	2,414,253
10	2009	4,715,581	2,861,695
11	2010	5560235	3437944.7

3.3. *Data Processing and Analysis*

3.3.1. *Selection of Sample Study Area*

Sampling is very important in any research since it is very difficult and takes more time to include all the study areas and populations. Research without sampling is also much costly and time consuming as it needs more questioners to be distributed for water users. To select sampling areas, the major factors were; accessibility, problems regarding to water pressure and topography of the kebeles. Based on those main criteria, among the 13 kebeles in the town,4 kebeles, namely; Mentina, Bosa Adis, Bochobore and Ginjo guduru were selected for the data collection and assessments of the level of water supply and its satisfaction.

3.3.2. *Sample size*

According to Jimma zone central statistics agency report, there are about 8700 households in those selected sample kebeles. To get the representative sample of the total population/

households, using sampling technique is important. Therefore in this study, systematic random sampling technique was used to take households as a sample household. This was achieved by taking 5% (435) of the total household from targeted kebeles listed above. The number of sample hoses from the selected kebeles is given in Table3.3.

Table 3.3Number of sample houses in the selected kebeles

S.N.	Sample kebeles	Total number of houses in the selected kebeles	No. of representative houses
1	Mentina	2100	105
2	Bosa Addis ketema	2200	110
3	Bocho bore	2400	120
4	Ginjo Guduru	2000	100
5	Total	8700	435

As it is described earlier, the systematic random sampling technique was used to select households as a single household represented about 20 households of selected kebeles. This means the sample house was taken at each interval of 20 houses. This figure was calculated by the following equation (Equation 3.1). The first water users would be taken by lottery method and then at every 20th interval, individual household was interviewed.

Interval of water user = $\frac{\text{Total number of water user}}{\text{sample size}}$……………………………………………..…….3.1

Interval of water user = $\frac{8700}{435} = 20$

3.3.3. Water Supply Coverage

The water supply coverage of the tow was evaluated based on the collected per capita consumption of water from the sample kebeles. The per capita consumption of water was collected from each selected households during data collection. And finally, aggregated to the whole population gives the per capita demand of the town.

3.3.4. Water loss analysis

The amount of water loss in distribution system at the town level was gained from the total volume of water produced and the total volume of water billed, that gained from JWSSSE. The following equation (Equation 3.2.) was used to calculate the amount of total yearly water loss.

Total water loss (%) = $\frac{\text{Total water production} - \text{total billed water}}{\text{total water production}}) * 100$……………………………3.2.

3.3.5. Simulation of existed distribution system

All the above data discussed in *section 3.2.2.*, were used as an impute for Water GEMS V8i software, to evaluate the hydraulic performance of the distribution system in terms of pressure and velocity distribution.

The following section describes the process of putting together the water distribution network data in Water GEMs V8i software. The first step in starting the model is to set up some important parameters like the unit system (SI or US customary), temperature of the liquid/ water which should be pre define values used by the software. Therefore in this analysis, water temperature of 20 C^0, International System Units (SI unit) and Hazen-Williams for pressure friction method were pre-defined impute data. Hence, lengths, pressures, head, elevations are taken in meters and diameters of pipes are defined as millimeters. Then, the junction and other point elements of the network data were imputed to the software through Model Builder tool. Then to draw the whole pipe network, each junctions and other point element were joined by pipe tool from the software tools. Finally, the detailed available data (*discussed in section 3.2*) of each element were imputed.

After the all the respective data were assigned, the status of control valve was letting water flow only in the direction of their first to their second node. This setting is important to avoid backwards flow from tanks or reservoirs whose inlets discharge above surface water or for emitter taps which would become sources in the absence of flow. Finally, the pressure and velocity distribution variation along the whole network were evaluated through steady state analysis scenario found in Water GEMS software.

3.3.6. Simulation of optimized system

The management of pressure and flow velocity is placed on the forefront of the strategic solutions for reducing water loss. In this study, some strategies were implemented to manage the pressure and flow velocity and to improve the hydraulic performance of the water supply system. Such a strategy requires an iterative approach of upgrading the water distribution system. For this study, PRVs (Pressure Regulating Valves), FCVs (Flow Control Valves) and bypass lines were proposed to implement to control and bring the pressure and velocity within the recommended range of 15 - 60m and 0.3-2.5m/s respectively. Furthermore, a new line was proposed in an attempt to curb the insufficient flow velocity issue that was mainly observed in Jiren Kella zone.

The distribution system has several misconnections in its existing state. In order to optimize the system, it has been reconfigured the pipe type and arrangement in such a way that some of the observed issues were corrected. For example, the other proposed improvement was that the direct pumping situation from old treatment plant to the Jiren Kella pressure zone was altered and re-connected the outlet from old boye treatment plant to the Clear water tank of the new treatment plant.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Water Supply Coverage

The volume of water consumed was aggregated to the whole population of the town, so as to analyses the distribution of existing of water supply coverage. The evaluation of the water supply coverage was done by using information gained during data collection that the volume of water consumed by the local users. This was done by taking sample households from the selected kebeles. Therefore, based on the result, the majority 176 (44.89%) households consume in between 50 to100 l/day, 164 (41.84%) households consume less than 50 l/day and 53(13.52%) household respondent used more than 100 liters per day (Table 4.1).

Table 4.1 Water consumption of selected kebeles

			Water consumption per households (lit/day)		
S.No.	Kebeles	Households	< 50	50-100	>100
1	Mentina	105	32	61	12
2	Bosa Addis ketema	110	65	35	10
3	Bocho bore	120	29	59	32
4	Ginji Guduru	100	37	35	28
	Total	435	163	190	82
	Percentage (%)		37.50%	43.70%	18.80 %

The distribution of water consumption varies among the kebles. Kebles such as merkato, hermata and mentina are having a better average consumption while the other kebeles (*bosa kito)* consume a less amount of water while compared with the other kebeles.

According to Jimma zone Health Office survey (2011), the average family size of the household of the town is 5. However; in this study, during sample survey, the average family sizes of the households are appeared to be 6 and the calculated average daily water consumption of households per day is 57.89 liters. That means, average water consumption per person per day is 9.6 l/ c/ d. (53.34%) liters. Comparing with the WHO standard water demand (liter per capita per day) which is 80 l/c/dy, the community's water consumption level is very low relative to the amount of water required to individual for domestic consumption per day.

Table 4.2Per capita water consumption of selected kebeles

S.No.	Kebeles	Average Daily water consumption (Liter)	Number of people	Average family size	Per capital consumption (lit/cap/day)
1	Mentina	62.85	582	6	11.34
2	Bosa Addis ketema	41.41	533	6	7.69
3	Hermata Mentina	63.96	540	4.59	13.93
4	Hermata merkato	62.34	499	6.4	9.74
	Average	57.89	1,547	5.47	10.67

Table 4.3Daily Water consumption in liter per day

S.No.	Standard (liter/cap/day)	Observed (lit/cap/day)	Difference (lit/cap/day)	Percentage (%)
1	80	10.67	9.33	53.35%)

4.2. Levels of customer satisfaction

The level of water supply satisfaction was evaluated based on the answers of the sample population given for the raised rank/levels of satisfaction. Table 4.4 shows the levels/ rank of satisfaction with the corresponding number of respondents from each kebeles.

Based on the aggregated result gained from the sample kebeles, the level of satisfaction of the population in different kebeles is found to be different. Accordingly, the level of customer satisfaction in Bochobore kebele was found to be higher ie. the maximum percent (33.3 %) leis on the rank of "high" while in Bosa Adis,the maximum percent (36.4%) lies on the rank of "very low". Generally, the maximum percent (34.5 %) water supply satisfaction for the whole sample kebeles was laid on the rank of "moderate".

Table 4.4 Level of water supply satisfaction

Sn.	Kebeles	Household	Level of satisfaction (in number)				
			Very high	High	Moderate	Low	Very low
1	Mentina	105	10	30	50	10	5
2	Bosa adis	110	5	15	20	30	40
3	Bochobore	120	20	40	30	20	10
4	Ginjo Guduru	100	5	15	50	20	10
5	**Total**	**435**	**40**	**100**	**150**	**80**	**65**

Table 4.5. Level of water supply satisfaction in percent

			Level of satisfaction (in %)				
S.No.	Kebeles	Households	Very high	High	Moderate	Low	Very low
1	Mentina	105	9.5	28.6	47.6	9.5	4.8
2	Bosa adis	110	4.5	13.6	18.2	27.3	36.4
3	Bochobore	120	16.7	33.3	25	16.7	8.3
4	Ginjo Guduru	100	5	15	50	20	10
5	**Total**	**435**	**9.2**	**23**	**34.5**	**18.4**	**14.9**

4.3. Water loss analysis

To estimate the amount of water loss from the distribution system, the total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings were used. The result of the analysis shows that, there is high amount of water loss in the distribution system due to different cause of water losses such as real loss, apparent loss and unbilled authorized consumption. The total monthly water production and consumption of the town was given for eleven years (2008- 2018) (Table 4.6).

Table 4.5Summary of water production volume and water loss(2008– 2018)

Sn.	Fiscal year	Water production Volume (m^3)	Billed water Consumption (m^3)	Water Loss (m^3)	Water Loss in Percent
1	2008	2,047,800	1,254,272	793,528	38.75
2	2009	2,230,800	1,335,940	894,860	40.11
3	2010	2,316,800	1,428,655	888,145	38.33
4	2011	2,426,500	1,465,002	961,498	39.62
5	2012	2,691,210	1,511,416	1,179,794	43.84
6	2013	2,744,590	1,701,896	1,042,694	37.99
7	2014	2,821,384	1,767,036	1,054,348	37.37
8	2015	3,418,778	2,208,994	1,209,784	35.39
9	2016	4,339,210	2,483,181	1,856,029	42.77
10	2017	4,715,581	2,891,879	1,823,702	38.67
11	2018	5560235	3468128.7	2092106.3	37.7
	Total	**35,312,888**	**21,516,400**	**13,796,488**	**39.14**

In Jimma town, the annual average water loss for the consecutive eleven years (2008 – 2018) is founded to be 39.14 % out of the total production. This amount is 13,796,488 m^3 out of the total water production of 35,312,888 m^3per 11 years. This percent loss is more than the acceptable percent value of water loss from developing countries which is 15-26 %.

As the information gained from JTWSSSE, the minimum selling cost of water supply is varying from 1.6 to 3.6 Ethiopian Birr (ETB) per m^3. As can be seen from the table below (Table 4.7), annually, JTWSSSE is losing large amount of money due to water loss.

Table 4.6 Annual average water loss and the corresponding economic loss

	Yearly Water Loss (m^3)	Cost per m^3 (ETB)	Annual Economic Loss (ETB)
1	793,528	1.60	1,269,644.80
2	894,860	1.60	1,431,776.00
3	888,145	1.60	1,421,032.00
4	961,498	1.60	1,538,396.80
5	1,179,794	1.60	1,887,670.40
6	1,042,694	3.60	3,753,698.40
7	1,054,348	3.60	3,795,652.80
8	1,209,784	3.60	4,355,222.40
9	1,856,029	3.60	6,681,704.40
10	1,823,702	3.60	6,565,327.20
11	2092106.3	3.60	7,531,582.68
Total	**13,796,488**	3.60	**49,667,357.88**

4.4. Hydraulic performance of the existed system

In this study, the hydraulic performance of the system was evaluated in terms of pressure and velocity distribution variation along the whole system. That means the system performance was checked by a hydraulic performance indicators (Velocity and pressure). For this analysis, Water GEMS V8i, the hydraulic modeling software, was used to analyze each nodal pressure and velocity in the distribution system. The variation of pressure at the junctions as well as that of velocity in the distribution network was subsequently studied using the existing situations of the network.

4.4.1. Velocity variation

Velocity of water flow in a pipe is also one of the important parameters in hydraulic modeling performance evaluation of the efficiency of water supply distribution line. According to Water pipeline design guideline (2004),the allowable velocity in urban water supply system should not be less than 0.3m/s to prevent sedimentation and not to be more 2.5 m/s to prevent erosion and high head loss. Therefore, in this analysis, the hydraulic model of existed water network was evaluated to check whether optimum velocity was maintained in the system or not.

Based on the results of the steady state scenario shown in Figure 4.1, in the existed system, 172 pipe were found to have very low flow velocity of below 0.3 m/s, almost all of the rest were found to have a value that is beyond the recommended flow velocity of 2.5 m/s. On the other hand, only 132 pipes have a velocity value that falls within the recommended range.

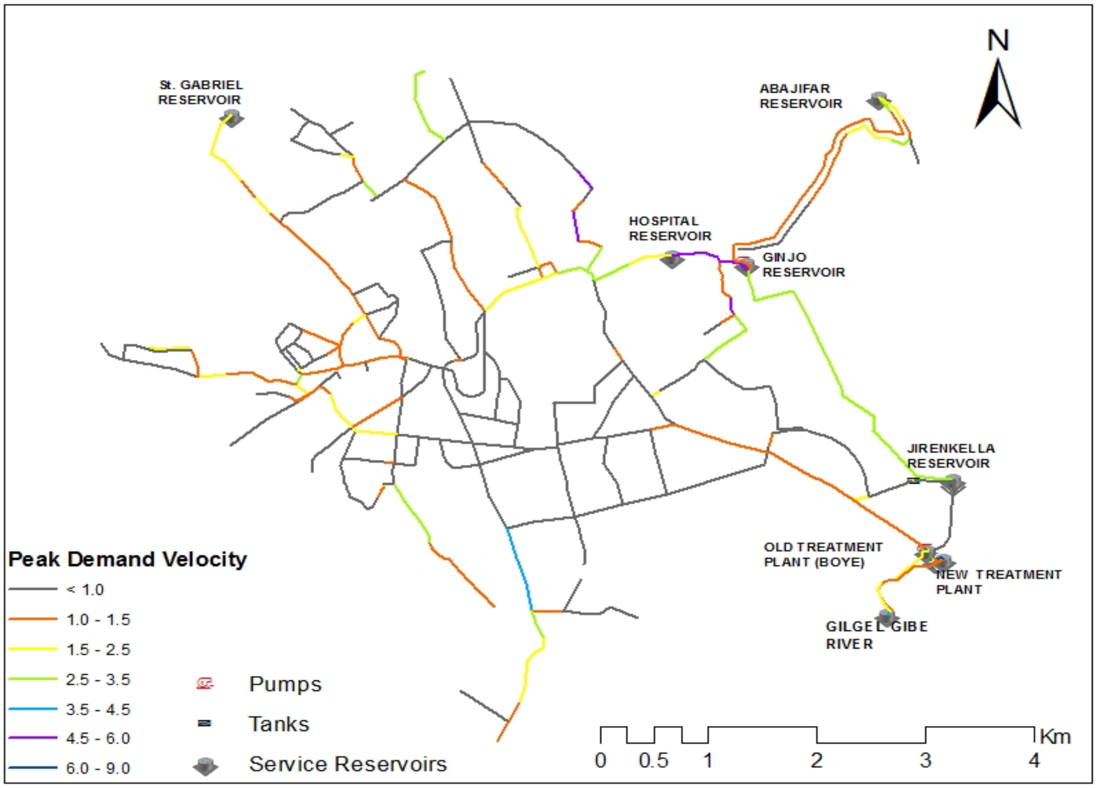

Figure 4.1Velocity distribution variations of existed condition

4.4.2. Pressure variation

To see the pressure variation in the distribution system, the hydraulic model was developed for three separate scenarios: base demand, minimum demand and peak-hour demand scenarios. The minimum demand scenario was especially significant for observing the extent and level of pressure variation and thus, possible locations of water leakage in the system. Minimum demand scenario correlates to the time of day, during which there is almost no withdrawal of water from the system, which consequently leads to the development of a high level of pressure in the distribution network. The result of the simulation at minimum demand has revealed that the pressure in most part of the distribution system is beyond the optimum range of 15 m - 60 m recommended by water pipeline design guideline (2004)(Figure 4.2).

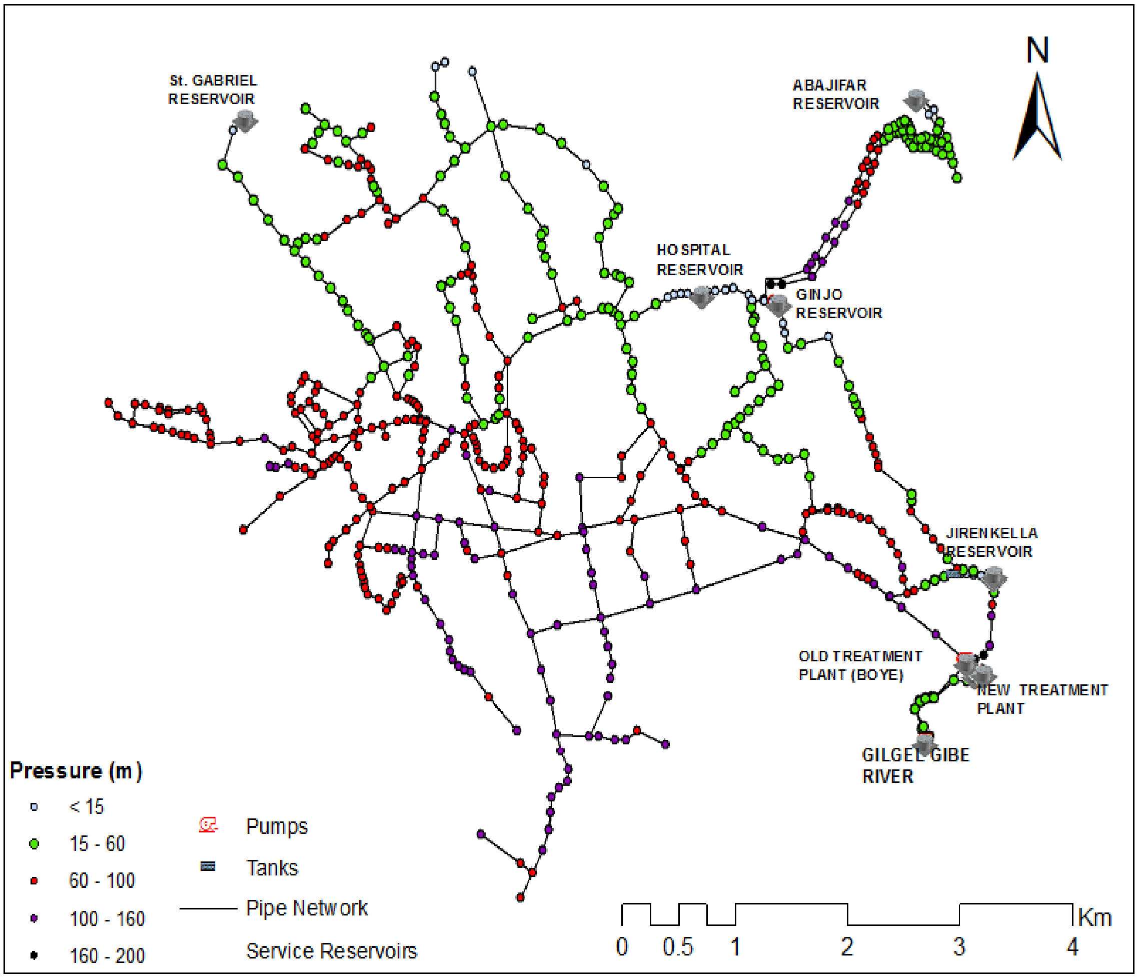

Figure 4.2 Pressure distribution variations for existed condition

From the result of the hydraulic model, it can be concluded that the pressure and velocity in most part of the distribution system do not fall within the recommended range. This leads further exacerbated water loss from the system in some areas and very low pressure or non-flow situation occurs at some areas. Due to an over-sizing of the pipes, the flow in the pipe has become inadequate thereby leading to storage and siltation problems. Pipe burst due to the high-pressure values is expected to exacerbate the water loss problem. It is also important to note that above noted problems are more pronounced in Jiren Kella pressure zone (Figure 4.2), where direct pumping is practiced.

4.5. Optimized Situations of the Hydraulic Model

As can be seen in section 4.4, the result of the simulation for the existed system has many problems regarding to the fair distribution of pressure and velocity which are basic controlling hydraulic parameters. Those problems can be a cause of high amount of Non-Revenue Water (NRW) and uneven distribution of pressure and velocity. In order to explore alternatives for solving the problems, a second hydraulic model with several improvements to the system has been performed. The optimization of the distribution system is especially important for reducing the high rate of NRW observed in the study area by balancing or maintaining the pressure and velocity in the recommended range. This was done by trial and error procedure of changing some network elements properties and source of supply.

The optimization of the system also focuses on achieving, through the establishment of a fully pressurized network, an improved pumping regime and an improved pressure regime throughout the network. Eliminating wide pressure fluctuations and the frequent emptying and filling of network pipes associated with the present intermittent supply regime that occurs especially in JirenKella pressure zone can be expected to reduce pipe wear and the resulting leaks and breaks. Securing a continuously pressurized network and an improved pressure regime through the rational allocation of all available treated water sources is therefore regarded as a key element of the overall water loss reduction strategy in Jimma town's water supply network.

The process of developing the optimized model, the existing network was upgraded, the water supply system reconfigured and the pressure zones delineated in accordance with maintaining the recommended pressure and velocity ranges.

4.5.1. Upgrading the network elements

The management of pressure and flow velocity is placed on the forefront of the strategic solutions for reducing NRW. Such a strategy requires an iterative approach of upgrading the water distribution system. For this study, PRVs (Pressure Regulating Valves), FCVs (Flow Control Valves) and bypass lines were implemented to bring the pressure and velocity within the recommended range of 15-60m and 0.3-2.5 m/s respectively. Furthermore, a new line was proposed in an attempt to curb the insufficient flow velocity issue that was mainly observed in JirenKella zone.

4.5.2. Re- configuration of pressure zone

As noted before, the distribution system has several misconnections in its existing state. In order to optimize the system, it has been reconfigured in such a way that some of the observed issues were corrected. Primarily, the direct pumping situation in JirenKella pressure zone was altered connecting the outlet from Boye treatment plant to the Clearwater tank of the new treatment plant (Figure 4.4).

4.5.3. Optimized pressure distribution

As noted before, the distribution system was subdivided into four pressure zones based on the topographical layout of the town and the configuration of existing water supply system. Nevertheless, in its existing conditions, the system is operated in such a way that the pressure zones do not play any operational role. Currently, there are cross-connections between the subsystems, which have led to an unbalanced distribution of pressure and velocity throughout the system. The problem has also led to a shortfall between supply and demand as well as a high rate of NRW in the system. For the optimized model, all pressure zones have been made utterly independent by using gate valves to close the pipes that run from one zone to another. Each zone is also made to be supplied from its own reservoir. Consequently, all of the nodes that are found in the same pressure zone are made to have nearly similar within recommended range of pressure and velocity. The delineation of the pressure zones has also been adjusted by considering the above noted points.

After the pressure zones were delineated the distribution system has been modeled and designed to accommodate the water demand of the ultimate design period. The following points have been given due consideration while delineating the pressure zones:

- Maintaining the allowable operating pressure and velocity of flow;
- The locations of the existing service reservoirs and areas commanded by the respective reservoirs; and
- Development pattern of the town on the bases of the available development and land use plans

As noted previously, one of the goals of optimizing the hydraulic network was to bring the pressure and velocity distribution closer to one that lies within the optimum range than that of the existing situations distribution system. For comparing the pressure in the systems, peak-hour demand scenario was chosen (Figure 4.3, Figure 4.4. and Table 4.8). As per the analysis' results of the optimized situation, 315 nodes were found to have pressure values that fall within the optimum range, which shows a significant improvement compared to that of the existing situation. The nodal pressure of the existing situation's model and that of the optimized situation are presented in Figures 4.3 and 4.4 respectively.

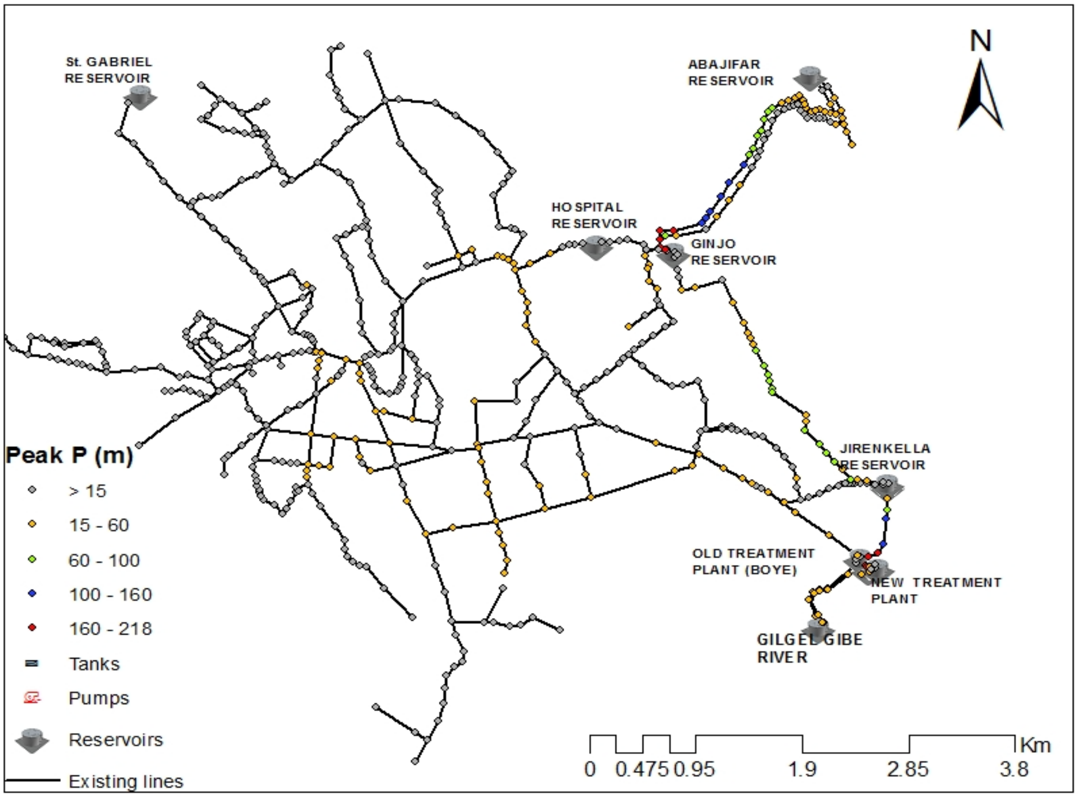

Figure 4.3P ressure distribution of the existing situation

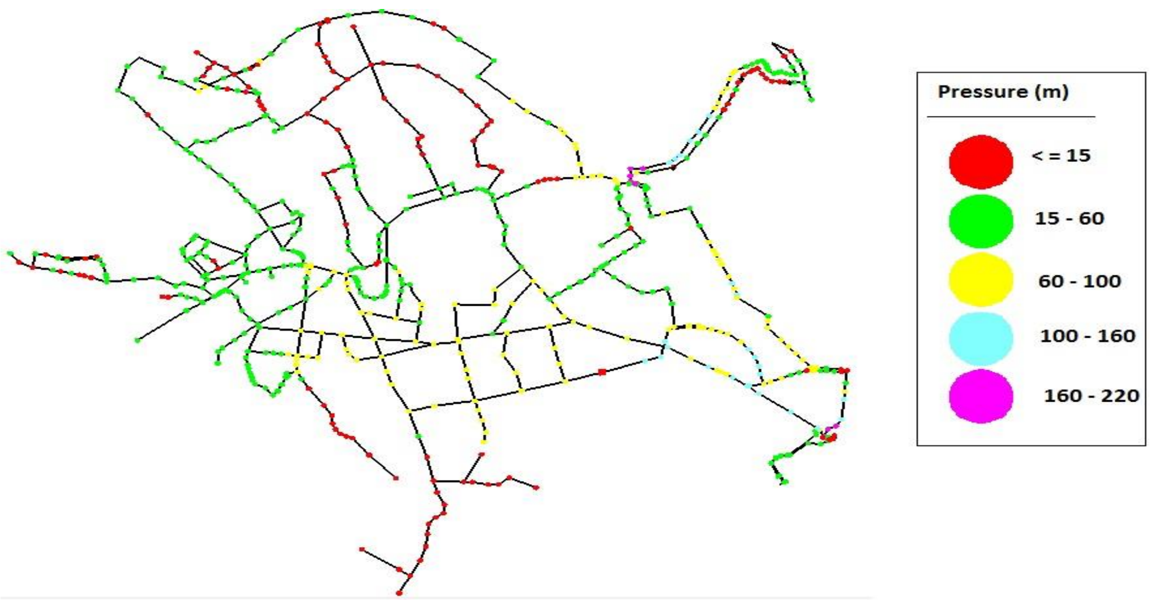

Figure 4.4 Pressure distribution of the simulated situation

Table 4.7 Comparison of pressure distribution of the optimized and existed situation

Pressure range	No. of Nodes innumber			
	Existing Situation's H. Model		Optimized Situation's H. Model	
Within 15 - 60 m Pressure Range	146	25%	315	52%
Within 15 - 100 m Pressure Range	167	29%	433	71%
Total	583		614	

4.5.4. Optimized velocity distribution

Similarly, the network system was optimized for the velocity distribution. And the optimized situation's hydraulic model is compared with that of the existing situation. In this regard, peak hour demand is considered since it provides an insight into the highest buildup of velocity in the system. Accordingly, the velocity in most of optimized pipes, falls within the optimum range (0.3 – 2.5 m/s) better than that of the existing situations of the system (Table 4.9, Figures4.5 and 4.6). In its existing situation, the flow in most of the pipes (67)was below 0.3 m/s, which leads to the siltation and thus fast deterioration of the pipes.

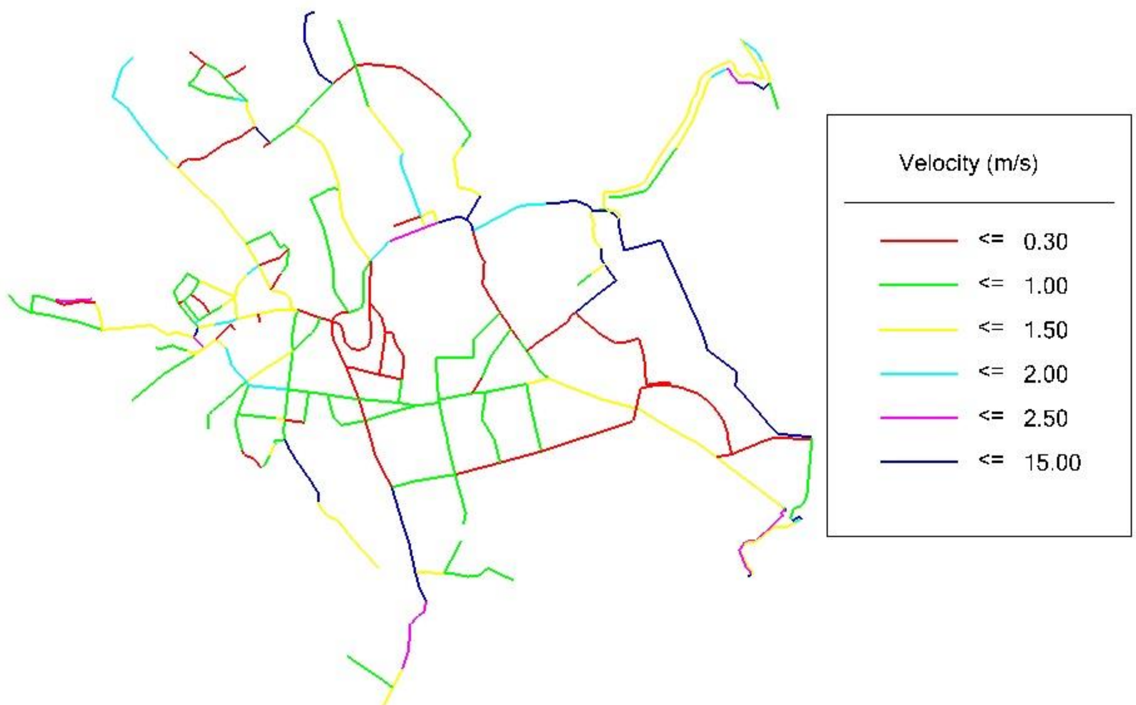

Figure 4.5 Velocity distribution of the existing situation

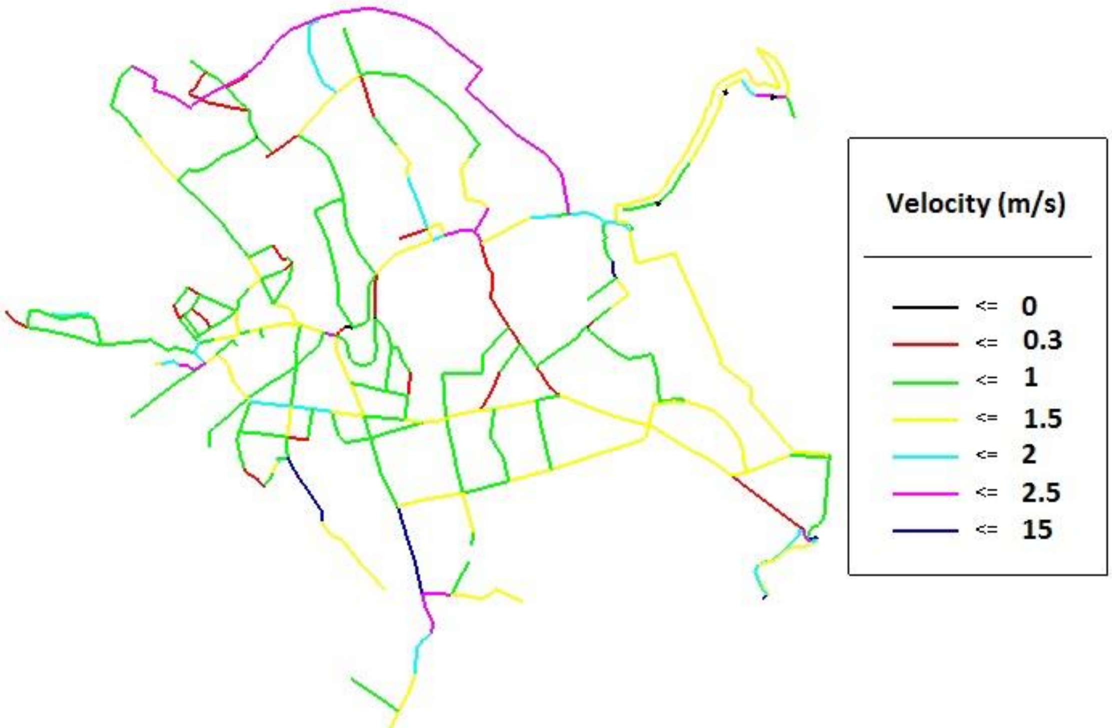

Figure 4.6 Velocity distribution of the optimized situation

Table 4.8Comparison of velocity distribution of the optimized and existed situation

Velocity distribution	No. of Pipes in number			
	Existing Situation's H. Model		Optimized Situation's H. Model	
Within 0.3 - 2.5 m/s Velocity Range	651	81%	593	87%
Total	526		688	

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study attempted to present a comprehensive over view of the status of the water supply coverage, the annual water loss and the consequent loss of cost posed on JTWSSSE and the hydraulic performance of the existed system. The findings of this study reveal that the current average per capita water supplied is found to be 10 l/c/dy. Therefore, the water demand recommended by WHO which is 80l/c/d is not fulfilled. But, according to the analysis result done to investigate the level of water supply satisfaction, it was found that in moderate range (Table4.5).

The study also reveals that the average annual water loss in the system for the consecutive eleven years (2008 – 2018) is founded to be 39.14 % out of the total production. This amount is 13,796,488 m^3 out of the total water production of 35,312,888 m^3 per 11 years. Hence, the annual percent loss of the town is more than the expected percent value of water loss which is 15 – 26.7 % foe developing countries.

The existed system hydraulic performance analysis result indicated that the pressure and velocity distribution in the whole system was found to be out of the recommended range. From the whole junction (600), 10% junction experiencing negative pressures and 20% are exposed to very low pressure which is less than 15 m of water. And 40 % junctions in existed system show in the recommended range of 15 -100 m of water. The rest 30% of the junction are exposed to very high pressure which is greater than the standard (100 m of water). To maintain the distribution system in safe and good performance condition, some re-arrangements and modifications of elements in a distribution system were proposed and simulated. Hence, the result shows that, most of the junction were experiencing with standard pressure (70%).

5.2. Recommendation

Based on the findings of this study, the following recommendations are forwarded.

- The daily per capita water supply of the town should satisfy the requirements of WHO standard.
- In order to achieve the reduction of NRW in Jimma town from a level of 39.14 % at the Present to a level of acceptable limit annual water loss of 15 %, therefore, Non-Revenue Water Reduction and Pressure management for Jimma Water Supply System must be done.
- There should be re-arrangements of pressure zones, PRVs, pipes and avoiding direct pumping to some pressure zone.

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APPENDIXES

Appendix 1: QUESTIONARY

Questionnaire for water supply customers

1. Name …………………. Kebele ……………………………..
2. Gender Male ☐ Female ☐
3. Ethnic Oromo ☐ Amhara ☐ Dawro ☐ others ☐
4. Daily water used per house (l/dy) <5050-100>100 ☐ ☐ ☐
5. State you level of satisfaction:

Very high ☐ High ☐ Moderate ☐ Low ☐ Very low ☐