JIMMA UNIVERSITY

JIMMA INSTITUTES OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING,

ENVIRONMENTAL ENGINEERING CHAIR

ASSESSMENT OF DISINFECTION BY PRODUCT AND EVALUATION OF WATER DISTRIBUTION SYSTEM USING WAT PRO& WATER GEMS SOFTWARE: CASE STUDY OF JIMMA CITY, ETHIOPIA

BY: RUTH FANTU GASHAW

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

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JIMMA, ETHIOPIA

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JAN 2024

JIMMA, ETHIOPIA

Declaration

This thesis is my original work and has not been presented for a degree in any other University.

Ruth Fantu	....	....
Name	Signature	date

I will submit this thesis for examination with my approval as University Supervisor, Examiner and Chairperson of Department.

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Approval Sheet

This thesis entitled "Assessment of disinfection by product and evaluation of water distribution system using wat pro& water gems software: case study of jimma city, Ethiopia" has been approved by the following examiners for fulfilment of the requirements for the degree of Master of Science in Environmental Engineering.

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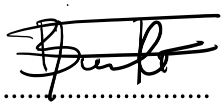
Mr. Beekan Gurmessa (MSc)		....
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ABSTRACT

Disinfection, water quality and water supply distribution system are an important parameters that could affect water companies and their consumers in worldwide. The effect of Water quality and unbalanced addition of disinfectant which affects the health of water and its distribution network are common problems that most African community encounter. The major goal of this study was to evaluate the hydraulic performance of the water distribution network and the level of disinfection by product at Jimma water treatment plant using wat-pro and water-Gems software. The findings indicate that giardia and virus percent are reduced by 23.5 % and 76.26 % respectively; so these indicate the water quality is poor according to the standard. Chlorine is by product from the disinfectant; due to its unbalanced dosage it can form disinfection by products, which are nasty and can increase a risk of bladder cancer and other adverse consequences on human health after a long period of time. At the design period of 2019, the study area's maximum daily demand is calculated as 30,310m3/day but the source maximum yield is only 27,000 m3 per day, therefore the existing water distribution system cannot be considered sustainable. According to the simulation's results for the current extended time at peak hour flow, the hydraulic parameters performance is 26.59% for (<0.6 m/s) which is at 7:00 AM, but most of the distribution pipelines has the optimum range 64.43% for (0.6 to 2 m/s), 2.88% for (2 to 2.5) m/s, and 6.07% for (>2.5 m/s) higher velocity ranges. While the low hour flow hydraulic parameters performance is 49.74% for (>-5m) for lowest pressure range; 16.29% for (-5 to15 m); 32.07% for (15 to 70 m) and 1.88% for (≥70 m) higher pressure ranges which is at 2:00 AM. The pressure performance index was under 50% (half), but due to the acceptable velocity performance index, the hydraulic performance index became 0.38 which is within the permissible standard. The above results show that the percent reduction of giardia and virus is under the standard value and the performance of the distribution pipelines coverage percent of jimma is little and less than half percent. So the town's current water removal efficiency and the distribution network are underperforming and do not adequately supply water to the various demand categories. Therefore, the existing disinfection by product and distribution system of Jimma town is not sustainable. To increase the sustainability improving the disinfection by product and finding additional source of water for areas which the town treatment plant can't reach should be mandatory.

Key words: Chlorination, Disinfection by Products, Hydraulic parameter, Hydraulic performance index, Water gems, Wat pro.

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TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

ACRONYMS AND ABBREVIATION

CDC	CENTERS FOR DISEASE CONTROL AND PREVENTION
CSA	CENTRAL STATISTICAL AGENCY
DBP	DISINFECTION BY-PRODUCT
DCI	DUCTILE IRON
DO	DISSOLVED OXYGEN
GPCD	GALLONS PER CAPITAL PER DAY
GPS	GLOBAL POSITIONING SYSTEM
GS	GALVANIZED STEEL
GTP	GROWTH AND TRANSFORMATION PLAN
HAAs	HALOACETIC ACIDS
HDPE	HIGH DENSITY POLYETHYLENE
JTWSSA	JIMMA TOWN WATER SUPPLY AND SEWERAGE AUTHORITY
JTWSSE	JIMMA TOWN WATER SUPPLY & SEWERAGE ENTERPRISE
KEITI	KOREAN ENVIRONMENTAL INDUSTRY & TECHNOLOGY INSTITUTE
NAM	NATIONAL METEOROLOGICAL AGENCY
NOM	NATURAL ORGANIC MATTER
NRW	NON REVENUE WATER
PBT	PRESSURE BREAK TANK
PRV	PRESSURE RELEASE VALVES

PVC	POLYVINYL CHLORIDE
TDS	TOTAL DISSOLVED SOLIDS
THMs	TRIHALOMETHANES
UV	ULTRA VIOLET
WDS	WATER DISTRUBUTION SYSTEM
WHO	WORLD HEALTH ORGANIZATION
WSS	WATER SUPPLY SYSTEM
WTP	WATER TREATMENT PLANT

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Chemicals called disinfection by products (DBPs) are created when chlorine is used to sanitize drinking water in order to stop the spread of illness. In lakes and rivers, decomposing organic waste like leaves or plants combines with chlorine to produce DBPs. Two of the most prevalent types of DBPs found in chlorinated drinking water are trihalomethanes (THMs) and halo acetic acids (Noguera-Oviedo & Aga, 2016).

Disinfection is a term used to describe a technique that gets rid of most or all pathogenic germs on inanimate items, with the exception of bacterial spores. In medical facilities, things are typically cleaned using liquid chemicals or wet pasteurization. The effectiveness of disinfection can be limited or eliminated by any of the many variables that affect the process (Rutala & Weber, 2019)**.**

Disinfection has unquestionable importance in the supply of safe drinking-water. The destruction of pathogenic microorganisms is essential and very commonly involves the use of reactive chemical agents such as chlorine, an effective barrier too many pathogens (especially bacteria) during drinking-water treatment and should be used for surface waters and for groundwater subject to faecal contamination. Residual disinfection is used to provide a partial safeguard against low-level contamination and growth within the distribution system (Cumings, 2017).

Disinfection by product (DBP) refers to the chemical compounds that are formed as a result of the disinfection process used to treat water or other substances. When disinfectants, such as chlorine or chloramine, are added to water to kill harmful microorganisms, they can react with naturally occurring organic matter and other substances present in the water. These reactions can lead to the formation of disinfection by-products.

Common disinfection by products includes trihalomethanes (THMs), haloacetic acids (HAAs), chlorite, and bromate. These by products can have potential health risks if consumed in high concentrations over a long period of time. Therefore, regulatory agencies set limits on the allowable levels of DBPs in drinking water to ensure public safety. Efforts are made by water treatment facilities to minimize the formation of disinfection by products through various strategies such as optimizing disinfectant dosage, using alternative disinfectants, and implementing advanced treatment processes.

Chemical disinfection of a faecally polluted drinking water supply will lower the overall risk of disease but may not always make the source safe. For instance, the use of chlorine to disinfect drinking water has limitations when it comes to certain viruses and protozoan infections, like Cryptosporidium. Pathogens that are protected from the effects of disinfectants by flocs or particles may also have subpar disinfection performance. High turbidity can shield microorganisms from the effects of disinfection, promote bacterial development, and increase the need for chlorine. It is crucial to implement a comprehensive management strategy that combines disinfection with a number of barriers, such as source water protection, appropriate treatment processes, protection during storage, and distribution, in order to prevent or eliminate microbial contamination (Cumings, 2017).

The distribution network, which mostly consists of pipes, pumps, junctions (or nodes), valves, fittings, and storage tanks, is in charge of distributing water from the source or treatment facilities to its customers at useable pressures. Due to the direct relationship between the population's wellbeing and the correct operation of water distribution networks, they play a significant role in modern civilizations (Anore, 2020). Systems for distributing water may be looped or branched. In general, looping systems are preferable than branched systems because they allow for the isolation and repair of broken pipes with minimal impact on consumers elsewhere. On the other hand, in a branched system, the water supply will be cut off to everyone downstream from the break until the repairs are complete (Anore, 2020).

A major concern in engineering behaviour and control of any WDS is performance measurement. Water quality deterioration, capacity constraints, aging and deteriorating infrastructure, and rising demand are the most frequent problems in water distribution networks. Investments in new infrastructure will result in more effective and efficient water services as productivity rises. In many developing countries, the total water demand of the system exceeds the capacity of production due to rapid population increase and substantial water losses from the distribution network. Intermittent water supplies with lower system pressures are frequently used to reduce overall demand and ensure a fair distribution of the water supply (Anore, 2020).

1.2 Statement of the problems

The assessment of disinfection by products (DBPs) and the performance of the water supply distribution network are crucial aspects in ensuring the provision of safe and reliable drinking water to the residents of Jimma Town. However, there is a lack of comprehensive studies that have investigated the levels of DBPs, quality of water and the performance of the water supply network in this specific context. Therefore, the following are problems which need to be addressed:

Some residue created during the sedimentation process and it is necessary to maintain a disinfectant residue in the finished drinking water in order to prevent microbial regrowth in the plant. And also sludge of dusts and other dirty particles have often observed in house hold drinking water containers that result in water born disease in the town. Waterborne diseases such as diarrhea, cholera, and hepatitis can present in areas where drinking water is contaminated. These diseases can lead to severe illness, long-term health complications, and even death, particularly among vulnerable populations such as children and the elderly. There is a need to assess the levels of DBPs, including trihalomethanes (THMs), haloacetic acids (HAAs), and other emerging DBPs, to determine their potential health risks and compliance with regulatory standards. The existing water treatment systems in Jimma water purification plant are insufficient to effectively remove these contaminants. However, the water supply in Jimma town is of inferior quality (Kifle & Gadisa, 2008). Monitoring and testing procedures for drinking water quality are often inadequate or inconsistent, leading to a lack of reliable data on the safety of drinking water sources.

Finally the performance of the water supply distribution network in terms of hydraulic efficiency, water quality, and overall reliability has not been thoroughly evaluated in Jimma Town. Inadequate and unavailability of water supply distribution occurs recurrently here and there all over the town. The water distribution system and treatment facility in Jimma town are not effective and fail to provide sufficient water to meet the diverse demands of the town, which is below global standards (Ebsa & Dibaba, 2022).

Therefore, this study aims to address these problems by conducting a comprehensive assessment of DBPs and evaluating the performance of the water supply distribution network using WAT PRO and WATER GEMS software in Jimma Town, Ethiopia. By doing so, it will contribute to the understanding of water quality issues and provide valuable insights for improving the overall efficiency and reliability of the water supply system in the town.

1.3 Objectives of the study

1.3.1 General Objective

The general objective of this study is to assess the levels of disinfection by-products (DBPs) and the performance of the distribution network in Jimma Town using Wat pro and Water gems software.

1.3.2 Specific objectives

- To assess the level of disinfection by product and drinking water removal efficiency at treatment plant;
- To analyze the current and the future water supply and demand of the Jimma town;
- To evaluate the hydraulic performance of the water distribution network.

1.4 Research Questions

- ✓ How much is the level of disinfection by product and drinking water removal efficiency at treatment plant?
- ✓ What is the current and future water demand and supply of the town?
- ✓ What is the efficiency of the hydraulic performance of the water distribution network?

1.5 Significance of the study

Some studies have been investigated on similar title with this study, but they are not specifically to Jimma town, so, this study refers to Jimma town and it provided some recommendations. The result of the study can be used as an input for water supply distribution design of Jimma town treatment plant and disinfection of contaminated water system. The result can also be applied to Jimma and other towns which have similar cases to the study area and it can serve as reference for further investigation. By addressing the above objectives, the researcher tried to identify all potential issues and challenges related to water quality, supply, and distribution in Jimma Town. This information will be crucial for policymakers, urban planners, and stakeholders in making informed decisions and implementing effective strategies to ensure the provision of safe and reliable drinking water to the growing population of Jimma Town.

1.6 Scope of the study

The scope of study area is limited because of lack of fund and extension of the area. Therefore the research focuses on the assessment of distribution network systems, drinking water removal efficiency and disinfection by-products by using Water GEMS V8i and Wat pro software modelling in case of Jimma town treatment plant.

CHAPTER TWO

LITERATURE REVIEW

2.1 Components of water quality

2.1.1 Microbial Aspects

All pathogenic microorganisms should be absent from water used for drinking. Additionally, it shouldn't have any bacteria that would suggest excremental pollution, the main indicator of which are the coliform bacteria found in warm-blooded animals' feces (Fayyad et al., 2016). The microbiological quality of drinking water is managed and the presence of coliform bacteria is monitored by utilizing certain treatment techniques (Hirani et al., 2014). The most common disinfectant is chlorine since it is easily available and reasonably priced.

2.1.2 Chemical Aspects

Water sources may become chemically contaminated as a result of specific industries, agricultural activities, municipal solid waste, urban runoff, or natural sources. There is a chance that hazardous substances in drinking water could have immediate or long-term negative health impacts. Chemicals become a health risk after being exposed to them in drinking water for longer periods of time than just a few months (Guilbert, 2006). Because the quantities of contaminants in drinking water are rarely high enough to induce acute health consequences, chronic health effects are more frequent than acute effects. There are numerous indications that chemical pollution caused negative issues with human health in urban watersheds (Norton et al., 2021)**.**

2.1.3 Physical Aspects

Drinking water must be free of suspended particles and offensive flavours, odours, and colours. These are commonly referred to as aesthetic criteria. The parameters that can be perceived by the senses turbidity, colour, taste, and odour are considered aesthetic. They can lead to the water supply being rejected and other (potentially lower-quality) sources being accepted, and they are easy and affordable to assess qualitatively in the field, making them crucial for community water supply monitoring. Water's physical characteristics also include factors like pH, TDS, salinity, and hardness. The physical quality is affected by the chemical quality as well. Other physical qualities can indicate if corrosion and encrustation are likely to be serious issues in pipes or fittings. The appearance, taste, odour, and feel of water define what people perceive when they drink or use it and how they rate its quality. True colour (i.e., the colour that remains after any suspended particles have been removed), turbidity (the cloudiness caused by fine suspended matter in the water), hardness (the decreased ability to get a lather using soap), Total Dissolved Solids (TDS), pH, temperature, taste, odour, and dissolved oxygen are the measurable factors that determine these largely subjective qualities (Tizibtu, 2021).

2.1.4 Biological aspects

A wide variety of living things, including aquatic plants, animals, algae, bacteria, parasites, and viruses, naturally inhabit water. While some of these species are safe for humans, others may be dangerous. We are most concerned with pathogens, or germs that cause disease. Depending on the language and region, we may also refer to these diseases as microorganisms, microbes, or bugs. The second leading killer of children in the world today is polluted water. An estimated 1.5 million people every year pass away from diarrhea and other illnesses brought on by dirty water and inadequate sanitation. A health issue brought on by inadequate access to water and sanitation affects about half of all individuals living in underdeveloped nations at any given moment (UNDP, 2010)**.**

According to the WHO Guidelines for Drinking Water Quality, infectious diseases brought on by pathogenic bacteria, viruses, protozoa, and helminthes are frequently found in drinking water and have a significant impact on public health. While there are a number of water contaminants that could be detrimental to people, it is most important to make sure that drinking water is free of pathogenic bacteria (Guilbert, 2006)**.**

2.2 Disinfection by-products

Disinfection of water refers to the elimination, inactivation, or eradication of pathogenic bacteria. Growth and reproduction of microorganisms are stopped as a result of their destruction or deactivation. People will become unwell from drinking water if bacteria are not eliminated from it.

Originally defined as molecules created when natural organic matter (NOM) in water effluents combines with a disinfectant like chlorine and ozone, disinfection by products (DBPs) are a type of Transformation Product (TP) (Noguera-Oviedo & Aga, 2016). Chlorite ion, which is a by-product of breakdown that is unavoidable, and chlorate ion are the principal by-products from the use of chlorine dioxide. As hypo-chlorate matures, it also produces chlorate. Changes in process conditions, such as removing precursor compounds before application, the use of a different chemical disinfectant with a lower propensity to produce by products with the source water, and the use of non-chemical disinfection are the three main strategies that can be used to reduce the concentrations of DBPs. DBPs are removed before distribution (Cumings, 2017).

2.3 Water treatment

The technologies for treating water include techniques for removing both soluble and insoluble materials, such as turbidity, algae, other microorganisms, bacteria, disinfection by-products, and inorganic matter from surface waters. An advanced water treatment method, a membrane filtration method, a slow filtration approach, a quick filtration method, a disinfection only method, or a mix of many water treatment methods are examples of water treatment techniques. The most crucial factor in selecting the best water treatment method is that it should guarantee that any type of raw water will meet drinking water requirements, and that it will work with the size (or installed capacity) of a WTP, the Operation and Maintenance staff's capacity for Operation, Maintenance and control of the WTP, among other factors.

2.3.1 Collection of water

A pump transports the water from the dams and reservoirs to the water treatment facility. A watershed is the general area from which a stream or river receives its water. A catchment is a natural drainage area where water flows to a low point and is bordered by sloping terrain, hills, or mountains. Almost everyone resides in a catchment, which may have hundreds of smaller catchments inside it. The major catchment will be impacted by what happens in each of the lesser catchments (Laura Winkle, 2004)**.**

The quality of the water extracted from the catchment depends on the catchment itself. Few communities have unpolluted water sources, and most sources' water quality is jeopardized by activities taking on in the catchment. Surface water resources and groundwater resources are two different types of water resources. The quality of the catchment determines the quality of the water harvested in both situations (Laura Winkle, 2004)**.** Large pumps are employed at the water treatment facility to transport the water up to the building. In order to save money on pumping, treatment facilities are frequently designed to use gravity water flow as much as feasible (Mansoor Ahammed, 2019)**.**

2.3.2 Coagulation and flocculation

By using the coagulation and flocculation processes, settlement can be accomplished much more quickly by adding aluminium sulphate or ferric chloride to the raw water. The procedure is managed to ensure that both the pollutants and the coagulant chemicals are eliminated. The most frequently used water treatment system in the world, used regularly for water treatment since the early 20th century, combines coagulation, flocculation, sedimentation, and filtration (Laura Winkle, 2004).

To eliminate contaminants during traditional water treatment, certain chemicals are added to raw water. While certain particles will naturally separate themselves from water when left to stand (a process known as sedimentation), others won't. A soluble chemical or chemical combination is added to the water to help particles that are slow to settle or are not settling out more quickly. Coagulation is the process and such a molecule is known as a coagulant.

2.3.3 Sedimentation basins and tanks

Rainfall on the ground causes surface runoff, which in turn mobilizes and carries downstream solid particles (Falco et al., 2020). Transported sediments in reservoirs have a tendency to settle on the bottom of the reservoir due to the lower flow velocity, whilst erosion occurs downstream of the dam (Rulot et al., 2012). Standing water will sometimes cause some particles to naturally settle out (a process called sedimentation). It is the method that is most frequently used to remove inorganic settle able matter from row water. The solids are eliminated before the water enters the filter, lowering the solids load on the filter and raising the treatment plant's effectiveness (Swamee & Tyagi, 2014).

2.3.4 Sludge collection and thickening

Thickening, digesting, conditioning, dewatering, and incineration are just a few of the unit activities and processes that can be used to treat sludge. The putrescible organic components make up the remaining 92–98% of the sludge's composition. The sludge needs additional treatment before being disposed of since it contains a large amount of organic material (Gurjar & Tyagi, 2017). Sludge that accumulates at the bottom of mixing tanks is released into a valve and gravity fed through pipes to thickening tanks. The sludge is further treated and polyelectrolyte is added at the thickening tanks to aid in the settling procedure. On a belt press, the sludge is dewatered before being compressed to create a dry cake. The dry cake is gathered by the conveyer belt and put into a storage tank (Laura Winkle, 2004).

2.3.5 Filtration

Filtration involves passing water or wastewater through a porous material to remove particulates that cannot be settled. Water can be treated by passing it through a bed of tiny particles, typically sand, which is one of the most basic and traditional methods. This method is known as sand filtering. The water is simply sent through the filter in its most basic form without any additional pre-treatment, like the inclusion of a coagulant. Typically, this kind of filter will get rid of larger bacteria as well as some other particles like fine suspended particulates (Farzaneh & Mokshapathy, 2018). When the water being treated moves through the sand filter very slowly, sand filtration is much more effective. The surface of the sand particles eventually develops a thin coating of bacteria. Although some people might term this layer slime, water experts refer to it as a biofilm. Even extremely minute particles adhere to this biofilm and are kept there while water with significantly higher quality exits the filter (Laura Winkle, 2004).

2.3.6 Disinfection

As a public health measure, water disinfection slows the spread of disease. It is done to get rid of any potentially dangerous bacteria in the water supply and stop them from re-growing in the distribution systems. The cleaning of water sources is crucial for maintaining good public health. Waterborne illness becomes an issue without disinfection, leading to high new-born death rates and short life spans. In several regions of the world, this is still the case. Disinfectants can eliminate harmful pathogenic germs from water, rendering it safe for consumption. The primary disinfection procedures are Chlorination, Chloramination, Ozone and Ultraviolet irradiation (Farzaneh & Mokshapathy, 2018).

2.4 Effect of polluted water on health and environment

By exposing communities to different microbiological, chemical, and other threats, unsafe drinking water, inadequate sanitation, and poor hygiene can pose serious health risks. The most prevalent cause of diarrhoea, which accounts for 4% of all fatalities worldwide and 5% of health problems that result in impairment, is gastrointestinal infections, which claim the lives of about 2.2 million people annually worldwide, the majority of whom are children in underdeveloped nations (Razvi & Prasad, 2020). Around 2.5 billion people lack access to appropriate sanitation, and around 780 million people lack access to clean, safe water. As a result, diseases and natural calamities associated with water cause 6 to 8 million deaths annually. In Sub-Saharan Africa, Ethiopia has one of the lowest rates of readily available, high-quality water supplies (Leta & Dibaba, 2019)**.**

The receiving watershed might be significantly impacted by inadequate wastewater treatment. There is a temperature range where all aquatic species can survive. Their reproductive cycle, growth, and life can be hampered or put in danger when there are abrupt fluctuations within specific ranges. Discharged effluents from wastewater treatment facilities often raise the oxygen demand level of the receiving water due to the organic load of polluted water. Dissolved Oxygen (DO) levels in surface water that gets improperly treated wastewater are decreasing more quickly (Buckner et al., 2017)**.**

2.5 Water Distribution Systems

A hydraulic infrastructure called a water distribution system is made up of components including pipes, tanks, pumps, and valves, among others. Supplying consumers with water is essential; creating a new water distribution system or extending an existing one requires a reliable supply of water. Investigating and establishing a trustworthy network is also crucial for assuring adequate head. For individuals concerned in the designs, construction, and maintenance of public water distribution systems, computation of flows and pressures in network pipes has been of tremendous utility and interest (Zolapara, 2021)**.**

In many parts of the world, the problem of urban water scarcity is getting worse very quickly. The appropriate management of the various components that make up urban water supply systems is necessary to solve the issue of water scarcity in cities (Hajibabaei et al., 2019). A water distribution system's principal goal is to deliver water at the necessary pressure and amount to all consumer ends (Sivakumar & Prasad, 2014).

A water distribution system provides the required water supply for the buildings and properties within a community. This particular system consists of a water supply network with hydraulic and hydrologic engineering features that may transport potable water from a treatment facility or wells to residents or consumers. The water distribution system manages the collection, treatment, storage, and delivery of water. While the system's primary duties are simple, the way it typically operates is altered by the ongoing changes in the demands of the present and the future (Pits, 2020)**.**

2.5.1 Problems in Water distribution System

Leaks are one of the most prevalent issues with most water distribution systems. While leaks that are obvious can be stopped immediately away, more leaks go unnoticed because they are hidden from view. The leaking problem is not really resolved by this passive leakage control technique. Those who are responsible for the upkeep of water distribution systems can provide a more dependable solution for any leakage issues. They can work with experts in leak detection to inspect the pipes on a regular basis. These experts are outfitted with tools that enable them to find leaks in pipes and other system components even while they are above ground. With all the information they have obtained, they can quickly calculate and analyse the state of the systems and then suggest the following steps (Pits, 2020).

The occurrence of financial losses in water distribution networks is another issue. This particular issue might quickly result in a drop in revenue and billed volume. All unauthorized connections and other instances of water theft must be located and stopped in order to resolve this issue. As soon as possible, issues and mistakes with data handling, billing, and metering must also be fixed. Use the water management system as well because a city's water system requires a lot of energy but also performs consistently well in terms of water quality. Therefore, it is suggested to adopt coordinated and interdisciplinary water supply system planning and management to address these issues (Antonowicz et al., 2018).

2.5.2 Water distribution network simulation

The technique of replicating the actions of one system using the capabilities of another is known as simulation. Under a variety of circumstances, it can be used to forecast how the system will react to events without interfering with the real system. Before spending time, money, and resources on a real-world project, flaws in proposed or current systems can be foreseen and analysed using simulations (Methods et al., 2003).

The goal of water distribution network simulation is to offer the answers to the differential algebraic equations needed to create the mathematical model of a WDS. Prior to implementing the operational activities on an actual water network, simulation is a crucial tool for evaluating the

WDS reaction to various operational actions (such as valve opening and closing) or control techniques. The most fundamental model simulations in water distribution networks are either steady-state or extended-period simulations (Methods et al., 2003).

2.5.2.1 Steady-state simulations

Demands, pressures, and flow rates are constant across all nodes and pipes, representing a snapshot of how the WDS is operating. However, in actual systems, the loading circumstances and states change over time. Therefore, it is necessary to assess a WDS's performance throughout time. The engineer must therefore be able to forecast the potential occurrence and performance impacts of activating zones in a steady state analysis, which requires an accurate and numerically stable formulation (Hanimann et al., 2016). Represent a certain point in time and are used to predict how a system will behave under static conditions. By assuming that demands and boundary conditions did not change over time, it computes hydraulic parameters including flows, pressures, pump operating characteristics, and others. This kind of analysis is typically used to assess the system's short-term impact of demand conditions (Methods et al., 2003).

2.5.2.2 Extended- period simulations

This kind of analysis assumes that the system is in a constant condition at each interval of time while nevertheless taking fluctuations in tank water levels and demand into account. Analysing a system's dynamic behaviour over a period of time on the assumption that the boundary conditions and hydraulic demands would change over time (Paluszczyszyn et al., 2015). As a result, extended period analysis is a technique used to assess system performance over time. It enables users to simulate pressure and flow rate changes, tank filling and emptying, and regulating valve opening and closing throughout the system in response to changing demand conditions and automatically generated control strategies. Consequently, model based simulation can offer useful information to help an engineer make informed decisions, regardless of the magnitude of the project (Methods et al., 2003).

2.6 Water Demand

The amount of water users need to meet their demands is known as their water demand. It is frequently equated, in a simplistic manner, with water consumption. Theoretical water demands in the majority of developing nations are much higher than actual consumptive water use. Domestic water demand, which covers both in house and out of house use, is divided into distinct categories much like how urban water demand is. Drinking, cooking, cleaning, laundry, and car washing are all examples of in house uses, but out of house applications include things like watering gardens, swimming pools, and fountains (Kefyalew, 2019).

The allocation of baseline demand is the most popular basic unit loading technique. This method involves calculating the unit demand (for example, the number of gallons or litters per capita per day) for the relevant load classification, then multiplying the result by the number of customers (hectares of a given land use, fixture units, or equivalent dwelling units) that contribute to the demand at a specific node (Methods et al., 2003). Therefore, the baseline demand and other demand in the water distribution system, including unaccounted for water, are estimated using the average day demand. As a result, the majority of modellers calculate the water demand analysis for a particular municipality by multiplying the baseline demand by a range of peaking variables (Helio Duvaizem, 2009).

Metropolitan water demands in many African cities are frequently non-homogeneous because different service levels exist within the same urban region. Household connections, standpipes, and even no service at all are all possible service levels. Any socially advantageous measure that lowers average or peak water withdrawals or consumption from either surface or ground water, along with the preservation or improvement of water quality, is referred to as water demand management (Kefyalew, 2019)**.**

2.6.1 Variations in water demand

2.6.1.1 Seasonal Variation:

The amount of water that is needed varies by season. The demand for water is highest during the dry season because more people use it for cooling down, watering their lawns, and street sprinkling. While demand will decrease during the rainy or wet season because fewer people take baths and there is no need to irrigate their lawns. Therefore, the "maximum day water demand" is taken into account to accommodate seasonal changes in water consumption and is utilized to size sources, treatment facilities, and rising mains. Therefore, the average-day demands can be multiplied by the peaking factor given to the node to determine the maximum day demands (Bogale, 2016)**.**

$$Q = PF * Qa \quad (2.2)$$

Where, Q = Maximum day demand (m3/s) PF = Peaking factor between maximum day and average day demand Qa = Average day demand (m3/s)

2.6.1.2 Daily Variation:

This difference is mostly influenced by societal norms, climatic factors, and the city's designation as an industrial, commercial, or residential area. Due to more comfortable bathing, washing, and other activities compared to other working days, there is a higher water demand on Sundays and holidays. As a result, to calculate the maximum day and peak hour demand, the average daily water demand is calculated by adding the household, non-domestic, and NRW demands (Bogale, 2016)**.** It was expressed as economic calculations throughout the duration of the project.

$$Q = \text{per capital water consumption} * \text{Total population of the town} \quad (2.3)$$

Where, Q = Average day demand (m3/s)

2.6.1.3 Hourly Variation:

Most people use water during these hours for bathing, cleaning, and cooking, morning and evening hours in the majority of developing nations see the highest water demand. The biggest demand of any hour during the maximum day is therefore during peak hours. Additionally, it depicts the hourly fluctuations in water demand brought on by local residents' behavioural patterns (Bogale, 2016)**.**

$$Qp = PF * Qa \quad (2.4)$$

Where, Qp = Peak hour demand (m3/s) PF = Peaking factor between maximum hour and average day demand Qa = Average day demand (m3/s).

2.6.2 Water demand forecast/projection

For a variety of reasons, water managers predict future water demand. These analyses can assist managers in planning for future water purchases or system development, future revenue and expense forecasting, and optimizing system operations by assisting them in understanding the spatial and temporal patterns of future water usage. For anticipating future demand, a variety of mathematical techniques are used, such as extrapolating historical trends, linking demand to socioeconomic factors, and more intricate simulation modelling. The amount of variables and the degree of segmentation of water consumers by industry, region, season, or other criteria determine the complexity of the models. Models differ based on the length of the forecast. Short-term projections are more beneficial for determining water rates, whereas long-term forecasts are often more useful for infrastructure and capital planning.

Water demand forecasting uses previous data on urban water usage as well as some correlation factor historical data to anticipate the future demand. For a sustainable supply of water to the customers with great quality, quantity, and pressure, an accurate estimate of water demand is required. Water demand forecasting can be approximated by creating suitable mathematical models based on the predictor variables that affect the demand for water. Water demand forecasting is vital for water resources planning and optimal allocation. The town's water consumption patterns are influenced by climatic variables (rainfall and temperature), socioeconomic factors (family income and water price), population growth, technological advancements, supply costs, and the state of the water distribution infrastructure (Zubaidi et al., 2020).

Estimating current per capita water consumption, which is typically expressed as gallons per capita per day, and multiplying this figure by the anticipated future population have historically been the simplest and most used methods of predicting future water demand. Population projections may be based on more in depth analysis by demographers or forecasters, basic linear growth, exponential growth, or a percentage rise each year. This straightforward strategy has limitations since it fails to take into consideration how technology, the economy, or culture has changed over time. A wider range of variables, including population fluctuations, water pricing, climatic changes, consumer behaviour (greater efficiency and conservation), and new laws, may be considered in more detailed models (Abate, 2016).

$$DWD = Pn * \ AWD \tag{2.5}$$

DWD= domestic water demand, Pn= population at the target year and AWD = average per capita domestic water demand.

2.6.3 Peak Factors

Peak factors that apply to the entire system will be applied to the base average-daily demand. The ratios of maximum-daily consumption to average-daily consumption and peak-hour consumption to average-daily consumption records should be multiplied by each node base demand in order to model the maximum-daily and peak-hour demands practically (MoWR, 2006).

2.6.3.1 Maximum Daily Factor

The maximum day factor is used to calculate the demand on the day with the highest annual consumption by dividing the average daily demand by the maximum day factor. A useful criteria for determining the capacity of water supply facilities, such as water intake facilities, water treatment facilities, and distribution centres (reservoirs), transmission mains, etc., is the maximum daily demand (MoWR, 2006).

Table 2. 1 Recommended maximum day factor (OWWDSE, 2008)

Population size	Maximum day factor
<2,000	1.3-1.5
2,000-10,000	
10,000-50,000	
50,000-80,000	1.2
>80,000	

2.6.3.2 Peak Hour Factor

The water system's ability to transport water is determined by the demand during the peak hour in order to meet peak demand throughout the day. This parameter is used in the design of the distribution network's overall conveyance as well as the capacity of high pump systems at distribution reservoirs (MoWR, 2006).

Table 2. 2 Recommended Peak Hour Factors

Population Range	Peak Hour Factor
< 20,000	2.0
20,001 ~ 50,000	1.9
50,001 ~ 100,000	1.8
> 100,000	1.6

2.6.3.3 per Capital Water Demand

Based on an analysis of the operational data from JTWSSE for 2018, base values of 46.0 lpcd for private connections (HC + YCA), 25.0 lpcd for YCC, and 2.0 lpcd for PF are adopted. According to the definition of a mode of service generally used in Ethiopia, private connections can be classified into HC and YCA, although JTWSSE's operational data does not separate them by mode of service, i.e. HC and YCA, in terms of the amount of water consumed.

Table 2. 3 Projection of Per-Capita Water Demand (National Planning Commission (NPC), 2016)

Level	Population	Per-capita Water Demand by 2020
I	Greater than 1,000,000	100 lpcd
II	100,000 ~ 1,000,000	80 lpcd
III	50,000 ~ 100,000	60 lpcd
IV	20,000 ~ 50,000	50 lpcd
V	Less than 20,000	40 lpcd

2.6.3.4 Domestic demand adjustment factor

Given that the people's method of water consumption is dependent on them in terms of amount and frequency, the socioeconomic and climatic conditions have a significant impact on the household water demands of the project area. In this situation, it is required to adjust the per-capita residential water demands in order to estimate more precise, dependable, and realistic water demand (MoWR, 2006).

Table 2. 4 Socio-economic Factors

Group	Description	Factor
A	Towns enjoying high living standards and with high potential for development	1.10
B	Towns having a very high potential for development, but lower living standards at present	1.05
C	Towns under normal Ethiopian conditions	1.00
D	Advanced rural towns	0.90

The climatic peak factor adopted for any particular scheme should be selected according to the particular climatic conditions depending on annual precipitation.

Table 2. 5 Climatic Effects Factors

Group	Mean Annual Precipitation, mm	Factor
A	600 or less	1.10
B	601 ~ 900	1.05
C	901 or more	1.00

2.7 Water pressure

2.7.1 Low pressure

The amount of pressure loss caused by friction at the pipe wall is further influenced by the water demand, the characteristics of the fluid flowing through it, the speed at which it is traveling, the internal pipe roughness, pipe length, gradient, and pipe diameter. Such circumstances may arise when there are properties on high ground, remote properties at the end of long stretches of pipe, demands that are higher than the design demand, pipes with insufficient capacity (too small a diameter), rough pipes (such as corroding iron pipes or pipes with a build-up of sediment), equipment failures such as pumps and valves, (Kefyalew, 2019) and by selecting the inappropriate design of a water system type without taking several variables in site into account (Yahia, 2018).

Generally poor pressures are typically brought on by either limited pipe or pump capacity, high heights, or a combination of the two. Therefore, maintaining sufficient water pressure inside the pipe is one of the most important hydraulic integrity factors. In order to attain a high level of hydraulic integrity, the water utilities should combine effective system design, operation, and maintenance with good monitoring (Kefyalew, 2019).

2.7.2 High pressure

High pressure systems frequently result in pipe breakage (bursts), which increase energy consumption, leakage, (Ghorbanian et al., 2015) and significant water losses across distribution networks. As a result, PRVs should be utilized to lower and regulate system pressure when dealing with high pressures. Using PRVs to apply pressure management strategies is still one of the most popular ways to reduce leakage. In order to solve these issues and maintain a suitable pressure in the system, pipelines and pumps must be of the appropriate size. However, it is crucial to size control valves according to the desired flow conditions and pressure differential (Bonthuys et al., 2020).

2.8 Hydraulic Performance Index

According to the standard codes the values of H_{des} and H_{max} are considered 30 and 50 m, respectively and in addition, the values of V_{min}, V_{max}, $V_{opt,}$ and V_{optu} are defined 0.3, 2.5, 0.8, and 1.2 m/s, respectively. The desired values of pressure and velocity in these approaches are based on the defined standard values and hence these approaches are chosen because the authors evaluate the applicability of the proposed method for a part of System Dynamic framework methods in water distribution networks. HPI is estimated from both System Dynamic framework methods and from penalty curve (Hunde & Itefa, 2020).

Average values of the pressure and velocity are simulated in the SD model based on the variables affecting the system and also the proposed penalty curves by were employed to develop a hydraulic index in the SD framework. As shown in Figure, these curves indicate the different performance levels against the flow velocity in pipes and the pressure of nodes. The value of one shows the excellent level of performance and ≥0.75, ≥ 0.5, ≤ 0.25 describe the suitable, acceptable, and unacceptable performance of the system, respectively. H_{des} is the minimum suitable pressure for which the demand is satisfied. The values of H_1, H_2, and H_3 are the pressures in which the outflows are equal to 0.25, 0.5, and 0.75 of the required nodal demand and are considered as $H_2 = 1/4H_{des}$, $H_1 = 1/16H_{des}$, $H_3 = 9/16H_{des}$ as shown by V_{max} and V_{min}, respectively. Furthermore, the domain of the optimum velocity is indicated by V_{opt} and V_{optu} (Hajibabaei et al., 2019).

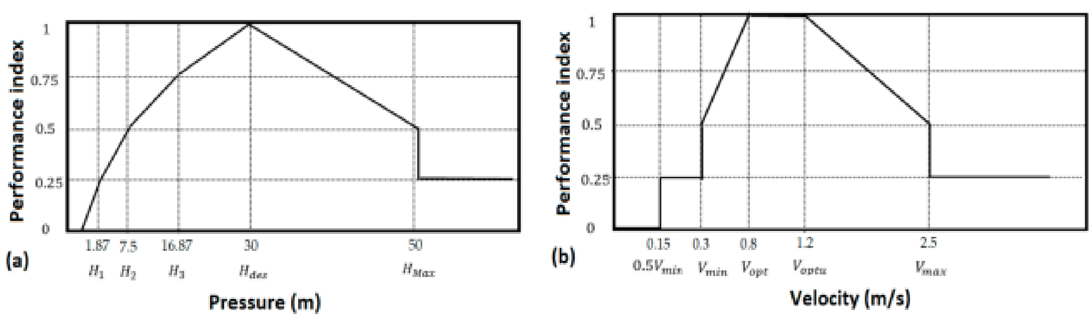

Figure 2. 1 Modified penalty curves for: (a) pressure and (b) velocity based on the standard codes

The maximum and minimum flow velocities, which are described in the standard codes, are shown by V_{max} and V_{min}, respectively. Furthermore, the domain of the optimum velocity is indicated by V_{opt} and V_{optu} (Hajibabaei et al., 2019).

2.9 Modeling software

Water CAD is a hydraulic software and water quality modelling application for water distribution systems. It helps engineers and users to analyse, design and optimize water distribution systems. It is developed by the Bentley company and has the following capabilities; Building a network and performing a steady state analysis, Extended period simulations (EPS), Interface and graphical editing, Streamlined model building, Water quality analysis, Automated Fire flow analysis, Reporting results, Pressure dependent demand, Darwin designer to optimize a pipe network, Critical and segmentation and Comprehensive scenario management (Robert, 2019).

EPANET is software that models water distribution piping systems. It is a public domain software that may be freely copied and distributed. EPANET performs extended period simulation of the water movement and quality behaviour within pressurized pipe networks. EPANET's water quality analyser can: Model the movement of a non-reactive tracer material through the network over time, Model the movement and fate of a reactive material as it grows (e.g., a disinfection by-product) or decays (e.g., chlorine residual) over time, Track the percent of flow from a given node reaching all other nodes over time, Allow growth or decay reactions to proceed up to a limiting concentration, Allow for time-varying concentration or mass inputs at any location in the network, Model storage tanks as being complete mix, plug flow, or two-compartment reactors so both software that can use for simulation of water quality and distribution performance.

Water GEMS and Wat pro are the most recent version of the Water CAD and EPANET. They are simple software for modelling or simulating WDS and DBPs. Engineers and utilities can use Water GEMS to assess, design, and enhance WDS operating in the matter of discharge, pressure head, constituent concentration analyses, and pump simulation, among other features (Abed, 2023).

2.10 Model calibration and validation

The process of perfecting a model so that it accurately simulates field conditions over a given time horizon is known as model calibration. To produce the desired output data, fine-tuning involves making small adjustments to the input data (Hunter Jr, 2011). As a result, the model will not be completely accurate, and in order to calibrate it, the observed data must be faithfully simulated. In light of this, calibration is a significant part of the modelling process, and adequate calibration was accomplished using precise field data. Additionally, state that hydraulic model calibration is a required step in modelling and that it is done so in order to increase confidence, comprehend mistakes, and spot them (Methods et al., 2003).

CHAPTER THREE

MATERIALS AND METHODS

3.1 General description of the Study area

Jimma is one of the zones of the Ethiopian Region of Oromia. It is the largest city in south-western Ethiopia. Jimma town is Located in the Jimma Zone of the Oromia regional state at 352 km southwest of Addis Ababa at an average altitude of 1780 m above sea level . Has a latitude and longitude of 7°40′N 36°50′E (Leta & Dibaba, 2019).

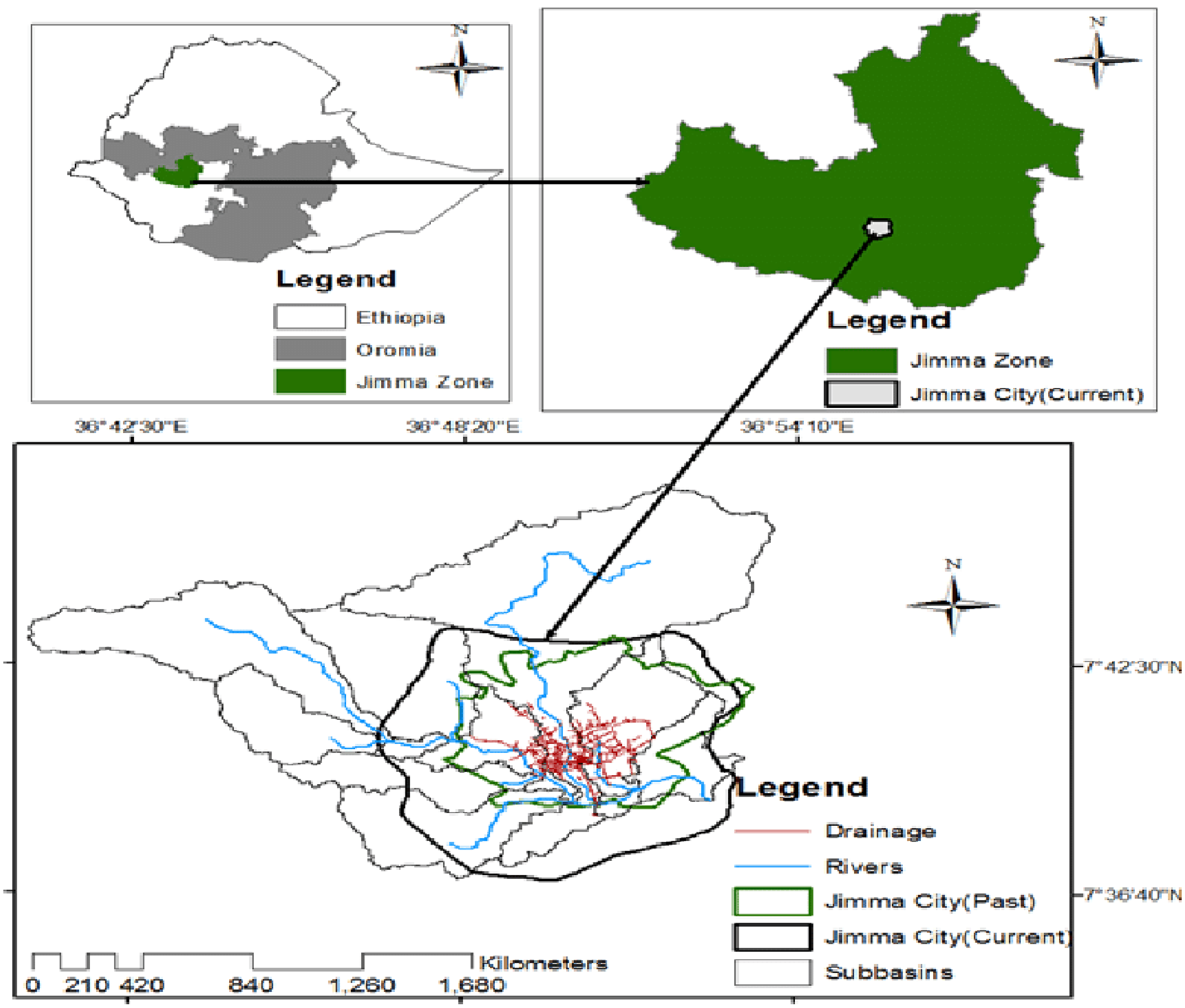

Figure 3. 1 Locational map of the study area

3.1.1 Population of the study area

The city has a population density of about 3521 person's per km in 2015 and an average population growth rate of 4.9% per year (Leta & Dibaba, 2019). The city has 120,960 population numbers at 2007 E.C (ASHENAFI, 2014).

3.1.2 Rainfall and Climate

Jimma has a relatively cool tropical monsoon climate as Köppen climate classification. It features a long annual wet season from March to October. Temperatures at Jimma are in a comfortable range, with the daily mean staying between 20 °C and 25 °C year-round .The town is found with abundant mean annual rainfall between 1800 and 2300 mm which makes this region one of the best watered Ethiopian highland areas (Fufa & Addisu, 2021).

3.2 Study design

The study was conducted by using both descriptive and analytical methods. This means the methodology used in the study is software analysis of the data, and the data was collected from the site.

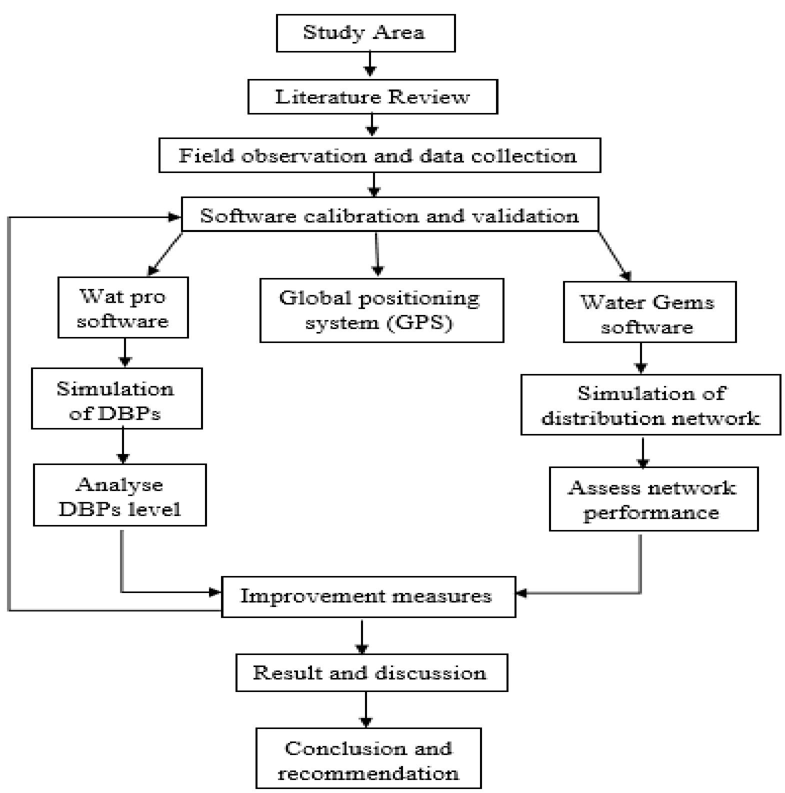

Figure 3. 2 Flow chart of the study design

3.3 Description of disinfection by products

There are two types of disinfections namely primary and secondary disinfection are used in the treatment plant. Secondary disinfection preserves disinfectants latent in the final drinking water. Which means it prevents the regrowth of bacteria as water moves through the distribution system. The level of microorganism deactivation was accomplished by primary disinfection. Prior to sedimentation or filtration, the major disinfection of microorganisms that could alter residual chemicals takes place early in the source water treatment process. But no residue is produced during this stage of treatment. The disinfectant (chlorine) or disinfection by-product may present in the stream of left over waste from the water treatment facility (filter backwash).

Even though no residue is produced during this process, the resulting drinking water may have a disinfectant residue. However, the clear well water (processed water in a reservoir) was used to backwash the filter. As a result, the disinfectant that was added to the finished drinking water may present in the filter backwash. When chlorine is added to water, it produces nascent oxygen which quickly and effectively kills microorganisms (Datturi et al., 2015).

The treatment plant use Aluminium sulphate ($AlSO_3$) and chlorine (Cl_2) as the disinfection agents utilized in both old and new treatment plants. Aluminium sulphate is only utilized in the pre-distribution settlement process, whereas chlorine is used during the distribution to the community. An average of 400–600 mg/l/h aluminium sulphate and 60-200 l/h chlorine employs during the distribution process for both the old and new treatment plants.

Figure 3. 3 Chemicals rapid mixing in new and old WTP (Photo taken by the researcher)

3.4 Description of the existing water Supply System and Distribution Network

Boye Treatment Plant provides the potable water for Jimma Town. It comprises of two stations: the original, which has been operational since 1987 E.C., and the new, which was put into operation in 2005 E.C. The Gibe River supplies the treatment facility with its raw water, and after undergoing numerous treatments.

Grit removal at the intake site, receiving well, flash mix tank (dosing coagulant and coagulant aids), flocculation tank, and sedimentation tank, rapid sand filtration with backwash equipment, clear water tank, and clear water pumping station are some of the water treatment components or processes that make up the rapid sand filtration method. The purified water is pumped into the clean water wells. The water tanks, designated as reservoirs R1 and R2, provide clean water to their rear wash tanks for cleaning the treatment plant filters and provide water to be pumped to the people of Jimma Town.

There are four pressure zones in the Jimma Town Water Supply Distribution System: the Aba Jifar, Ginjo, Hospital, and Jiren Kela zones. Jiren Kela pressure zone, the widest of these four pressure zones, has one Pressure Break Tank, two service reservoirs (referred to as "storage tanks" and PBT). Each of the other three pressure zones has an own storage tank. Without any intermediate storage, the water from the ancient Boye Water Treatment Plant is piped directly into the supply network, where it primarily ends up in the Jiren Kella pressure zone. On the other hand, 600mm DCI transmission lines are used to transport the water from the new water treatment plant to the two Jiren Kella reservoirs at first. Customers in the Ginjo, Hospital, and Jiren Kella pressure zones receive water from the Jiren Kella reservoir supply. Immediately downstream of the Jiren Kella reservoirs, the transmission pipe's diameter is decreased to 500 DCI.

The twin Jiren Kella reservoirs, each with a capacity of 2x2000m3, are located at Jiren Kella Hill and were built to provide water to the Jiren Kella pressure zone through a 600mm DCI pipe as well as to fill the hospital and Ginjo reservoirs using a 500mm DCI pipe. Ginjo reservoir then supplies water to the Aba Jifar pressure zones. Ginjo distribution pressure zone is supplied by the 800m3 Ginjo reservoir. While the pumping station is located at the Ginjo reservoir property, this reservoir also fills the Aba Jifar service reservoir using a 150mm DCI pipe. Hospital pressure zone is supplied by Hospital reservoir, which has a capacity of 2500m3, while Aba Jifar service reservoir, with a capacity of 250m3, provides Aba Jifar distribution pressure zone. The old clear water treatment plant provides direct pumping through 400mm DCI pipe to the Jiren Kella pressure zone.

Figure 3. 4 Raw water (Photo taken by the researcher)

Figure 3. 5 a) Sedimentation, b) sand filtration, c) control get valves of old WTP (Photo taken by the researcher)

Figure 3. 6 Old WTP pump house and switch board (Photo taken by the researcher)

Figure 3. 7 New WTP pump house and switch board (Photo taken by the researcher)

Figure 3. 8 a) Sedimentation, b) sand filtration, c) control get valves of new WTP (Photo taken by the researcher)

Figure 3.9 Clear water tank (Photo taken by the researcher)

3.4.1 Distribution of pipeline network

Pipelines are positioned in accordance with the town's master plan road. Although the number of pipes in the pressure zone is limited and insufficient to supply enough water, they are nevertheless supplying water to the neighbourhood close to the previously agreed plan. Pipelines are now distributing to the almost established settlements after a number of years, but they have not yet been documented. The list of pipes in the subsystem are Ductile Iron=12810m, PVC= 59897m, GS=1389m, HDPE=638m, DCI=3042 Total length=77,776m (JTWSSA, 2020).

3.4.2 Storage tank

A storage tank is a building that stores water and makes water available to the system as needed. The amount of water required to meet the community's peak hourly demands is equalized in storage tanks. The five storage tanks in the study area serve to both store water and balance the flow to each service region.

Table 3. 1 Storage tank data (JTWSSA, 2020)

Lable	Elevation(m)	Easting X(m)	Northing Y(m)	Volume(m^3)
Jiren Kela Reservoir 2	1895.3	266036.6	847642.5	2000
St.Gebrael	1763	259383.76	851389.1	2500
Hospital Reservoir	1785.5	263440.88	849953.2	2500
Ginjo Reservoir	1837.5	264126.06	849879.5	800
Aba Jifar Reservoir 1	2014.56	265349.98	851558.9	250
Jiren Kela Reservoir 1	1895.3	266039.24	847669.7	2000

3.4.3 Power supply units

The community has access to power supply service. The town transformer, which is provided by Jimma Electric Power, supplied power to the water system. For the full 24 hours of its intended use, the water distribution system is in operation. However, in the event of a power outage, there is no backup generator for the distribution system.

3.5 Data sources

3.5.1 Primary data

The major data sources for this study like water capacity, distribution system, and laboratory data of disinfectant dosage, water demand and pressure are primarily collected from Jimma water Supply & sewerage Enterprise and Boye water treatment. And for the necessary data gathering in order to understand the current state of the water treatment and delivery, actual field investigation, measurements, or survey works, including straightforward observations of the Jimma Town Water Treatment Plant at the sites, have been used. Elevation, Northing, and Easting of junction at each distribution line were measured using GPS in order to cross-check the water supply data obtained from the municipality.

3.5.2 Secondary Data

The Secondary Data are collected from some journals, research reports, Books and published papers. Additionally, information gathered from accountable organizations such the Jimma Town Sewerage Authority and Water Supply. The Jimma town water supply and sewerage authority has provided information on the town's water supply, including information on pipe length, diameter, and material used, number and volume of reservoirs or tanks, number and yield of each borehole or ground water source, number and types of pumps, and valves.

3.6 Data Collection

Jimma Town's structural and land use maps, as well as other technical drawings and excel data, were acquired from MS Consultancy, a consulting firm that created the new expansion project for Jimma Town's water supply distribution system.

Reliable input data were gathered by surveying the locations of some components of the distribution system, such as the location and elevation of the water storage tanks, and pressure reducing valves of the network, using GPS. This allowed for the effective modeling of the distribution network and the creation of a reliable model.

The drawing was compared to a distribution system map provided by JTWSSE, and JTWSSE staff members provided additional explanations regarding several missing components. The operational staff was also consulted for information on the operation, including manual controlling mechanisms and the link between pump head and discharge.

To properly create the model and assess the distribution system, it was essential to have built drawings that showed the alignment, connectivity, materials, diameter, locations of other system components, pressure zone boundaries, altitudes, and other notes and background information. Additionally, information describing the scope of Jimma Town's potential future expansion was taken from the 2006 revision of the 1994 master plan for the development of Jimma Town (Consultancy, 2018).

Figure 3. 10 Map of the distribution system (Consultancy, 2018)

3.7 Tools and materials

Different flow gauges and pressure gauges are very important to collect field data at any point where field measurements seem to be most relevant for improving model calibration, as well as to collect the necessary quantity of flow and pressure measurement. However, the majority of the materials were unavailable and it was uncomfortable to calibrate due to the time duration. A combination of Water GEMS and Wat pro soft wares were used for the model development in this study.

3.7.1 Water GEMS software: for performance of water distribution network

With advanced interoperability, geospatial model building, network optimization, and this software that performs extended period simulation (EPS) of hydraulic and water quality behavior within pressurized pipe networks, it offers engineers an easy-to-use environment for designing and analyzing water distribution systems. Pipes, nodes (i.e., pipe connections), pumps, valves, and storage tanks or reservoirs make up a network. Water Gems displays the pressure at each node, the height of the water in each tank, and the flow and velocity of the water in each pipe. At all nodes, estimated residual chlorine can be analyzed (Mehta & Joshi, 2019).

3.7.2 Wat pro Software:

Wat-Pro is a useful program for analysing and designing a water treatment system. In this program, engineers can create a simulation of a water treatment plant and predict water quality with specific parameters. Wat Pro software simulates plant performance using quality factors as pH, Total Organic Carbon (TOC), Specific UV Absorbance , and operation parameters of process tanks (Robert P Beres, 2016). One application is the design and sizing of water treatment systems that reducing the production of disinfection by products like chlorite, chlorate, HAAs, and THMs. The contrasting effectiveness of chlorine, ozone, chlorine dioxide, and chloramines in killing viruses and Giardia that assessing treated water quality for a suggested change in plant operation (Robert P Beres, 2016).

3.8 Model Building and data entry

3.8.1 Importing the data

To import the laboratory appendix data into wat-pro software, first of the entry data must be arranged then plot and import the layout and then edit the arranged parameters data in each icon. Finally check the connection and calculate to get simulation result. Calibration on wat pro in disinfectant parameters is performed on chlorine, chloromines and chlorine dioxide formation and in DBPs TTHMs, HAAs, chlorite, Giardia reduction, virus reduction, crypto reduction, and turbidity.

The pdf document which is found from JTWSSE is changed to excel format and the data is arranged; then the Excel data was imported in to the Water GEMS software to get the exact design. Water-GEMS detected some types of errors and suggested for the solution. Then finally from the available information, baseline demands (average consumption conditions), current maximum day consumption conditions, minimum demand conditions, peak hour demands, future developments, and the resulting increase in water consumption conditions were assessed for each of the performance metrics for drinking water, inactivate giardia and viruses, disinfectant decay and PH, disinfection by product formation.

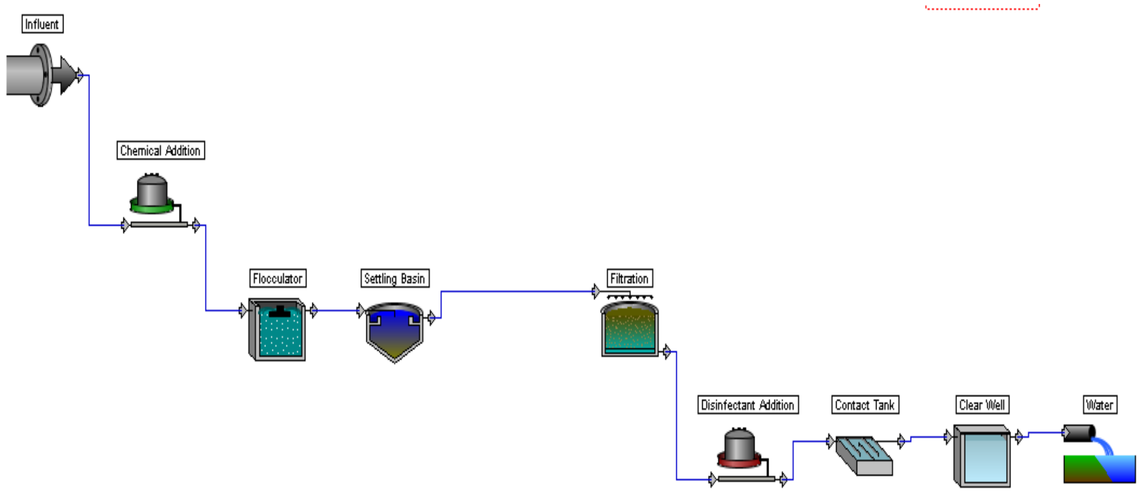

Figure 3. 11 Water treatment steps of Jimma WTP

3.8.2 Data entry and data Verification

Data preparation and analysis procedures were used to identify and fix data problems that occurred throughout the data collection process and were connected to network data, demand data, and operational data. The data were then incorporated into the model using tables after being processed. The hydraulic model was tested and calibrated by focusing on the maximum and minimum values, which were identified using the data sorting and colour coding features of the water GEMS software. Laboratory data was entered into the Wat Pro program, which was used to gather information for data processing and analysis.

3.9 Calibration Data Measurement

All of the data acquired at some crucial locations in the distribution network, including as flow measurements at pumping stations and pipe statuses, were used for the model calibration once all the error messages discovered during the model testing procedure had been fixed. The model was simply made suitable for usage once the observed and simulated values were in agreement. After comparing the model flow and the measured flow, the observed pipe statuses with the model adjusted pipe status and the same as velocity measurement calibration.

3.9.1 Pressure Measurements:

Devices for measuring pressure must be placed far from sources and close to areas with strong demand (Mohd et al., 2017). However, it was quite challenging to get pressure measurement gages for this study. As a result, no pressure measurements were employed in the study for model calibration.

3.9.2 Flow Measurements:

At several crucial locations throughout the distribution network, namely at treatment facilities and pump stations, flow measurements are typically taken. Throughout the distribution system, it is also feasible to measure the flow in the pipes at significant and representative locations. But there is no other ways to measure the flow through pipes of the distribution system other than the mains. For the current study flow measurements were collected from pumping stations with flow measuring gages.

3.10 Model calibration and validation

Based on the various calibration standard requirements for hydraulic network and water quality modelling, model calibration and validation were carried out. Model calibration is the process of fine-tuning a model until it accurately replicates field conditions for a given time horizon. As a result, the model will not be completely accurate, and in order to be calibrated, it must faithfully simulate the observed data. Additionally, according to (FDRE MoWE, 2019), calibrating a hydraulic model is a crucial modelling step that takes place in order to improve confidence, comprehension, and the ability to spot mistakes made during the model-building process. Flow information was gathered across the water distribution system to show the quality of the service. A flow gauge that is frequently used at pumping stations was used to measure the flow. The difference between model simulation and actual field data, however, might result from a number of distinct sources. Since observed and computed flows may be agreed upon, calibration can be carried out by changing simply internal pipe roughness values or nodal demand estimates.

3.11 Future Demand Estimation

3.11.1 Population Forecasting

Numerous techniques exist for predicting population expansion, including the arithmetic growth approach, the geometric growth method, the exponential growth method, the incremental rise method, etc. Geometric approach population forecasting is preferred for rapidly expanding cities where relatively strong economic activity is seen and at the same time continuous city expansion due to various reasons is experienced. Central Statistical Agency (CSA) established urban growth rates at the national level to forecast the population using equation (3.1) (Ahmed, 2016).

$$P_n = P_0 (1 + 0.01r)^n \quad \text{..} \quad (3.1)$$

Where P_n = future population, P_0 =Present population, r =growth rate, n =design period in years.

3.11.2 Domestic water demand

To determine how much water will be needed to satisfy and serve demand at the conclusion of the design period, a water supply project must be designed. This entails figuring out how many people would be fed, figuring out how much water they would use per person, and looking at any potential influences on consumption. The amount of water needed for drinking, cooking, bathing, gardening, and sanitizing purposes varies depending on the consumers' style of living. The coverage of the town's domestic water supply by service type's connections was evaluated using the mode of serves projection (derived from urban model) characteristics. These domestic water supply are the percentage of users from House Connection (HC), Yard Connection Alone (YCA), Yard Connection Common (YCC), Public Fountain (PF), and Traditional Source Users (TSU). Tradition Source Users (TSU) is not part of the water supply system managed by JTWSSA.

Table 3. 2Serviced Population in Percentage (JTWSSA, 2020)

Item	Unit	2020
Percentage of Serviced Population	%	75.00
- House Connection (HC)	%	11.46
- Yard Connection Alone (YCA)	%	63.00
- Yard Connection Common (YCC)	%	0.32
- Public Fountain (PF)	%	0.22

Table 3. 3 Per-Capita Water Demand(JTWSSA, 2020)

Item	Unit	2020
Per-Capita Water Demand	lpcd	80.00
- House Connection (HC)	lpcd	110.00
- Yard Connection Alone (YCA)	lpcd	75.00
- Yard Connection Common (YCC)	lpcd	30.2
- Public Fountain (PF)	lpcd	2.7

The total population of the research region multiplied by the mode of connection service % for that year yields the population used by service type. Litter per capita per day of service type divided by the percentage of the population that uses the service type gives; the average daily demand for litter per capita per day. For other demands, the same scenarios were employed. The lower limit of the range take for domestic demand by mode of service connections kinds, current and projected population size in terms of mode of services, and domestic water demand analysis by mode of services were done by taking into account Jimma Town's capability.

3.11.3 Non- domestic water demand

3.11.3.1 Public and commercial water demand

The water needed for public purposes, including parks, offices, hospitals, hotels, offices, and other public institutions. Additionally, water is needed for commercial facilities including theatres, railroads, restaurants, bus stations, local refreshments, shopping malls, and other business hubs. The benchmark for public and commercial water demand, according to MS Consultancy, is 30% of total water demand.

3.11.3.2 Industrial water demand

There aren't many large industrial sectors in the study region, but there are some minor ones, such those for chicken, which need water from the towns. According to JTWSSE's operation statistics for 2018, the industrial water demand will be estimated by adopting 10% of the home water demand. This excludes Jimma Industrial Park's operational demand because the park has a separate water supply system.

3.11.3.3 Water requirement for fire fighting

The amount of water needed annually to combat fires is minimal. The demand, however, can be quite high at times of need and, frequently, dictates how the distribution system's storage and pumping needs are designed. In this instance, suspending the supply to customers and rerouting it for this use is judged to have satisfied the need for firefighting water and the project's needed reservoirs' capacity has been increased by 10% to cater for the firefighting requirement (MoWR, 2006).

3.11.3.4 Water Demand for Other Public Uses

Other public uses include the need for water in mosques, abattoirs, public buildings, and prisons. According to earlier studies, this demand represents 20% of the average residential day's need.

According to JTWSSE's operation data for 2018, the proportion of water consumption for institutions and other public purposes, such as municipal institutions, hospitals, schools, etc., to home water consumption is approximately 21%. In this analysis, taking into account the city's expansion, the water demand for other public uses is established at 15% of domestic water demand. This is because water demand is taken into account above.

3.11.4 Total water demand

This is the total amount of water needed for the study area. By adding up all residential, non-domestic, and unaccounted for water demand, the total water demand was calculated. Most of the water provided for combating fires was used in institutions.

Table 3. 4Existing 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

3.11.5 Future per capita water demand determination

If the current water source is assumed to continue for the future as it is, the per capita water demands for the design years 2014 E.C up to 2019 E.C were calculated by using equation (3.1).

3.11.6 Peak Factors

Peak factors that apply to the entire system were applied to the base average-daily demand. The ratios of maximum-daily consumption to average-daily consumption and peak-hour consumption to average-daily consumption records are multiplied by each node base demand in order to model the maximum-daily and peak-hour demands practically. The need for water is not continuous and varies throughout the day. Water delivery facility is designed to accommodate the highest day and hour peak demand.

3.11.6.1 Maximum Daily Factor

The projects of a comparable nature in Ethiopia, maximum day factors range from 1.25 to 1.5. The maximum daily factor in this study, 1.25, was chosen to match the water supply plan used in earlier studies, namely the Jimma Town Water Supply Project and the Jimma Town Water Supply Rehabilitation and Expansion Project (Consultancy, 2018).

3.11.6.2 Peak Hour Factor

Given that the city's current population is 120,960 which is more than 100,000, it is determined to adopt the peak hourly factor "1.6" in accordance with the standards that established in 2006 as indicated by (MoWR, 2006).

3.11.6.3 Per Capital Water Demand

According to the aim set forth by GTP-II (MoWR, 2006), per-capita water demand is determined by population density and subsequent town raking. Given that Jimma Town will have a population of 207,573 by 2020, it can be classified as Level II, with targets of 80 lpcd to be met by that year.

3.11.6.4 Domestic demand adjustment factor

To calculate domestic water requirements apply, the values are provided by (MoWR, 2006). Jimma City is grouped into Group B in this study, which includes places with a very high potential for growth but lower living standards right now, taking into account the socioeconomic situation as mentioned in the Inception Report. As a result, a 1.05 socioeconomic factor is chosen. And the annual precipitation, according to data from Ethiopia's National Meteorological Agency (NAM), placing the city in Group C and giving its climatic impact factors 1.0.

3.12 Hydraulic Performance Index

The components of WDNs are related to the performance indices, which are produced from the penalty curves. The performance of each node and pipe is then extrapolated to the entire network in the following step. The following functions are utilized for this:

$$PIP = \frac{\sum_{j \in Nj} Q_j^{req} \times (PIPE_j)}{\sum_{j \in Nj} Q_j^{req}} \qquad (3.2)$$

$$PIV = \frac{\sum_{j \in Np} V_{ij} \times (PIVE_j)}{\sum_{j \in Np} V_{ij}} \qquad (3.3)$$

where PIP is the network's pressure performance index, $PIPE_j$ is the pressure performance index of the node j, N_j is the number of nodes, Q_j^{req} is the required nodal demand of the node j, PIV is the velocity performance index of the network, N_P is the number of the pipes, $PIVE_j$ is the velocity performance index of the pipe j, and V_j is the volume of the pipe j. Thus, according to (Capt et al., 2021),HPI is introduced, which is dependent on the average pressure and average velocity of WDNs in the SD model, to combine the hydraulic variables of the whole system and WDNs' components (pipes, nodes) which is calculated as follows:

$$HPI = \frac{(1 - \alpha+\beta /N_i) \times PIP + (1 - \gamma+\delta /N_j) \times PIV}{2} \quad (3.4)$$

HPI stands for hydraulic performance index, PIP for pressure performance index, and PIV for velocity performance index. The coefficients and are determined using the average flow velocity, and the coefficients and are calculated with regard to the average pressure. where Ni is the total number of nodes, α is the number of nodes with pressure less than 30 m, β is the number of nodes with pressure more than 50 m, Nj is the total number of pipes, γ is the number of pipes with the flow velocity less than 0.8 m/s, and δ is the number of pipes with the flow velocity exceeding 2.5 m/s. Based on the variables affecting the system, average values of the pressure and velocity are simulated in the water GEMS during simulation. In contrast to PIP and PIV, which reflect the pressure at nodes and the flow velocity via pipes, respectively, these coefficients describe the average pressure and velocity of the system.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Assessment the requirement formation and of disinfection by product in drinking water

4.1.1 Requirements of treatment

The surface water treatment regulations mandates that all community and public water systems that use surface water sources or groundwater that is directly influenced by a surface water must eliminate or inactivate Giardia cysts to a minimum of 99.9% (log-3) and viruses to a minimum of 99.99percent (log-4) levels. However, the outcome of the Wat pro-simulation treatment plant indicates that the actual result was below the predetermined standard. Consequently, the Wat pro's results for Giardia reduction or inactivation is 23.5 percent (log-3) and for virus's reduction or inactivation is 76.26 percent (log-4). As a result, this outcome not complies with the Surface Water Treatment Rule's treatment standards, preventing the town's treatment plant from functioning effectively in the event that giardia, viruses, or crypto are inactivated or removed so the performance is not good. The results are listed as follows for various disinfectant dosages.

Table 4. 1 Inactivation

Disinfectant Dosage(mg/L)	Giardia Reduction(log(10))	Virus Reduction(log(10))	Crypto Reduction (log(10))
3.2	23.463	76.257	2
4.85	23.674	76.257	2
6.13	23.892	76.257	2
7.73	24.158	76.257	2
9.12	24.327	76.257	2
10.6	24.512	76.257	2
11.95	24.756	76.257	2
13.46	24.915	76.257	2
14.8	25.098	76.257	2
16.29	25.41	76.257	2

The above table show that the amount of disinfectant can have an impact on the reduction or inactivation of Giardia but not on the reduction or inactivation of viruses and crypto reduction. Therefore, it is suggested that the disinfectant dosage have to be increased in order to increase the reduction or inactivation of giardia.

The water quality management is not as a guideline of the national and international standards as some parameters depart from these guidelines. This also clearly shows that there is a lack of good operation and management.

4.1.2 Formation of disinfection by- Product (DBP)

While chlorine has been successful in providing the majority of microbiological pathogens down to acceptable levels, it also produces trihalomethanes (THMs) and haloacetic acids (HAAs) as disinfection by products (DBPs) when it interacts with naturally occurring materials in water. As a result, the values of the DBPs are tabulated as follows:

Table 4. 2 DBPs

Disinfectant Dosage(mg/L)	TTHMs(ug/L)	HAA5(ug/L)	Chlorite(ug/L)
3.2	0.072	1.49	0
4.85	0.093	1.99	0
6.13	0.102	2.47	0
7.73	0.105	2.93	0
9.12	0.109	3.34	0
10.6	0.111	3.62	0
11.95	0.115	4.14	0
13.46	0.118	4.5	0
14.8	0.121	4.97	0
16.29	0.133	5.36	0

The result in above table shows that, the town's treatment plant contains disinfection by product. As a result except for chlorite, the values of trihalomethanes and haloacetic acid increases as the disinfectant dosage increase. Due of the numerous implications their existence (disinfection by products) may have a negative effect on people's health and quality of life. As a result, the town's treatment plant is not functioning well enough to treat drinking water and maintain people's health.

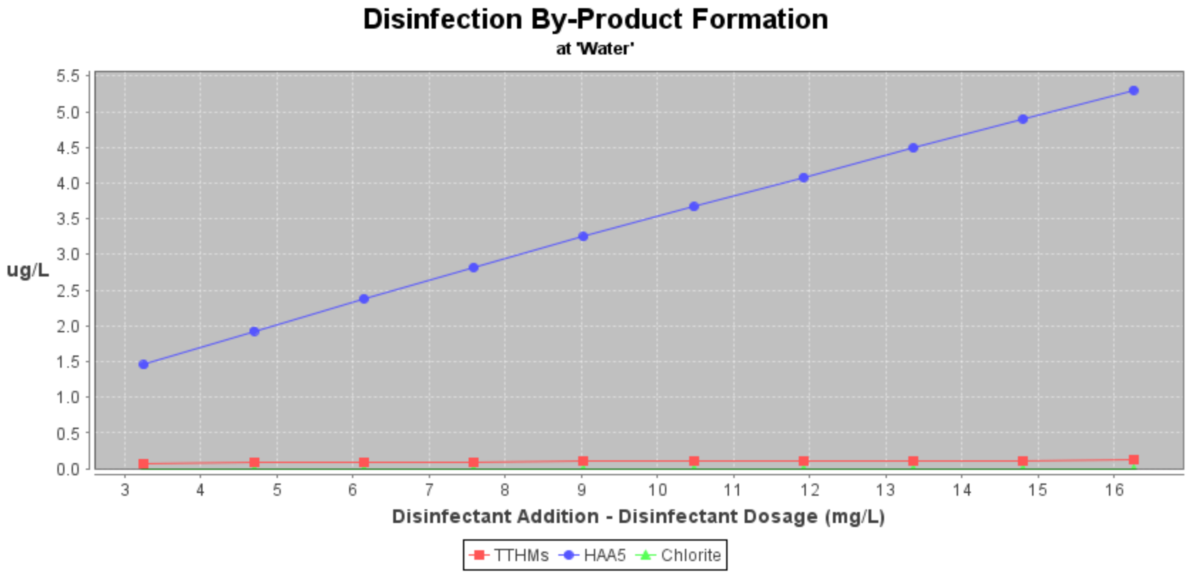

Figure 4. 1 DBPs graph

WTP of the treatment methods that are currently being used including chlorination has been assessed and simulated using the Wat Pro 4.0 simulator. The effectiveness of disinfection and the potential for DBP formation were used to evaluate the treatment methods.

Table 4. 3 Treated water output summary

Parameters	Criteria	Value	Unit
Effluent chlorine	4	2	mg/l
Effluent chlorine dioxide	0.8	0	mg/l
Effluent chloramines	1	0	mg/l
TTHMs	100	0.11068	ug/l
HAA5s	100	3.01508	ug/l
Chlorites	1	0	Mg/l
Total giardia reduction	3	24.0413	log(10)
Total virus reduction	4	76.257	log(10)
Total crypto reduction	1	2	log(10)
Turbidity	0.5	1.25	NTU

The above table provides an overview of the treated water's output. DBPs have the highest criterion values due to a health risk factor. Therefore, it is essential to consider DBPs formation potential while assessing the safety of water disinfection.

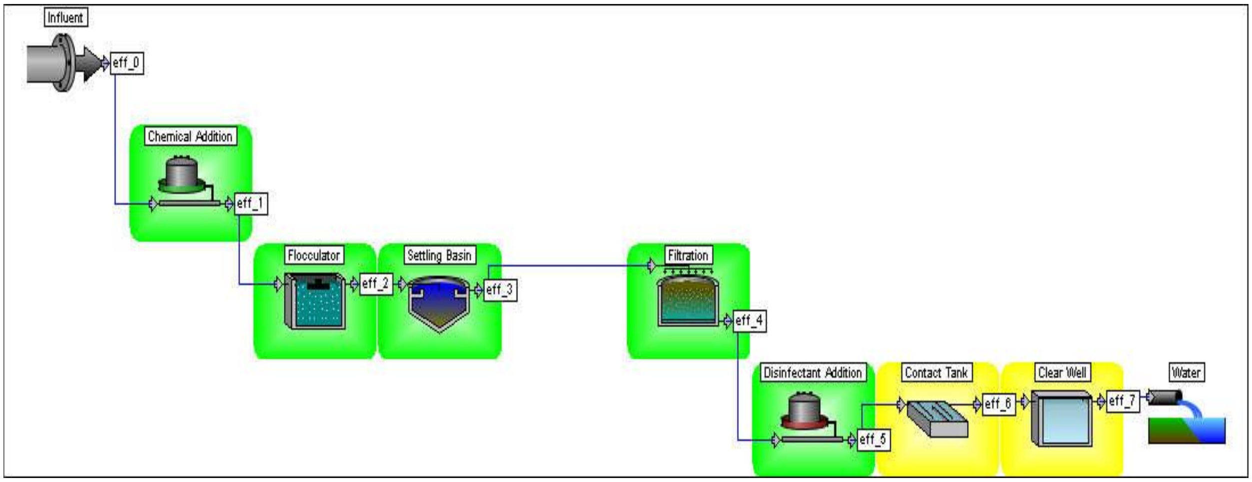

Figure 4. 2 Water treatment steps of WTP using Wat pro 4.0 process simulator

This method of disinfection may have significant problems, according to the effluent treated water quality determined through the modelling of the existing chlorination process. Temperature, pH, and contact duration during operation can all have a significant impact on how well bacteria are eliminated during disinfection by chlorination. These factors has minimal or no effects on the production of DBPs. For the purposes of simulation, the treated water's temperature was set at 20^{o}C throughout the whole treatment plant process. Furthermore, the temperature and time retention control tool particular to the chlorination contact tank was absent from the water treatment simulator program Wat Pro 4.0.

As information gathered from the treatment plant, high quantities of suspended solids which necessitate a high chemical dose are the reason for the flocculation-sedimentation basin's ineffective performance.

4.2 Hydraulic Performance Index

The hydraulic performance indexes compare node pressure (junction pressure) with pipe flow velocity. According to (Conety Ravi et al., 2019) state that the excellent level of performance index has a value of 0.75, 0.5, and 0.25 respectively, describing the suitable, acceptable, and unacceptable performance of the system. These performance indices, which are derived from penalty curves, are connected to the components of WDNs. In this study, the penalty curves analysis yielded a pressure performance index of the network of 0.43 and a velocity performance index of the network distribution of 0.68 independently. Therefore, based on the aforementioned basic performance analysis, the estimated hydraulic performance index for the study is 0.38, which shows that it is within the acceptable bounds. It indicates that the system is functioning as expected and meeting its design specifications. An acceptable hydraulic performance index indicates more efficient system with less energy loss.

4.3 Population Forecasting

Population of Jimma town based on 2007 E.C data was 120,960 (ASHENAFI, 2014). Taking 157,894 population of 2014 as a base demand, the population of Jimma town was predicted 186,846 in 2019 using the geometric population forecasting methods. Population forecasting growth rate is indicated in Table 4.4.

Table 4. 4 Urban growth rate for towns in Ethiopia

Year (E.C)	Urban Growth rate/r/
1995-2000	4.3
2001-2005	4.1
2006-2010	4.06
2011-2015	3.88
2016-2020	3.69
2021-2025	3.51
2026-2030	3.35

Table 4. 5 Population forecasting of Jimma town

Year(E.C)	2015	2016	2017	2018	2019
population	164,020	167,560	173,784	180,197	186,846

4.4 Water demand Estimation

4.4.1 Domestic Water Demand Estimation

The amount of water needed daily by humans for various domestic activities such as drinking, cooking, bathing, gardening, etc. Goal 1.3 of the Ethiopian government's Second Growth Transformation Plan (GTP-2) classifies urban water supply access depending on population size. Jimma Town, whose population at the time of its design was over 100,000, has been placed in Category 2 for classification purposes (Growth, 2015). Taking into consideration projected future population, serviced population, per-capita, water demand, factors, etc., domestic water demand is estimated as followings:

Table 4. 6 Estimated Domestic Water Demand

Item	Unit	Year					
		2014	**2015**	**2016**	**2017**	**2018**	**2019**
Total Population	Person	157,894	164,020	167,560	173,784	180,197	186,846
Percentage of Serviced Population	%	75.00	75.04	75.07	75.11	75.15	75.19
Serviced Population	Person	118,421	123,081	125,787	130,529	135,418	140,490
House Connection (HC)	Person	13,571	14,111	14,429	14,981	15,550	16,139
	%	11.46	11.465	11.471	11.477	11.483	11.488
Yard Connection Alone (YCA)	Person	74,605	77,578	79,321	82,351	85,489	88,733
	%	63.00	63.03	63.06	63.09	63.13	63.16
Yard Connection Common (YCC)	Person	379	395	406	424	441	461
	%	0.32	0.321	0.323	0.325	0.326	0.328
Public Fountain (PF)	Person	261	272	279	291	303	316
	%	0.22	0.221	0.222	0.223	0.224	0.225
Per-Capita Water Demand	lpcd	80.00	80.04	80.08	80.12	80.16	80.20
House Connection (HC)	lpcd	110.00	110.05	110.11	110.16	110.22	110.27
Yard Connection Alone (YCA)	lpcd	75.00	75.04	75.07	75.11	75.15	75.19
Yard Connection Common (YCC)	lpcd	30.2	30.22	30.23	30.25	30.26	30.28
Public Fountain (PF)	lpcd	2.7	2.71	2.73	2.74	2.75	2.77
Domestic Water Demand	m^3/d	9474	9851	10,073	10,458	10,855	11,267
Socio-Economic Factor	-	1.05	1.05	1.05	1.05	1.05	1.05
Climate Effects Factor	-	1.00	1.00	1.00	1.00	1.00	1.00
Average Domestic Water Demand	m^3/d	9948	10,344	10,577	10,981	11,398	11,830

4.4.2 Projected non- domestic water demand assessment

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

Table 4. 7 Estimated Non- domestic Water Demand

Item	**Unit**	**Year**					
		2014	**2015**	**2016**	**2017**	**2018**	**2019**
PCD	m^3/d	2984	3103	3173	3294	3419	3549
LD	m^3/d	497	517	529	549	570	592
FFD	m^3/d	995	1034	1058	1098	1140	1183
IAD	m^3/d	995	1034	1058	1098	1140	1183
OPUD	m^3/d	2089	2172	2221	2306	2394	2484
Non- domestic water demand	m^3/d	7560	7860	8039	8345	8663	8991

According to Table 4.7, water demand for public and commercial areas was higher than water demand for other non-domestic sectors, indicating that the public and commercial areas covered a larger area than other locations. The demands for domestic water as well as the overall water demand's share of the design period were examined. Domestic demand is greater than all other types of consumption among those groups.

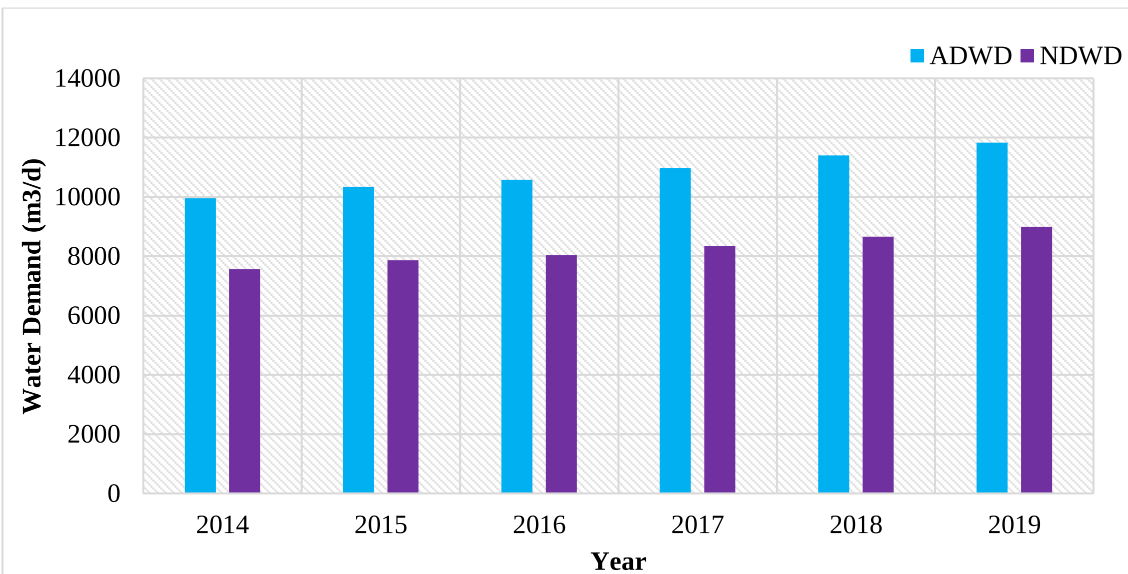

Figure 4. 3 Domestic water demand and Non- domestic water demand variation

4.4.3. Estimated average daily demand, maximum daily demand and peak hour demand

The total consumptions listed in the previous sections make up the term "water demand," which is used to calculate how much capacity is required from the sources.

Table 4. 8 Estimated average daily demand, maximum daily demand and peak hour demand

Water Demand	Unit	Year					
		2014	**2015**	**2016**	**2017**	**2018**	**2019**
ADWD	m^3/d	9948	10,344	10,577	10,981	11,398	11,830
NDWD	m^3/d	7560	7860	8039	8345	8663	8991
UFW	m^3/d	3419	3421	3422	3424	3426	3427
ADD	m^3/d	20,927	21,625	22,038	22,750	23,487	24,248
MDDF	-	1.25	1.25	1.25	1.25	1.25	1.25
MDD	m^3/d	26,159	27,031	27,548	28,438	29,359	30,310
PHDF	-	1.6	1.6	1.6	1.6	1.6	1.6
PHD	m^3/d	33,483	34,600	35,261	36,400	37,579	38,797

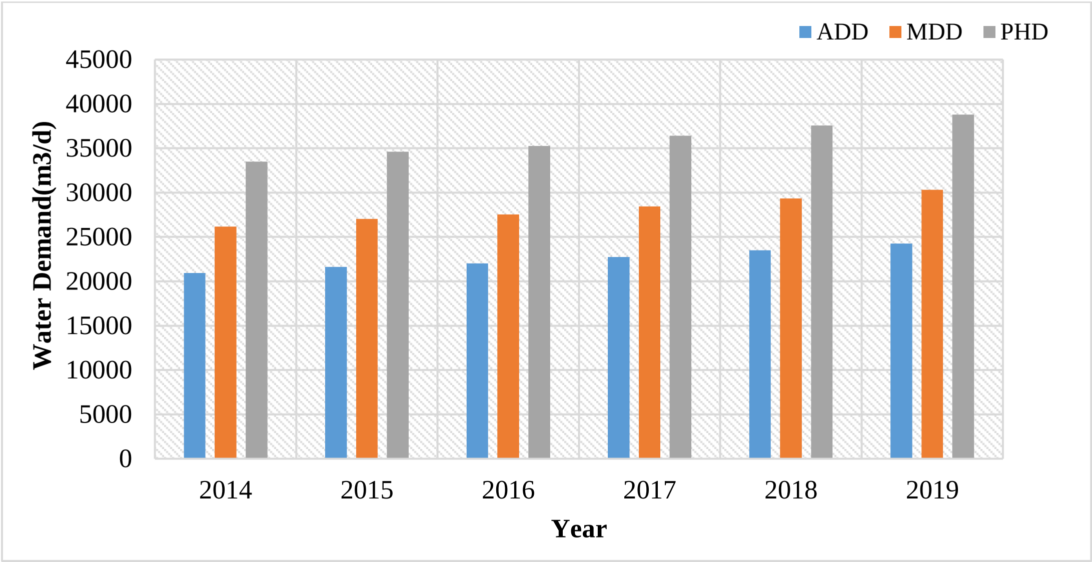

Figure 4. 4 Average daily demand, maximum daily demand and peak hour demand variation

4.4.4. Water demand and supply analysis

According to information gathered from conversations with water supply office experts, the source of power for the pump motor or a lack of power supply is the other issue with water supply. That implies the town's water supply is reliant on electric power. When electricity is available, the pumps can produce 7,027.2 m^3 per day (122 l/s times to operation hours per day) of water in their operation hours. Therefore the sources combined to discharge 27,000 m^3 per day.

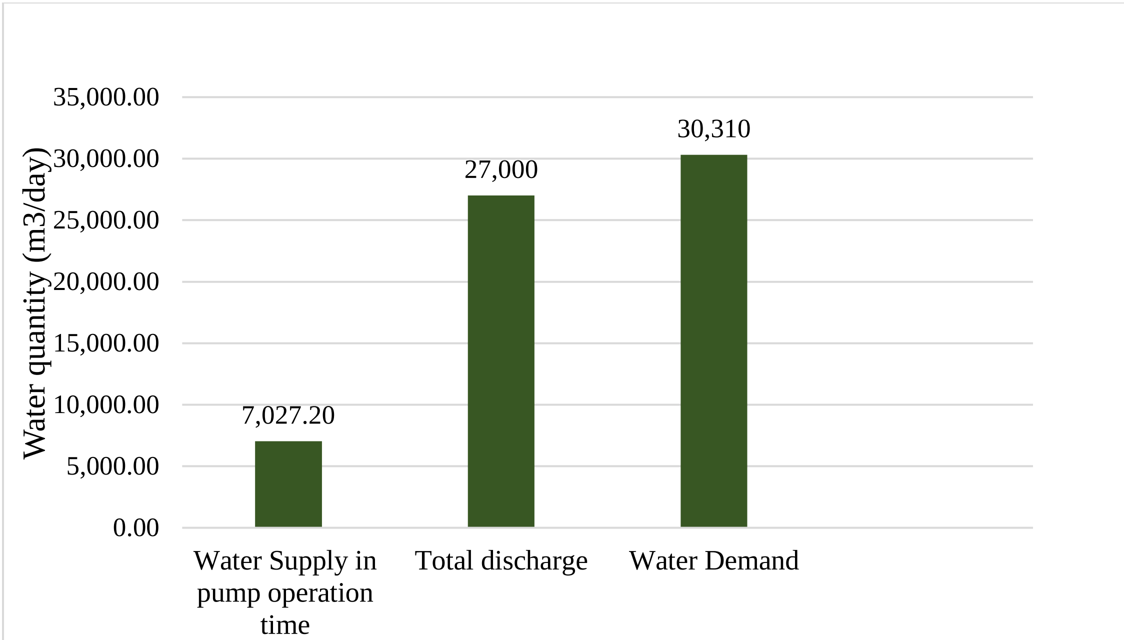

Figure 4. 5 Existing current water supply and future water demand

The maximum daily demand of the design period was 30,310m^3/day and 7027.2 m^3/day of maximum water deliveries to the system were made. This shows that the pumps' capacity was insufficient to meet Jimma Town's current water needs. The town's water supply and distribution system is considered to be not sufficient and not sustain when comparing the current water supply to the water demand during the design period.

4.5 Analysis the distribution system

4.5.1. Existing hourly hydraulic pattern

The system condition was calculated over a period of 24 hours with an hourly time increment, with the model run beginning at 12:00 AM (Mid night). The model was run for a 24 hour period with a three-hour time setting. However, to determine the current performance of the system in relation to system parameters like pressure and velocity, the peak and minimum hours of demand have been simulated for the analysis. The model may run continuously, however its simulation was modified to reflect the actual performance pattern. The model was run with a minimum hour consumption range of 1:00 AM to 4:00 AM (night) and a maximum hour consumption range of 6:00 AM to 9:00 AM (morning). It should be noted that the minimum hour consumption model is at 2:00 AM (after mid night), and the peak hour model completed at 7:00 AM (morning).

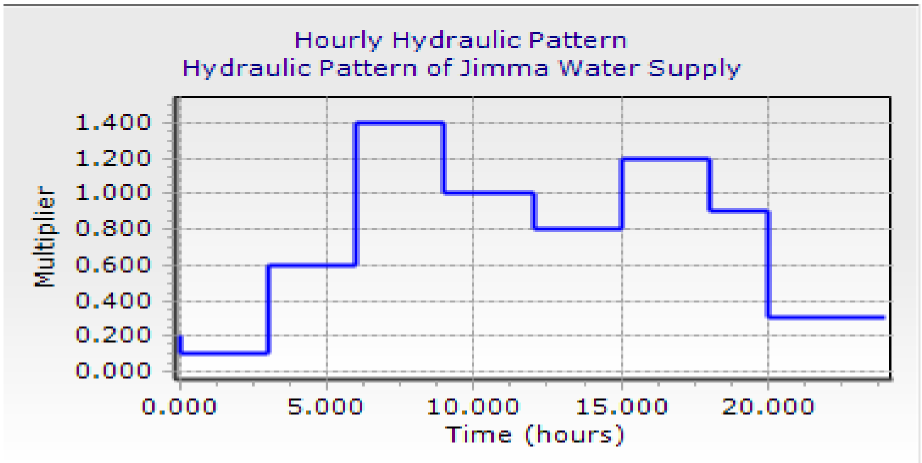

Figure 4. 6 Hourly hydraulic pattern of Jimma town water supply in 24 hours

4.5.2 Pressure of water in node water distribution network

The system's pressure rises during low consumption at night time and the leakage losses are anticipated to rise, whereas when there is high consumption, the pressure decreases and leakage losses are anticipated to fall. The hydraulic performance of the distribution network is negatively impacted by high pressure values after mid night (2:00 AM), when consumption is at its lowest.

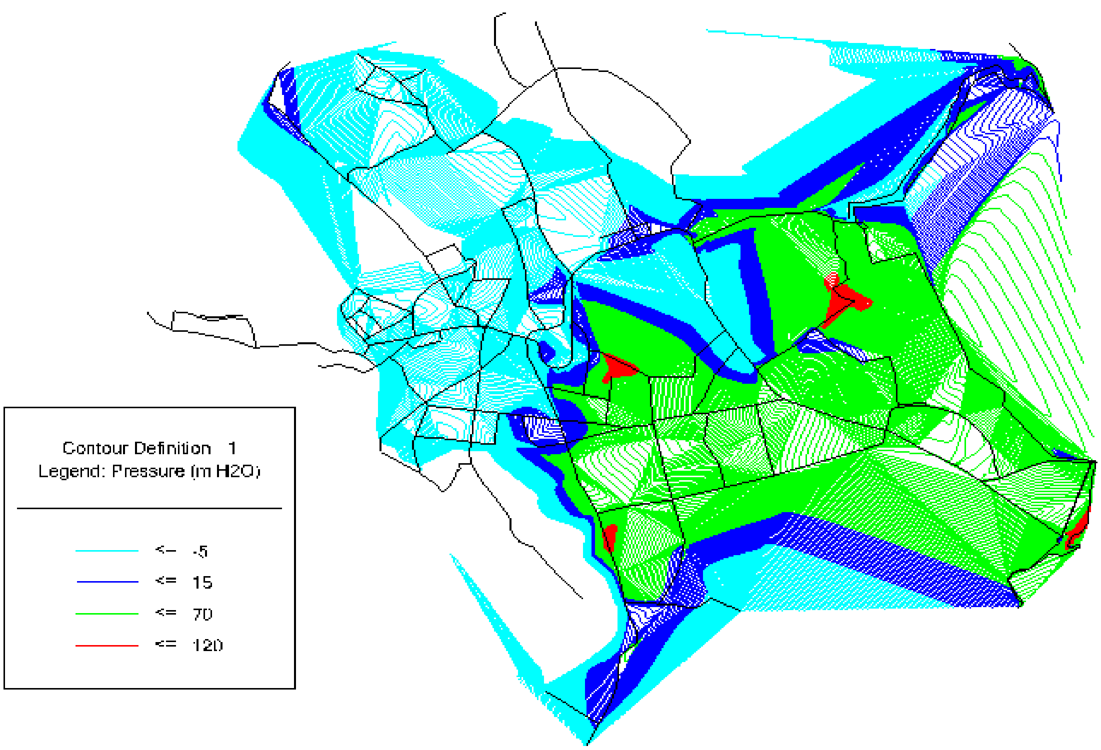

Figure 4. 7 Pressure of existing water supply distribution network at 2:00 AM (night)

The red colour denotes pressures above 120 mH2O, indicating that 0.17 percent of water distribution networks had pressures that were above the allowable limit of 120 mH2O. Between -5-15 mH2O 16.29 percent and 15-70 mH2O 32.07 percent, which were within the acceptable range, are indicated in green and blue. The light blue tint on the above figure indicates a pressure below the permitted range. It is based on the people served, the different kinds of homes in the area, and the topography. The adopted minimum and maximum pressure inside the network, topographical conditions, distance from the source position, storage elevation, and network size all affect the pressure at the node.

Table 4. 9 Table pressure result at 2:00 AM (night)

Pressure value	**<-5 mH2O**	**-5-15 mH2O**	**15-70 mH2O**	**70-120 mH2O**	**< 120 mH2O**
Number of nodes	290	95	187	10	1
In percentage (%)	49.74	16.29	32.07	1.71	0.17

After the model constrained a total of 583 nodes from the input of existing data, the results of the simulation run were received. From the Excel data, the nodes on each pressure range were counted. The above table demonstrates that 32.07% of the nodes were found to be within the recommended serviceable pressure range (15 mH2O to 70 mH2O) at low water consumption hour (2:00 PM), whereas 49.74% and 0.17% were found to be below and above the permitted values, respectively.

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

The design of new systems and the expansion of existing ones are both based on analyses of water distribution networks. The positioning and diameters of the pipes, as well as the distribution of the outflows, have an impact on design criteria such minimum stipulated flow rates and pressure distributions over a network. Network design is not an explicit process because a change in diameter in one pipe length will impact the flow and pressure distribution everywhere. Pressure and discharge issues in specific urban areas where elevation is quite high or the location is far from the water treatment plant are frequent problems in the distribution system (Lukman et al., 2012). Despite the fact that the two design guidelines use different values for the same concept, the study was conducted using the (MoWR, 2006). Early in the morning, there is a high water use there for take morning time at (7:00 AM).

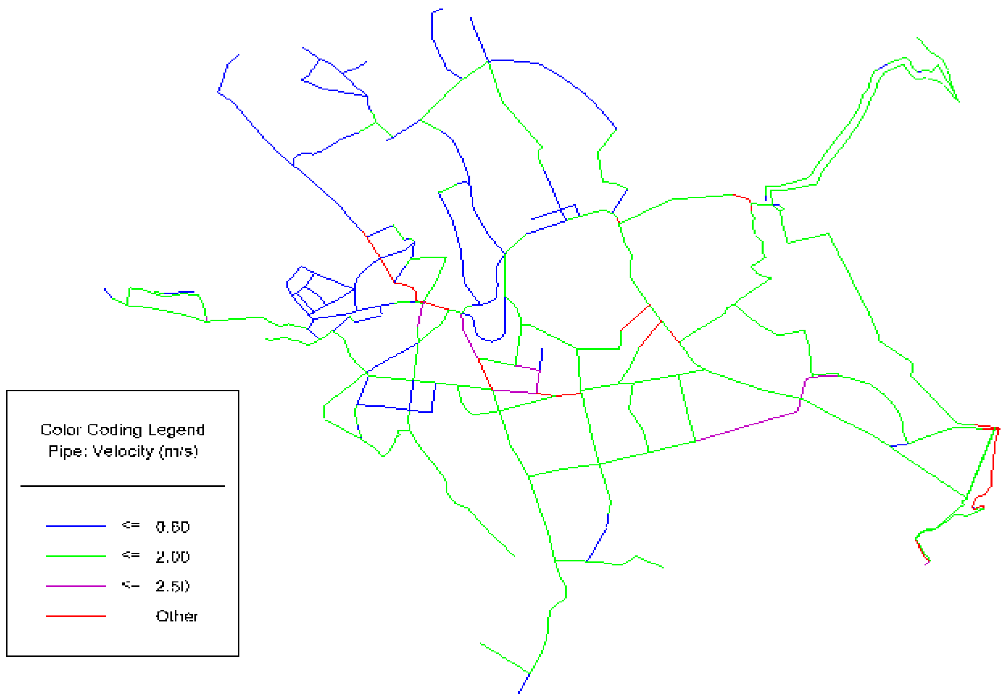

Figure 4. 8 Velocity in the existing distribution network at 7:00 AM (Morning)

Nearly half of the distribution network depicted in green on the figure was in locations where the permitted velocity range (0.6 m/s–2 m/s) was present, in contrast to the blue colour, which has been described on the figure with a velocity value less than the allowable value. Purple colour denotes a tiny coverage area with velocity values between 2 and 2.5 m/s, while the red colour denotes a value that is excessive.

Table 4. 10 Table velocity result at 7:00 AM (Morning)

Velocity value	**< 0.6 m/s**	**0.6-2 m/s**	**2-2.5 m/s**	**>2.5 m/s**
Number of Pipes	175	424	19	40
In percentage (%)	26.59	64.43	2.88	6.07

A total of 658 pipes were reported from the excel data as the simulation run's outcome after the model was constrained from the input of existing data. The project inventory dialog box software was used to count the nodes on each pressure range. According to the above table, 64.43% of nodes were found to be within the suggested acceptable pressure ranges of (0.6-2 m/s) at the high water consumption hour (7:00 AM), whereas 26.59% and 6.07% were below and beyond the permissible values, respectively.

The water distribution network were faced a frequent pipe bursts and failures during low demand time and exposed to large volume of water loss especially in high pressure zone areas, while during high demand time mostly residences found in dense population and higher level of the town were not receiving continuous water from the system. Thereby, the same to the study on urban water supply system performance assessment (Kefyalew, 2019), water pressures in the distribution network were observed that not perfectly performing within the proposed maximum and minimum design criteria of MoWIE.

4.6 Model Calibration

A higher coefficient value ($R^2 \geq 0.95$), which is supported by the study findings of (Capt et al., 2021) indicates that the Water Gems model has a good capability to forecast the flow at the pipe. The correlation coefficient equation (R^2) approach was used to manually carry out the validation task, which was then explained and graphically represented. According to the figure explanations, 96.47% is the correlation value (R^2) for the flow value. The pipe around pumping stations is where the flow value data were measured. The degree of accuracy (error of difference) and the coefficient of determination (R^2) are two ways to be taken into consideration for the model performance measure. The values and outcomes of the calibration model check are described in Appendix E. The link coefficient of one, which is the best correlation between observed and simulated flows is given by all observed flows being roughly equivalent to the pressures in simulations.

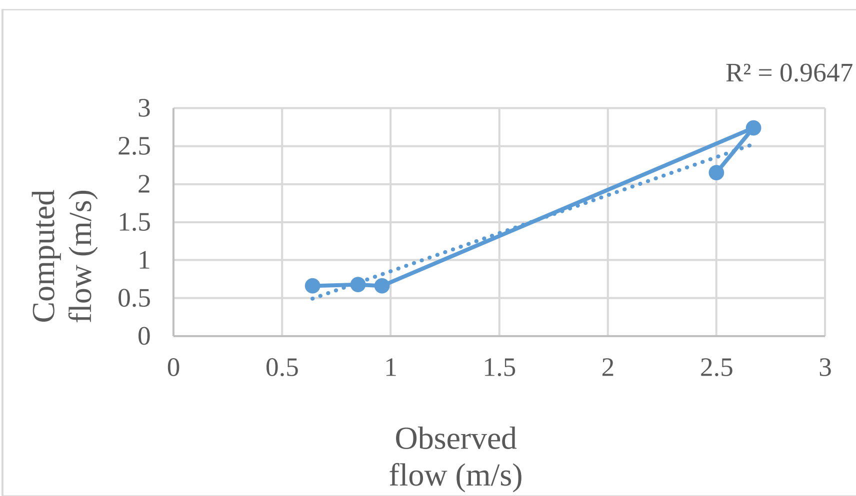

Figure 4. 9 Coefficient determination value (R^2)

4.7 Model Calibration and validation

Based on the various calibration standard requirements for hydraulic network and water quality modelling, model calibration and validation were carried out. According to (Mala-Jetmarova et al., 2018) model calibration is the process of fine-tuning a model until it accurately simulates field conditions over a given time horizon claim that hydraulic model calibration is an essential modelling step that must be completed in order to improve confidence, comprehend faults produced throughout the model-building process, and detect them.

Data were gathered from field-selected sample locations in the pumping station for model calibration and validation. Based on the comparison of model flow and measured flow in the chosen nodes, model calibration was established. Because there was no other way to measure the pressure via the junction of the distribution system other than the mains, flow measurements were made in the current study at the pumping stations; where flow measuring gages are located at five pipes (P-113, P-408, P-419, P-453, and P-112). Fire hydrant flow tests must be carried out in order to collect test data for simulation of high flow circumstances and for analysis of the system behaviour under severe conditions (Methods et al., 2003). Unfortunately, the lack of flow measuring gages made it impossible to conduct a fire hydrant flow test, and all of the hydrants are inoperable.

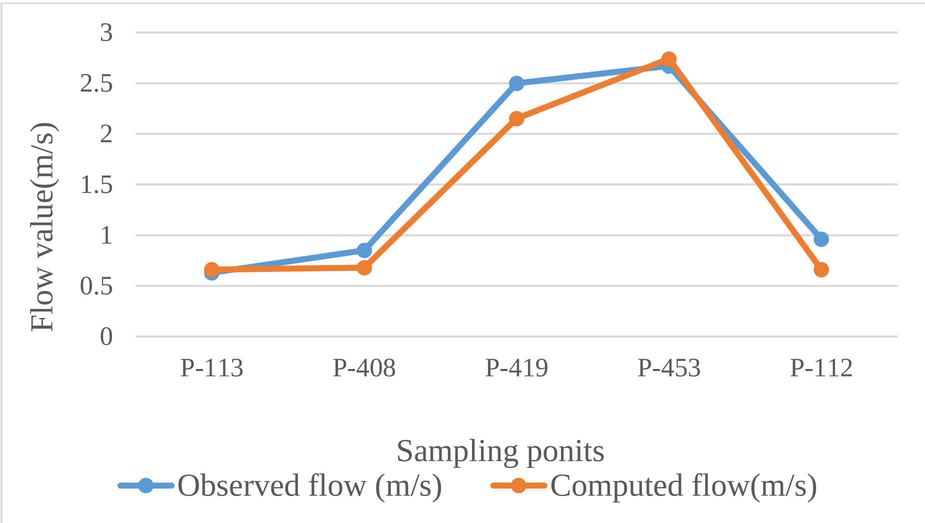

Figure 4. 10 Flow value vs sampling point for observed and computed flows

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The future water demand and population of Jimma town has been projected by geometric population forecasting method from 2014 up to 2019. The town's current water distribution system was set up with a population of about 157,894 people. However, relative to the future population of 186,846 it was over served that the town has poor coverage. Most of the time, some districts in Jimma Town are facing lack of an access of potable water supply. As a result the people living in these areas are travelling more than a kilo-meter to fetch water from springs developed by Jimma University students on DTTP programs and some are using the Awetu River for home uses.

The maximum water demand prediction for the designed period of 2019 is 30,310m^3/day and the present water output of Jimma town, which is 7027.2m3/day indicates that the town's water supply is not sustainable and comparable. Even if in some distributions there are same pressure values with the standard level, in most distributions the pressures are below the limit. In general, the simulated hydraulic result shows that Jimma Town's current hydraulic performance is not sufficient.

Due to the usage of chlorine, disinfection by product was formed in the water distribution system. The findings indicate that the giardia and virus percent were reduced by 23.5 % and 76.26 % respectively. The calculated giardia and virus inactivation (elimination) were lower than that of the surface water treatment standard. This is a sign that treatment processes contribute significant effect in the quality of drinking water as a result of the unbalanced addition of chlorine. Chlorine can maintain a water clean, but because it is by product from the disinfectant; due to its unbalanced dosage when it reacts with organic matter it can form disinfection by product. And these DBPs are nasty and can cause a risk of liver disease after a long period of time. Therefore the disinfectant dosage must be applied according to the standard.

According to the pressure and velocity performance indices, which were approximately 0.43 and 0.68, respectively, the model simulation results and penalty curve values are in a favourable scenario. The pressure performance index was under 50% (half) but due to the acceptable velocity performance index, the hydraulic performance index became 0.38 which is within the permissible standard. This is because the performance analysis of the water distribution network evaluates the junction pressure and pipeline water velocity.

Generally, it can be said that Jimma town's current water distribution system and treatment facility are ineffective and unable to meet the needs of various categories of the town and also supply inadequate water to the town's demand.

5.2 Recommendations

To enhance the effectiveness of the current Jimma Town water supply system, the following recommendations have been made in connection to water quality, operation and distribution system respectively.

- It is advised that routine bacterial and chemical water quality testing must be performed each day before the distribution. And the disinfectant dosage should be as stated on the Ethiopian guideline for drinking water quality. To get a comprehensive picture of the water balance and proper dosage of disinfection by products, the system for documenting water production and consumption should also be updated.
- For proper system operation and maintenance, an updated water supply system map that show the layout, sizes, and lengths of the distribution and transmission pipes as well as the locations of valves, flow meters, fire hydrants, reservoirs, pumping stations, and sources must be prepared and made available in the water utility office. Also all sources, reservoirs, and collection chambers should install water meters at the intake and outlet pipes, and correct water production documentation should be in place.
- If the current network topology has to be used, the long last solution to solve the pressure deficit problems in some district is to establish a new pressure zone which includes service areas above.
- Generally it is important to install additional pressure control valves, set up boosting stations and replace the old pipes with new ones which have better diameter size in order to reach the systems' allowable pressure range. Additionally, spare components and fittings that can applied to the necessary requirements should be used.

As the researcher’s observation in order to prevent shortage of water supply, water loss and consumer complains, jimma town water supply and sewerage should respond to maintenance request from customers. In order to improve its services and raise customer satisfaction, the water utility should regularly survey its consumers to determine their level of satisfaction and any service flaws. Additionally, pumping stations must be equipped with backup generators in case of a power fluctuation and shortage.

Finally, since sustainability assessment is a broad concept, this study does not sufficiently explore all sustainability indicators in every locations of the town because of the limited time and resources. Therefore, additional further research should be done utilizing various assessment techniques on all sustainability parameters, including water quality assessments.

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APPENDIXS

Appendix A; Existing water supply distribution network junction in Jimma Town causes low flow

Junction table at 8:00 PM (night)				
Label	**Elevation (m)**	**Pressure (m H2O)**	**X (m)**	**Y (m)**
J-1	1,705.31	58	265,112.58	847,474.25
J-2	1,711.14	-32	264,974.33	847,574.66
J-3	1,728.72	3	264,917.10	847,614.07
J-4	1,731.75	5	261,712.71	848,608.95
J-5	1,732.31	-11	261,698.19	848,570.70
J-6	1,747.85	-77	259,183.89	850,997.58
J-7	1,750.61	-2	259,736.00	850,378.70
J-8	1,748.16	-11	260,495.78	849,559.14
J-9	1,719.90	-17	260,927.98	849,008.59
J-10	1,741.36	-18	260,837.13	849,276.42
J-11	1,715.90	-34	261,642.50	849,273.99
J-12	1,715.28	-42	261,641.57	849,178.05
J-13	1,724.10	3	260,506.45	850,872.12
J-14	1,725.55	-142	260,446.00	847,571.27
J-15	1,727.53	-88	260,438.82	847,604.05
J-16	1,731.53	-44	260,386.09	847,813.09
J-17	1,731.10	-64	260,404.00	849,143.28
J-18	1,729.87	-59	259,796.91	849,055.62
J-19	1,725.44	-39	259,833.15	848,974.24
J-20	1,714.40	-14	260,802.85	848,411.89
J-21	1,730.65	56	260,128.58	848,570.79
J-22	1,727.38	24	259,878.79	849,003.44
J-23	1,969.76	42	265,676.85	851,012.74
J-24	1,975.30	4	265,398.07	851,139.88
J-25	1,971.07	50	265,225.27	851,274.70
J-26	1,947.73	53	265,012.93	851,117.77
J-27	1,971.16	45	265,264.56	851,220.14
J-28	1,973.79	49	265,171.39	851,252.16
J-29	1,975.06	54	265,654.27	851,080.22
J-30	1,936.56	56	264,941.69	850,940.28
J-31	1,987.81	58	265,564.59	851,339.62
J-32	1,925.86	60	264,827.59	850,675.56
J-33	1,913.54	59	264,717.93	850,497.78
J-34	1,736.47	59	263,257.65	848,517.24
J-35	1,706.01	-36	265,121.13	847,475.36
J-36	1,960.83	52	265,061.54	851,196.05
J-37	1,827.12	47	264,057.25	850,017.24

J-38	1,965.50	60	265,716.82	850,885.22
J-39	1,905.36	12	264,514.06	850,205.87
J-40	1,888.23	57	264,422.41	850,079.82
J-41	1,968.68	60	265,295.77	851,179.61
J-42	1,972.66	58	265,212.52	851,270.16
J-43	1,981.98	57	265,466.98	851,137.80
J-44	1,713.35	49	261,663.79	847,828.36
J-45	1,721.89	39	259,007.07	848,983.01
J-46	1,775.21	-60	263,735.12	848,892.60
J-47	1,721.24	50	262,331.67	849,883.11
J-48	1,741.30	98	262,663.67	850,588.18
J-49	1,762.05	-5	262,195.14	851,168.76
J-50	1,735.71	0	261,127.15	850,002.54
J-51	1,723.84	4	261,253.66	850,529.58
J-52	1,735.87	3	262,685.05	850,095.76
J-53	1,815.99	-7	263,889.93	849,880.73
J-54	1,800.00	-23	263,918.62	849,586.74
J-55	1,794.74	-36	263,882.65	849,262.72
J-56	1,802.41	-10	263,985.96	849,406.61
J-57	1,807.63	-38	264,013.53	849,358.49
J-58	1,775.07	-12	263,738.11	849,151.83
J-59	1,791.99	-10	264,061.76	849,150.66
J-60	1,782.82	-15	263,952.80	849,069.09
J-61	1,781.25	7	263,786.49	848,936.12
J-62	1,771.98	-22	263,853.98	848,774.88
J-63	1,787.03	56	263,651.27	849,974.84
J-64	1,806.09	56	263,985.78	849,515.41
J-65	1,729.06	10	262,775.61	849,495.61
J-66	1,734.20	-10	261,500.57	848,885.65
J-67	1,719.25	-36	260,579.86	850,706.59
J-68	1,776.21	-35	262,415.72	850,991.98
J-69	1,724.04	8	260,966.52	850,724.69
J-70	1,719.72	32	261,715.05	849,392.57
J-71	1,724.82	3	261,937.77	849,733.89
J-72	1,720.07	-3	261,405.28	850,091.03
J-73	1,744.32	26	262,700.80	850,633.70
J-74	1,707.87	21	260,659.94	850,512.10
J-75	1,731.78	28	261,692.02	850,905.15
J-76	1,735.48	-6	261,567.93	851,307.57
J-77	1,716.90	8	260,503.34	850,957.68
J-78	1,755.93	26	260,088.52	851,327.40

J-79	1,739.67	-37	261,255.02	849,720.31
J-80	1,751.28	23	259,856.49	850,352.70
J-81	1,773.99	-11	263,320.70	849,944.40
J-82	1,775.69	-12	263,255.57	849,942.41
J-83	1,775.24	-8	263,198.65	849,934.84
J-84	1,770.53	-2	263,141.00	849,911.96
J-85	1,763.52	4	263,035.72	849,856.46
J-86	1,750.96	1	262,847.35	849,756.27
J-87	1,742.54	-4	262,720.66	849,690.12
J-88	1,737.65	-9	262,833.53	849,384.16
J-89	1,737.03	2	262,823.24	849,287.84
J-90	1,733.48	-42	262,818.17	849,160.90
J-91	1,731.09	-37	262,906.00	849,013.85
J-92	1,730.76	-47	263,173.72	848,619.34
J-93	1,747.09	-55	262,657.77	849,797.13
J-94	1,746.72	-46	262,795.96	850,034.07
J-95	1,740.81	-47	262,577.10	850,108.45
J-96	1,732.54	-34	262,612.00	850,512.47
J-97	1,758.62	-32	262,008.66	851,288.84
J-98	1,758.43	-32	259,927.38	851,449.99
J-99	1,734.03	-25	262,562.94	849,823.13
J-100	1,732.80	-23	262,371.90	849,767.83
J-101	1,731.20	-37	262,254.25	849,722.24
J-102	1,727.96	-23	261,898.15	849,585.61
J-103	1,733.27	-13	261,343.33	851,130.81
J-104	1,717.38	-39	262,208.18	849,830.10
J-105	1,726.15	-39	262,109.82	850,100.32
J-106	1,729.21	-39	262,051.45	850,238.74
J-107	1,726.82	-39	262,018.04	850,333.45
J-108	1,735.57	-2	262,044.88	850,451.13
J-109	1,734.20	-28	261,901.18	850,637.11
J-110	1,777.41	-11	261,401.08	851,760.57
J-111	1,794.47	-10	261,160.61	851,832.39
J-112	1,738.07	56	259,927.02	850,393.11
J-113	1,735.29	-20	261,243.08	851,029.02
J-114	1,728.74	-9	261,120.92	850,901.83
J-115	1,717.22	-15	260,307.76	850,994.54
J-116	1,713.28	-10	260,727.14	850,552.84
J-117	1,890.84	-9	265,995.73	847,644.95
J-118	1,871.84	-17	265,929.72	847,649.46
J-119	1,853.58	-4	265,857.66	847,654.12

J-120	1,836.44	-9	265,798.13	847,658.81
J-121	1,819.13	-13	265,744.76	847,662.15
J-122	1,789.65	-6	265,598.70	847,637.06
J-123	1,759.17	-5	265,519.09	847,604.98
J-124	1,756.00	-40	265,433.14	847,568.02
J-125	1,730.05	-10	265,330.90	847,527.25
J-126	1,721.92	-17	265,267.40	847,499.81
J-127	1,715.98	-16	265,230.88	847,618.90
J-128	1,709.85	-10	265,222.52	847,711.41
J-129	1,714.71	-42	265,186.11	847,819.35
J-130	1,717.49	-59	264,771.66	848,151.34
J-131	1,721.98	-99	264,697.42	848,167.58
J-132	1,727.40	-124	264,563.06	848,198.09
J-133	1,770.17	46	264,120.45	848,588.86
J-134	1,732.89	-34	264,870.45	847,640.60
J-135	1,719.09	-39	264,830.12	847,660.61
J-136	1,696.20	-38	264,744.95	847,704.31
J-137	1,712.43	-34	264,575.91	847,801.63
J-138	1,703.45	-39	264,296.34	847,822.95
J-139	1,712.94	-20	262,158.10	847,975.25
J-140	1,709.19	-22	261,760.26	847,493.61
J-141	1,694.69	-30	262,014.14	846,874.63
J-142	1,707.41	-43	261,428.91	847,784.57
J-143	1,711.33	-34	261,359.13	847,853.11
J-144	1,696.86	-29	261,335.74	847,916.62
J-145	1,696.30	-22	261,292.83	848,082.91
J-146	1,708.13	13	261,601.66	848,039.32
J-147	1,710.64	-27	261,476.61	848,350.97
J-148	1,708.82	-22	261,338.81	848,703.22
J-149	1,710.95	-27	261,331.55	848,803.90
J-150	1,722.75	44	261,377.11	848,860.67
J-151	1,730.97	-3	261,428.42	848,885.78
J-152	1,735.80	9	261,715.65	848,668.64
J-153	1,714.98	-3	261,824.24	848,837.47
J-154	1,716.85	14	260,695.93	848,352.11
J-155	1,819.37	10	265,721.28	847,662.30
J-156	1,819.40	4	265,696.16	847,662.54
J-157	1,744.42	23	262,617.50	849,817.22
J-158	1,729.59	7	261,650.61	849,088.00
J-159	1,726.33	3	260,556.24	850,773.66
J-160	1,744.89	3	262,706.19	849,756.98

J-161	1,718.85	1	262,728.40	848,446.37
J-162	1,724.86	16	261,932.37	848,686.29
J-163	1,726.67	24	261,852.05	848,744.99
J-164	1,718.80	22	262,039.80	848,392.36
J-165	1,724.20	109	262,021.47	848,232.91
J-166	1,719.06	0	261,988.48	848,004.96
J-167	1,732.17	37	261,851.45	848,611.26
J-168	1,722.16	119	261,834.39	848,495.63
J-169	1,711.66	98	261,804.05	848,278.87
J-170	1,707.91	48	261,552.53	848,342.26
J-171	1,732.19	87	261,669.49	848,541.93
J-172	1,732.90	60	261,597.18	848,520.23
J-173	1,728.92	-24	261,515.16	848,541.31
J-174	1,722.85	3	261,468.04	848,587.92
J-175	1,716.87	4	261,449.73	848,668.39
J-176	1,720.81	4	261,440.25	848,715.58
J-177	1,725.84	-56	261,429.96	848,744.20
J-178	1,730.05	-43	261,412.07	848,775.55
J-179	1,780.77	-56	259,271.98	851,281.30
J-180	1,741.34	7	259,923.57	850,202.00
J-181	1,741.31	-47	260,252.37	849,878.29
J-182	1,739.05	-14	260,392.58	849,686.75
J-183	1,740.25	1	260,456.31	849,618.25
J-184	1,742.42	0	260,478.12	849,582.85
J-185	1,729.16	3	260,834.71	849,085.59
J-186	1,718.44	1	260,871.64	849,071.19
J-187	1,719.11	4	260,894.56	849,056.62
J-188	1,722.65	2	260,913.13	849,037.05
J-189	1,713.96	-7	260,934.90	848,925.71
J-190	1,706.31	-3	260,998.67	848,913.01
J-191	1,692.67	-6	261,218.84	848,837.86
J-192	1,732.34	14	260,829.40	849,526.69
J-193	1,725.33	11	260,912.21	849,511.21
J-194	1,726.00	0	260,891.92	849,345.22
J-195	1,727.28	14	260,529.99	850,819.53
J-196	1,738.20	7	262,720.17	850,081.91
J-197	1,719.54	37	260,642.92	850,639.19
J-198	1,727.56	33	261,204.83	849,830.70
J-199	1,713.24	18	261,394.98	850,171.05
J-200	1,712.48	48	261,440.87	849,826.95
J-201	1,727.99	42	261,342.59	850,323.42

J-202	1,717.98	35	261,558.84	849,593.02
J-203	1,722.62	24	261,417.02	849,976.30
J-204	1,735.07	45	261,330.75	849,403.97
J-205	1,722.89	22	261,345.93	849,191.12
J-206	1,728.39	23	261,359.96	849,097.14
J-207	1,732.46	22	261,612.75	848,928.06
J-208	1,829.13	23	264,073.03	849,889.83
J-209	1,716.44	28	261,176.27	848,730.59
J-210	1,711.89	5	261,138.35	848,683.88
J-211	1,710.07	34	261,075.42	848,633.70
J-212	1,708.17	30	260,905.06	848,132.10
J-213	1,705.88	17	261,103.02	848,109.30
J-214	1,699.63	45	260,865.69	847,782.68
J-215	1,734.60	17	262,533.52	850,401.47
J-216	1,716.71	18	260,763.57	847,576.43
J-217	1,758.72	54	262,567.08	850,818.08
J-218	1,818.35	60	265,660.73	847,657.72
J-219	1,721.89	22	260,384.43	849,040.87
J-220	1,726.34	54	259,887.72	849,223.95
J-221	1,713.93	51	260,742.70	848,902.71
J-222	1,727.69	21	260,362.30	848,803.61
J-223	1,706.19	20	260,974.47	848,831.50
J-224	1,710.13	19	260,961.72	848,760.69
J-225	1,720.93	34	260,945.98	848,656.45
J-226	1,738.96	21	260,161.65	848,598.67
J-227	1,741.64	18	260,083.66	848,966.96
J-228	1,728.61	24	260,342.56	848,772.53
J-229	1,712.85	20	260,923.55	848,915.04
J-230	1,709.13	23	260,952.40	848,909.82
J-231	1,705.72	21	260,995.16	848,897.71
J-232	1,800.66	26	264,128.41	849,201.14
J-233	1,825.63	54	263,999.49	849,897.70
J-234	1,816.00	35	263,882.37	849,825.34
J-235	1,935.32	34	264,978.73	851,002.10
J-236	1,987.32	35	265,527.80	851,110.41
J-237	1,834.73	26	264,157.11	850,017.44
J-238	1,940.05	35	264,905.17	850,833.84
J-239	1,968.98	40	265,580.88	851,078.47
J-240	2,002.03	33	265,507.18	851,449.04
J-241	1,970.67	-1	265,624.10	851,217.50
J-242	1,973.89	21	265,201.53	851,266.38

J-243	1,968.07	31	265,114.07	851,222.70
J-244	1,970.24	20	265,327.29	851,139.49
J-245	1,972.55	26	265,234.84	851,274.74
J-246	1,983.77	19	265,437.92	851,141.36
J-247	1,970.20	32	265,636.68	851,140.23
J-248	1,889.00	34	266,051.08	847,659.40
J-249	1,718.22	20	265,871.51	846,963.17
J-250	1,854.63	16	266,038.96	847,511.16
J-251	1,718.90	33	265,839.93	846,879.35
J-252	1,725.82	12	265,948.96	846,997.81
J-253	1,808.97	23	266,029.69	847,411.03
J-254	1,752.34	38	266,000.82	847,077.74
J-255	1,786.47	43	266,021.89	847,319.03
J-256	1,906.17	18	264,453.32	850,248.25
J-257	1,975.30	33	265,155.78	851,311.43
J-258	1,939.77	31	264,838.49	850,852.06
J-259	1,980.47	16	265,534.18	851,187.51
J-260	1,970.98	9	265,269.42	851,338.01
J-261	1,828.12	16	264,012.61	849,913.10
J-262	1,834.74	60	264,129.20	850,067.41
J-263	1,829.56	34	264,010.23	849,981.51
J-264	1,976.67	123	265,209.87	851,337.38
J-265	1,822.38	16	264,011.24	850,065.54
J-266	1,926.15	17	264,755.56	850,697.63
J-267	1,974.03	63	265,288.75	851,308.42
J-268	1,948.91	-80	264,941.22	851,135.86
J-269	1,963.33	-83	265,006.07	851,232.94
J-270	1,968.49	-82	265,100.68	851,285.93
J-271	1,970.28	-75	265,312.81	851,239.27
J-272	1,974.16	58	265,298.72	851,274.95
J-273	1,937.74	-76	264,873.57	850,974.34
J-274	1,956.06	-39	264,969.95	851,199.21
J-275	1,937.28	-34	264,916.23	851,024.46
J-276	1,984.71	-38	265,477.83	851,204.14
J-277	1,976.78	-36	265,362.71	851,201.63
J-278	1,974.23	-35	265,246.10	851,353.91
J-279	1,984.37	-41	265,429.23	851,223.26
J-280	1,833.59	-33	264,661.60	849,385.58
J-281	1,823.79	-41	263,998.78	849,885.80
J-282	1,823.17	-36	264,751.58	849,192.85
J-283	1,794.42	1	264,936.54	848,778.13

J-284	1,800.14	-122	264,868.17	848,927.70
J-285	1,832.94	-50	264,147.25	849,861.76
J-286	1,833.41	-124	264,147.55	849,814.95
J-287	1,780.84	-130	263,559.41	849,962.23
J-288	1,821.69	-144	265,306.71	848,253.39
J-289	1,825.17	-194	264,207.74	849,497.99
J-290	1,888.19	-177	265,996.12	847,672.87
J-291	1,813.79	-168	264,842.65	848,984.16
J-292	1,859.35	-145	265,855.49	847,687.05
J-293	1,801.95	-130	263,724.77	849,986.12
J-294	1,827.75	5	264,069.58	849,877.97
J-295	1,806.60	-277	263,861.73	849,935.31
J-296	1,798.38	-294	265,301.47	848,170.45
J-297	1,830.45	2	265,765.69	847,695.52
J-298	1,839.97	8	265,309.79	848,308.93
J-299	1,788.74	17	265,015.05	848,564.91
J-300	1,789.29	15	264,990.59	848,635.07
J-301	1,791.70	-6	265,014.26	848,530.20
J-302	1,836.15	-123	264,172.34	849,837.45
J-303	1,828.50	-127	264,178.40	849,620.61
J-304	1,829.15	-136	265,633.17	847,786.00
J-305	1,809.99	12	265,428.73	848,027.52
J-306	1,815.96	-227	263,890.05	849,890.82
J-307	1,821.03	-7	264,322.22	849,528.50
J-308	1,820.00	9	265,565.59	847,866.47
J-309	1,823.94	23	265,711.76	847,700.77
J-310	1,826.51	7	264,161.45	849,695.26
J-311	1,815.44	38	264,816.73	849,046.62
J-312	1,788.85	-11	264,968.50	848,696.37
J-313	1,779.57	-14	263,495.71	849,961.57
J-314	1,855.84	22	264,568.36	849,594.70
J-315	1,809.14	-17	265,498.12	847,944.89
J-316	1,815.23	22	264,792.50	849,094.95
J-317	1,702.44	-27	265,684.26	846,792.28
J-318	1,697.60	-25	265,471.98	846,336.68
J-319	1,704.35	46	265,802.68	846,785.51
J-320	1,708.49	54	265,376.99	846,621.20
J-321	1,707.02	4	265,382.53	846,615.98
J-322	1,705.98	-8	265,427.86	846,645.93
J-323	1,721.39	-10	265,873.82	846,820.89
J-324	1,704.99	-20	265,508.01	846,657.52

J-325	1,705.61	-14	265,487.74	846,644.68
J-326	1,698.47	-11	265,401.70	846,398.48
J-327	1,705.53	-9	265,487.14	846,652.22
J-328	1,710.66	50	265,759.92	846,895.05
J-329	1,704.49	-106	265,343.64	846,555.07
J-330	1,705.52	-40	265,337.34	846,555.05
J-331	1,700.15	-39	265,458.60	846,327.59
J-332	1,694.48	-44	265,416.15	846,407.42
J-333	1,731.58	-42	265,922.75	846,847.86
J-334	1,704.81	-239	265,509.50	846,648.13
J-335	1,706.05	-195	265,429.82	846,639.87
J-336	1,707.38	7	265,755.34	846,939.20
J-337	1,979.49	-262	265,392.01	851,211.08
J-338	1,731.84	2	265,932.30	846,885.35
J-339	1,709.44	61	265,221.45	847,385.64
J-340	1,722.36	-59	265,864.18	846,857.38
J-341	1,719.90	-30	265,848.39	846,864.18
J-342	1,724.15	59	265,873.31	846,868.45
J-343	1,725.65	59	265,889.86	846,837.89
J-344	1,712.27	33	265,789.61	846,957.41
J-345	1,710.49	19	265,775.88	846,970.45
J-346	1,786.30	16	261,076.42	851,797.14
J-347	1,758.99	-34	261,068.68	851,549.35
J-348	1,738.50	34	261,129.25	851,404.17
J-349	1,741.21	8	261,158.74	851,333.52
J-350	1,732.23	-36	261,207.53	851,226.62
J-351	1,717.14	20	260,472.62	850,995.69
J-352	1,722.14	19	260,411.68	851,042.40
J-353	1,725.97	23	259,986.20	851,171.75
J-354	1,713.57	3	259,918.60	851,125.44
J-355	1,753.07	-4	260,203.74	851,268.48
J-356	1,728.66	-55	260,211.71	851,017.24
J-357	1,721.01	-49	260,387.60	850,982.15
J-358	1,739.07	-54	260,425.51	851,255.18
J-359	1,724.14	-28	260,500.09	851,304.16
J-360	1,736.50	7	258,930.97	848,768.26
J-361	1,713.95	96	259,801.98	848,696.46
J-362	1,732.32	20	258,867.39	848,791.13
J-363	1,733.27	19	258,816.62	848,801.00
J-364	1,730.41	6	258,641.43	848,840.69
J-365	1,730.32	-40	258,252.46	848,950.73

J-366	1,722.52	-42	258,404.57	849,051.49
J-367	1,724.33	-198	259,040.88	848,918.23
J-368	1,708.32	-305	259,069.35	848,806.05
J-369	1,707.90	18	259,075.16	848,765.51
J-370	1,722.23	17	258,623.74	849,016.10
J-371	1,725.34	1	258,700.52	848,995.63
J-372	1,707.58	-6	262,669.48	846,300.89
J-373	1,705.80	59	262,190.45	846,207.93
J-374	1,699.20	58	262,175.60	845,908.44
J-375	1,690.23	54	262,106.30	845,829.23
J-376	1,713.94	36	261,831.30	845,288.49
J-377	1,702.15	39	261,278.40	846,906.98
J-378	1,704.39	58	261,333.85	846,877.27
J-379	1,700.01	59	261,389.29	846,857.47
J-380	1,719.34	45	261,549.68	846,653.52
J-381	1,727.30	53	261,710.68	848,973.45
J-382	1,972.36	-178	265,577.07	851,182.64
J-383	2,002.26	57	265,459.48	851,409.08
J-384	1,999.69	52	265,534.56	851,278.95
J-385	1,936.29	44	264,878.67	850,768.92
J-386	1,938.69	58	264,809.76	850,790.22
J-387	1,914.06	-40	264,628.10	850,525.12
J-388	1,904.65	46	264,622.14	850,364.94
J-389	1,903.86	-38	264,546.97	850,400.27
J-390	1,888.71	50	264,378.38	850,141.01
J-391	1,892.32	-42	264,420.02	850,190.01
J-392	1,827.77	47	264,054.12	849,884.69
J-393	1,815.65	4	263,916.11	849,745.34
J-394	1,807.77	-51	263,896.30	849,714.05
J-395	1,717.68	45	261,790.85	848,889.52
J-396	1,721.06	-38	261,362.42	850,107.17
J-397	1,723.95	44	261,302.98	850,092.57
J-398	1,734.77	-43	261,214.35	850,039.39
J-399	1,726.22	42	261,142.40	850,622.29
J-400	1,709.21	38	262,383.04	848,032.59
J-401	1,740.51	49	261,679.69	851,322.29
J-402	1,704.06	34	260,091.36	850,410.93
J-403	1,722.97	53	260,419.83	850,597.58
J-404	1,718.40	3	260,287.40	850,547.53
J-405	1,726.32	53	260,019.49	850,385.36
J-406	1,728.31	58	258,501.05	849,039.97

J-407	1,735.43	48	258,875.45	848,997.15
J-408	1,771.49	34	263,680.56	848,857.81
J-409	1,726.60	19	258,704.18	848,965.84
J-410	1,707.06	35	262,935.43	847,635.76
J-411	1,698.00	-17	260,861.45	847,724.98
J-412	1,733.26	-97	262,012.61	850,421.24
J-413	1,729.51	58	264,654.39	848,198.69
J-414	1,727.70	-96	264,424.00	848,179.49
J-415	1,752.54	-99	264,401.89	848,457.66
J-416	1,765.09	50	264,352.57	848,634.20
J-417	1,765.38	-99	263,990.03	848,664.62
J-418	1,729.00	94	262,987.71	848,887.67
J-419	1,735.79	-100	263,249.11	848,510.94
J-420	1,732.04	-8	263,094.54	848,726.79
J-421	1,751.75	-92	263,329.53	848,575.25
J-422	1,727.42	-30	262,732.64	848,625.03
J-423	1,731.37	-83	262,813.18	848,255.12
J-424	1,750.37	-177	259,318.80	850,900.35
J-425	1,747.90	-175	259,589.80	850,542.37
J-426	1,739.38	-127	260,034.62	850,090.86
J-427	1,742.83	-73	260,144.07	849,987.55
J-428	1,738.30	-37	260,300.52	849,804.73
J-429	1,720.63	-39	260,952.77	848,514.07
J-430	1,780.84	-26	263,856.60	848,993.96
J-431	1,755.21	-15	263,541.02	848,718.66
J-432	1,754.49	-15	263,437.79	848,652.04
J-433	1,771.64	-17	263,654.20	848,800.79
J-434	1,748.19	-13	260,038.75	851,266.14
J-435	1,749.93	-16	260,280.85	851,187.92
J-436	1,720.53	-22	258,166.45	849,058.65
J-437	1,722.73	-12	258,982.06	849,019.49
J-438	1,765.45	-20	264,219.27	848,597.91
J-439	1,726.03	-19	262,898.09	848,458.83
J-440	1,749.05	-41	259,461.81	850,708.21
J-441	1,712.35	-39	265,123.26	847,914.22
J-442	1,728.58	-39	265,051.12	848,001.69
J-443	1,725.56	-43	264,855.00	848,121.32
J-444	1,722.93	-47	264,653.03	848,171.51
J-445	1,722.46	-33	264,371.40	848,149.28
J-446	1,704.62	-41	264,362.76	847,937.91
J-447	1,713.57	-33	263,979.12	848,040.26

J-448	1,728.45	-40	263,624.65	848,175.90
J-449	1,715.98	-11	263,247.00	848,186.93
J-450	1,714.29	-39	263,296.75	847,931.06
J-451	1,712.83	-18	263,341.74	847,737.39
J-452	1,709.41	-24	263,394.56	847,528.00
J-453	1,732.23	-26	264,924.41	848,100.20
J-454	1,713.85	-38	260,867.19	849,551.13
J-455	1,725.59	-40	263,471.83	848,240.33
J-456	1,741.38	-30	260,500.09	849,259.94
J-457	1,720.71	-22	263,383.82	848,303.38
J-458	1,738.75	-36	260,831.12	849,428.27
J-459	1,723.49	-37	263,299.41	848,437.18
J-460	1,727.57	-3	260,730.33	849,675.77
J-461	1,704.76	-39	262,986.36	847,416.40
J-462	1,729.64	-33	260,735.27	849,107.15
J-463	1,702.90	-93	262,545.87	847,300.33
J-464	1,747.28	-100	260,615.48	849,350.26
J-465	1,701.05	-111	261,923.78	847,173.75
J-466	1,726.78	-23	262,847.32	848,107.19
J-467	1,709.29	-38	262,392.39	848,002.42
J-468	1,729.18	-33	262,713.26	848,096.32
J-469	1,708.09	-94	262,416.77	847,863.32
J-470	1,710.26	-100	262,464.96	847,670.41
J-471	1,706.94	21	262,481.29	847,566.40
J-472	1,700.37	-106	262,576.35	847,188.29
J-473	1,705.63	42	262,610.62	847,065.65
J-474	1,699.55	-55	262,649.31	846,923.01
J-475	1,697.50	-71	262,094.43	846,625.81
J-476	1,698.61	-103	260,872.05	847,836.66
J-477	1,712.15	-139	260,769.50	847,627.90
J-478	1,693.05	-158	264,148.01	847,774.72
J-479	1,712.76	-270	260,786.29	847,591.92
J-480	1,708.05	10	262,355.04	848,448.34
J-481	1,722.67	12	260,725.34	847,490.32
J-482	1,715.72	64	262,044.05	848,455.57
J-483	1,729.27	10	260,688.36	847,414.58
J-484	1,731.87	-3	261,861.43	848,687.63
J-485	1,724.95	-9	260,641.76	847,367.78
J-486	1,709.31	7	259,691.23	848,291.25
J-487	1,720.14	16	260,570.14	847,452.06
J-488	1,728.44	14	260,474.67	847,497.44

J-489	1,736.07	13	258,379.59	848,890.00
J-490	1,728.45	6	260,451.74	847,544.25
J-491	1,733.69	-1	260,423.66	847,639.36
J-492	1,729.98	-107	260,404.83	847,729.20
J-493	1,726.35	75	260,407.82	847,889.95
J-494	1,730.15	-110	260,515.28	848,174.15
J-495	1,706.26	-115	260,785.37	847,851.42
J-496	1,707.81	-117	260,717.39	847,857.72
J-497	1,713.09	42	260,648.71	847,869.02
J-498	1,716.00	-66	260,574.90	847,873.79
J-499	1,694.05	-31	261,064.53	847,810.97
J-500	1,700.90	-15	260,970.39	847,823.00
J-501	1,729.26	-14	259,792.71	849,108.47
J-502	1,726.67	-64	259,986.24	848,782.67
J-503	1,727.45	65	260,025.13	848,741.68
J-504	1,707.76	40	259,980.89	848,644.24
J-505	1,726.13	-92	260,084.53	848,543.16
J-506	1,741.14	-218	260,132.71	848,878.10
J-507	1,719.92	10	260,387.86	848,916.72
J-508	1,722.80	14	260,511.03	848,849.35
J-509	1,719.93	-46	260,612.52	848,874.71
J-510	1,737.68	-16	260,174.46	848,769.52
J-511	1,733.25	-32	260,496.97	848,214.07
J-512	1,722.00	-54	260,282.23	848,021.96
J-513	1,712.09	60	260,816.74	848,917.42
J-514	1,717.92	-114	260,166.81	847,928.84
J-515	1,717.02	49	260,126.23	847,884.47
J-516	1,740.05	40	260,194.22	848,626.35
J-517	1,726.12	-33	260,298.35	848,539.52
J-518	1,733.71	-11	259,950.55	849,063.83
J-519	1,725.38	-39	260,007.04	849,149.42
J-520	1,737.04	-37	260,017.92	849,016.30
J-521	1,731.06	-42	260,026.86	848,810.22
J-522	1,708.04	-38	259,832.76	848,533.15
J-523	1,703.96	-40	259,772.15	848,564.03
J-524	1,706.49	96	259,655.76	848,534.27
J-525	1,728.82	-21	260,371.70	848,103.11
J-526	1,719.29	-26	260,630.39	848,780.96
J-527	1,724.42	65	260,387.05	848,710.12
J-528	1,706.70	-40	260,873.93	847,643.12
J-529	1,710.05	81	260,912.74	847,557.34

J-530	1,702.93	2	260,981.92	847,444.34
J-531	1,726.23	92	264,559.45	848,181.50
J-532	1,712.09	97	259,727.98	848,669.57
J-533	1,702.16	9	259,559.46	848,764.81
J-534	1,712.73	25	259,075.86	848,718.34
J-535	1,725.24	59	258,741.41	848,820.15
J-536	1,727.00	-40	258,570.72	848,858.93
J-537	1,722.46	-14	258,616.05	848,999.83
J-538	1,706.01	-38	262,153.33	846,346.53
J-539	1,707.41	-141	262,440.44	846,331.68
J-540	1,706.12	-14	262,521.51	846,330.42
J-541	1,709.17	-37	262,769.63	846,304.46
J-542	1,718.95	-11	262,871.11	846,383.66
J-543	1,702.46	-9	262,258.43	846,061.52
J-544	1,702.03	-7	262,247.26	845,957.94
J-545	1,701.43	-109	262,098.87	845,710.43
J-546	1,704.44	-18	262,084.02	845,561.92
J-547	1,710.83	-65	262,029.57	845,396.09
J-548	1,719.31	-121	261,934.86	845,211.53
J-549	1,687.93	-39	261,121.98	847,246.82
J-550	1,686.44	-38	261,200.36	847,122.03
J-551	1,698.84	-23	261,203.16	847,027.76
J-552	1,699.22	-52	261,230.79	846,960.77
J-553	1,702.69	-37	262,161.32	847,238.64
J-554	1,747.31	30	259,822.75	850,295.35
J-555	1,710.79	34	259,912.59	848,519.70
J-556	1,715.69	47	259,982.15	848,467.68
J-557	1,723.89	45	260,349.81	848,373.30
J-558	1,725.90	21	260,426.48	848,276.71
J-559	1,715.87	26	259,973.41	848,479.85
J-560	1,714.12	32	264,337.19	848,006.37
J-561	1,707.11	-47	259,332.98	848,741.07
J-562	1,694.54	-46	261,801.15	846,378.29
J-563	1,699.89	-31	262,629.28	846,808.37
J-564	1,696.30	-41	262,608.75	846,660.88
J-565	1,706.22	-37	263,121.10	846,262.38
J-566	1,733.28	-35	261,831.77	845,005.62
J-567	1,702.78	7	261,482.11	845,526.24
J-568	1,713.18	7	260,123.28	847,746.80
J-569	1,713.36	-37	259,366.62	848,020.76
J-570	1,702.49	-80	259,601.50	848,540.75

J-571	1,718.15	-124	262,807.99	847,844.85
J-572	1,711.71	-41	261,718.96	847,647.66
J-573	1,706.84	1	261,347.98	848,629.54
J-574	1,730.46	44	261,638.46	848,956.34
J-575	1,727.92	-12	260,414.24	847,685.96
J-576	1,724.73	56	260,031.53	849,199.68
J-577	1,719.83	59	259,915.29	849,269.61
J-578	1,726.22	57	260,259.23	848,950.27
J-579	1,728.66	34	260,407.34	848,827.68
J-580	1,733.09	0	260,232.26	848,597.60
J-581	1,716.47	11	260,883.69	848,918.83
J-582	1,714.64	-4	265,521.96	847,162.77
J-583	1,717.77	-9	260,121.17	851,030.91

Appendix B; Existing water supply distribution network pipe in Jimma Town causes maximum flow

Pipe table at 7:00 AM (Morning)					
Label	Start Node	Stop Node	Diameter(m)	Material	Velocity (m/s)
P-10	J-123	J-124	600	Ductile Iron	1.18
P-100	J-164	J-165	600	Ductile Iron	0.15
P-101	J-165	J-166	600	Ductile Iron	2.14
P-102	J-166	J-139	600	Ductile Iron	2.65
P-103	J-484	J-167	600	Ductile Iron	1.3
P-104	J-167	J-168	600	Ductile Iron	1.31
P-105	J-168	J-169	600	Ductile Iron	1.32
P-106	J-169	J-165	600	Ductile Iron	2.12
P-107	J-169	J-170	600	Ductile Iron	1.79
P-108	J-170	J-147	600	Ductile Iron	1.78
P-109	J-152	J-4	500	PVC	0.29
P-11	J-124	J-125	500	PVC	1.18
P-110	J-4	J-5	500	PVC	0.3
P-111	J-5	J-171	500	PVC	0.3
P-112	J-171	J-172	500	PVC	0.31
P-113	J-172	J-173	500	PVC	0.33
P-114	J-173	J-174	500	PVC	0.33
P-115	J-174	J-175	500	Ductile Iron	0.34
P-116	J-175	J-176	500	PVC	0.34
P-117	J-176	J-177	250	PVC	0.35

P-118	J-177	J-178	250	PVC	0.35
P-119	J-178	J-149	250	PVC	0.36
P-12	J-126	J-127	250	PVC	1.68
P-120	J-146	J-166	250	PVC	2.11
P-121	J-179	St.Gebrael	250	PVC	0.59
P-122	J-179	J-6	250	PVC	0.6
P-123	J-6	J-424	400	PVC	0.6
P-125	J-425	J-7	400	PVC	0.6
P-126	J-180	J-426	400	PVC	0.59
P-127	J-426	J-427	400	PVC	0.59
P-128	J-427	J-181	400	PVC	0.59
P-129	J-181	J-428	400	PVC	0.59
P-13	J-127	J-128	400	PVC	1.68
P-130	J-428	J-182	400	PVC	0.59
P-131	J-182	J-183	400	PVC	0.6
P-132	J-183	J-184	300	PVC	3.01
P-133	J-184	J-8	300	PVC	3.02
P-134	J-8	J-464	300	PVC	3.01
P-135	J-464	J-462	300	PVC	3
P-136	J-462	J-185	300	PVC	3.01
P-137	J-185	J-186	300	PVC	3.01
P-138	J-186	J-187	400	PVC	3.01
P-139	J-187	J-188	400	PVC	3.01
P-14	J-128	J-129	400	PVC	1.68
P-140	J-188	J-9	400	PVC	3.01
P-141	J-9	J-189	400	PVC	3.01
P-142	J-189	J-190	400	PVC	3.01
P-143	J-190	J-191	250	PVC	2.71
P-144	J-191	J-149	400	PVC	1.95
P-145	J-8	J-460	200	PVC	0.06
P-146	J-460	J-192	200	PVC	0.8
P-147	J-193	J-194	200	PVC	0.38
P-148	J-194	J-10	150	PVC	0.62
P-149	J-462	J-10	200	PVC	0.4
P-15	J-129	J-441	200	PVC	1.68
P-150	J-197	J-67	200	PVC	1.87
P-151	J-106	J-107	200	PVC	0.77
P-152	J-116	J-197	100	PVC	1.51
P-153	J-52	J-95	100	PVC	1.06
P-154	J-83	J-84	100	PVC	0.88
P-155	J-68	J-49	250	PVC	0.01

P-156	J-195	J-13	250	PVC	0.36
P-157	J-82	J-83	250	PVC	0.88
P-158	J-101	J-104	80	PVC	0.32
P-16	J-441	J-442	80	PVC	1.68
P-160	J-100	J-47	100	PVC	0.05
P-161	J-72	J-199	250	PVC	0.1
P-162	J-207	J-574	250	PVC	0.3
P-163	J-200	J-203	250	PVC	0.1
P-164	J-199	J-201	250	PVC	0.1
P-165	J-66	J-206	300	PVC	0.4
P-166	J-94	J-196	300	PVC	1.19
P-167	J-93	J-157	300	PVC	1.25
P-168	J-160	J-93	300	PVC	1.21
P-169	J-96	J-48	300	PVC	0.96
P-17	J-442	J-453	200	PVC	1.68
P-170	J-70	J-202	200	PVC	0.1
P-172	J-206	J-205	300	PVC	0.4
P-173	J-203	J-72	300	PVC	0.14
P-174	J-12	J-11	150	PVC	0.29
P-176	J-198	J-50	150	PVC	0.4
P-177	J-69	J-116	300	PVC	0.08
P-178	J-81	J-82	150	PVC	0.88
P-179	J-93	J-94	150	PVC	0.09
P-18	J-453	J-443	150	PVC	1.68
P-180	J-47	J-104	80	PVC	0.02
P-181	J-201	J-51	80	PVC	0.4
P-182	J-196	J-52	150	PVC	1.12
P-183	J-104	J-71	150	PVC	0.01
P-184	J-574	J-158	100	PVC	0.3
P-185	J-157	J-99	200	PVC	0.71
P-186	J-87	J-160	200	PVC	4.2
P-187	J-202	J-200	200	PVC	0.46
P-188	J-11	J-70	400	PVC	0.32
P-189	J-66	J-207	200	PVC	0.3
P-19	J-443	J-130	200	PVC	1.68
P-190	J-48	J-73	200	PVC	1
P-191	Hospital Reservoir	J-81	200	PVC	0.88
P-192	J-102	J-70	150	PVC	0.74
P-193	J-67	J-159	150	PVC	0.74
P-194	J-159	J-195	200	PVC	0.8
P-195	J-113	J-114	200	PVC	0.89

P-196	J-99	J-100	200	PVC	0.71
P-197	J-158	J-12	200	PVC	0.29
P-198	J-205	J-204	200	PVC	0.4
P-199	J-100	J-101	200	PVC	0.72
P-2	J-118	J-119	200	PVC	1.88
P-20	J-130	J-131	200	PVC	1.68
P-200	J-101	J-102	200	PVC	0.47
P-201	J-193	J-458	200	PVC	0.12
P-202	J-458	J-464	200	PVC	0.43
P-203	J-191	J-209	400	PVC	0.92
P-204	J-209	J-210	300	PVC	0.93
P-205	J-210	J-211	300	PVC	0.93
P-206	J-211	J-429	300	PVC	0.93
P-207	J-429	J-212	300	PVC	1.92
P-208	J-212	J-213	300	PVC	1.95
P-209	J-213	J-145	300	PVC	1.97
P-21	J-413	J-132	300	PVC	1.27
P-210	J-212	J-476	300	PVC	0.03
P-211	J-476	J-214	300	PVC	1.73
P-212	J-477	J-479	300	PVC	0.7
P-213	J-479	J-216	300	PVC	0.7
P-214	J-216	J-481	300	PVC	0.86
P-215	J-481	J-483	300	PVC	0.86
P-216	J-483	J-485	300	PVC	0.86
P-217	J-485	J-487	300	PVC	0.86
P-22	J-132	J-414	300	PVC	1.27
P-220	J-490	J-14	300	PVC	0.26
P-221	J-14	J-15	300	PVC	1.6
P-222	J-15	J-491	300	PVC	1.02
P-223	J-491	J-575	300	PVC	0.57
P-224	J-575	J-492	300	PVC	0.64
P-225	J-492	J-16	300	PVC	0.64
P-226	J-16	J-493	250	PVC	1.11
P-227	J-493	J-494	80	PVC	0.23
P-228	J-494	J-212	80	PVC	0.61
P-229	J-476	J-495	80	PVC	0.05
P-23	J-414	J-415	80	PVC	1.27
P-230	J-495	J-496	80	PVC	0.47
P-231	J-496	J-497	100	PVC	0.13
P-232	J-497	J-498	100	PVC	0.05
P-233	J-498	J-493	100	PVC	0.05

P-234	J-213	J-499	100	PVC	0.5
P-235	J-499	J-500	300	PVC	0.12
P-236	J-500	J-476	100	PVC	0.12
P-237	J-464	J-456	100	PVC	0.02
P-238	J-456	J-17	300	PVC	0.01
P-239	J-17	J-219	100	PVC	0.51
P-24	J-415	J-416	80	PVC	1.27
P-240	J-219	J-576	200	PVC	0.06
P-241	J-576	J-577	200	PVC	0.01
P-242	J-577	J-220	200	PVC	0.03
P-243	J-220	J-501	200	PVC	0.01
P-244	J-501	J-18	200	PVC	0.04
P-245	J-18	J-19	100	PVC	0
P-246	J-19	J-502	200	PVC	0.03
P-247	J-502	J-503	200	PVC	0.1
P-248	J-503	J-504	100	PVC	0.11
P-249	J-504	J-505	100	PVC	0.24
P-25	J-133	J-417	100	PVC	1.26
P-251	J-219	J-578	100	PVC	0.09
P-252	J-578	J-506	100	PVC	0.01
P-253	J-219	J-507	100	PVC	0.27
P-254	J-507	J-579	100	PVC	0.22
P-255	J-579	J-508	300	PVC	0.37
P-256	J-508	J-509	80	PVC	0.37
P-259	J-222	J-510	80	PVC	0.04
P-26	J-417	J-62	200	PVC	1.26
P-260	J-510	J-503	100	PVC	0.32
P-261	J-224	J-225	100	PVC	2.44
P-262	J-225	J-429	200	PVC	1.7
P-263	J-429	J-20	200	PVC	0.1
P-264	J-512	J-514	200	PVC	0.83
P-265	J-514	J-515	200	PVC	0.83
P-266	J-515	J-568	200	PVC	0.83
P-267	J-505	J-21	200	PVC	0.82
P-268	J-21	J-226	100	PVC	1.14
P-269	J-226	J-516	300	PVC	1.22
P-27	J-62	J-46	200	PVC	1.26
P-270	J-516	J-580	100	PVC	0.77
P-271	J-580	J-517	100	PVC	0.77
P-272	J-19	J-22	150	PVC	0.04
P-273	J-22	J-518	200	PVC	0.03

P-274	J-518	J-519	200	PVC	0.03
P-275	J-519	J-576	200	PVC	0.03
P-276	J-518	J-520	200	PVC	0
P-277	J-520	J-227	200	PVC	0
P-278	J-227	J-506	80	PVC	0.02
P-279	J-506	J-521	80	PVC	0.01
P-280	J-521	J-502	150	PVC	0.01
P-281	J-22	J-521	150	PVC	0.02
P-282	J-555	J-522	150	PVC	1.2
P-283	J-522	J-523	150	PVC	0.91
P-284	J-523	J-524	200	PVC	0.62
P-285	J-524	J-570	300	PVC	0.65
P-286	J-511	J-525	300	PVC	0.83
P-287	J-525	J-512	200	PVC	0.83
P-288	J-509	J-526	200	PVC	0.4
P-289	J-516	J-228	100	PVC	0.33
P-29	J-1	J-2	100	PVC	1.85
P-290	J-228	J-527	100	PVC	1.02
P-291	J-221	J-513	100	PVC	0.92
P-292	J-513	J-581	100	PVC	0.92
P-293	J-581	J-229	150	PVC	0.03
P-294	J-229	J-230	150	PVC	0.86
P-295	J-190	J-231	150	PVC	2.42
P-296	J-231	J-223	150	PVC	2.44
P-297	J-230	J-231	150	PVC	0.8
P-298	J-477	J-528	150	PVC	0.7
P-299	J-528	J-529	150	PVC	0.68
P-3	J-119	J-120	150	PVC	1.88
P-30	J-2	J-3	150	PVC	1.85
P-300	J-84	J-85	150	PVC	0.88
P-300-B	J-529	J-530	150	PVC	0.74
P-301	J-511	J-494	200	PVC	1.6
P-302	J-85	J-86	100	PVC	0.88
P-303	J-86	J-87	100	PVC	0.88
P-304	J-90	J-91	100	PVC	1.27
P-305	J-91	J-418	100	PVC	1.27
P-306	J-95	J-215	100	PVC	0.87
P-307	J-215	J-96	100	PVC	1.26
P-308	J-73	J-217	100	PVC	0.02
P-309	J-217	J-68	100	PVC	0.01
P-31	J-3	J-134	100	PVC	1.85

P-310	J-108	J-109	100	PVC	0.67
P-311	J-109	J-75	100	PVC	0.81
P-312	J-445	J-560	150	PVC	2.13
P-313-b	J-560	J-138	150	PVC	2.13
P-314	J-25	J-42	80	PVC	0.84
P-314-B	J-533	J-561	80	PVC	1.21
P-315	J-561	J-534	80	PVC	1.11
P-316	J-424	J-440	80	PVC	0.53
P-317	J-440	J-425	80	PVC	0.6
P-318	BOYE	Boye WTP (Old TP)	150	PVC	4.94
P-319	J-31	J-241	100	PVC	0.73
P-32	J-134	J-135	100	PVC	1.85
P-320	J-383	Aba Jifar Reservoir 1	150	PVC	0.72
P-321	J-126	J-35	100	PVC	0.02
P-322	J-35	J-1	100	PVC	0.02
P-323	J-419	J-34	150	PVC	1.13
P-324	J-34	J-421	150	PVC	1.13
P-325	J-151	J-66	200	PVC	0.59
P-326	JK PR Tank	J-218	200	PVC	1.18
P-327	J-218	J-122	200	PVC	1.18
P-328	J-243	J-36	100	PVC	0.83
P-329	J-42	J-242	100	PVC	0.85
P-33	J-135	J-136	100	PVC	1.85
P-330	J-24	J-244	250	PVC	0.85
P-332	J-43	J-246	250	PVC	0.86
P-333	J-26	J-235	150	PVC	0.85
P-335	J-242	J-28	150	PVC	0.85
P-336	J-247	J-29	150	PVC	0.73
P-337	J-29	J-23	150	PVC	0.74
P-338	J-28	J-243	200	PVC	0.85
P-34	J-136	J-137	200	PVC	1.85
P-340	J-254	J-255	200	PVC	8.78
P-341	J-249	J-252	200	PVC	8.78
P-342	J-253	J-250	200	PVC	8.78
P-343	J-251	J-249	150	PVC	8.78
P-344	J-252	J-254	150	PVC	8.78
P-345	J-255	J-253	150	PVC	8.78
P-346	J-250	J-248	150	PVC	8.78
P-347	J-257	J-264	100	PVC	0.61
P-348	J-263	J-265	100	PVC	0.92
P-349	J-265	J-262	100	PVC	0.69

P-35	J-446	J-447	100	PVC	1.84
P-350	J-279	J-266	100	PVC	0.63
P-351	J-271	J-277	150	PVC	0.82
P-352	J-270	J-257	80	PVC	0.71
P-353	J-16	J-274	80	PVC	0.72
P-354	J-273	J-275	80	PVC	0.67
P-355	J-264	J-278	80	PVC	0.63
P-356	J-272	J-271	150	PVC	0.63
P-357	J-269	J-270	150	PVC	0.53
P-358	J-278	J-260	100	PVC	0.7
P-359	J-274	J-269	80	PVC	0.77
P-36	J-447	J-448	80	PVC	1.84
P-360	J-275	J-16	200	PVC	0.72
P-361	J-17	J-273	200	PVC	0.61
P-363	J-260	J-267	200	PVC	0.74
P-364	J-267	J-272	200	PVC	0.76
P-365	J-261	J-263	250	PVC	0.28
P-366	J-307	J-289	250	PVC	1.2
P-367	J-280	J-314	200	PVC	1.2
P-368	J-314	J-307	150	PVC	1.2
P-369	J-287	J-313	50	HDPE	1.13
P-37	J-448	J-455	300	PVC	1.84
P-370	J-63	J-287	50	HDPE	1.13
P-371	J-291	J-311	200	PVC	1.2
P-372	J-311	J-316	100	PVC	1.2
P-373	J-292	J-297	300	PVC	0.83
P-374	J-293	J-63	100	PVC	1.13
P-375	J-305	J-296	300	PVC	0.83
P-376	J-310	J-286	300	PVC	1.2
P-377	J-290	J-292	300	PVC	7.49
P-378	J-283	J-284	200	PVC	1.2
P-379	J-286	J-302	300	PVC	0.91
P-38	J-455	J-457	100	PVC	0.79
P-380	J-294	J-286	100	PVC	0.79
P-381	J-315	J-305	200	PVC	0.83
P-382	J-289	J-303	100	PVC	1.2
P-383	J-288	J-298	100	PVC	0.83
P-384	J-306	J-281	100	PVC	0.79
P-385	J-300	J-312	300	PVC	1.2
P-386	J-282	J-280	100	PVC	1.2
P-387	Jiren Kela Reservoir 2	J-290	300	PVC	7.49

P-388	J-312	J-283	100	PVC	1.2
P-389	J-296	J-288	100	PVC	0.83
P-39	J-457	J-459	100	PVC	0.79
P-390	J-284	J-291	100	PVC	1.2
P-391	J-302	J-285	400	PVC	0.91
P-392	J-309	J-304	100	PVC	0.83
P-393	J-303	J-310	400	PVC	1.2
P-394	J-298	J-301	100	PVC	0.83
P-395	J-308	J-315	200	PVC	0.83
P-396	J-281	J-294	100	PVC	0.79
P-397	J-297	J-309	200	PVC	0.83
P-398	J-304	J-308	100	PVC	0.83
P-399	J-301	J-299	300	PVC	0.83
P-4	J-120	J-121	150	PVC	1.88
P-40	J-459	J-419	300	PVC	0.79
P-400	J-293	J-295	100	PVC	6.16
P-401	J-299	J-300	500	Ductile Iron	0.83
P-402	J-295	J-306	150	PVC	6.16
P-403	J-316	J-282	100	PVC	1.2
P-404	J-324	J-328	500	GS	1.68
P-405	J-317	J-319	150	Ductile Iron	0.68
P-406	J-327	J-324	100	PVC	1.68
P-407	J-334	J-317	400	PVC	0.68
P-408	J-333	AERATOR	100	PVC	0.68
P-409	J-323	J-333	400	PVC	0.68
P-41	J-419	J-92	100	PVC	6.08
P-410	J-332	J-329	100	PVC	0.68
P-412	J-326	J-330	100	PVC	3.78
P-413	J-320	J-322	250	PVC	1.68
P-414	J-325	J-334	100	PVC	0.68
P-416	J-331	J-318	200	PVC	0.68
P-417	J-319	J-323	150	PVC	0.68
P-418	J-318	J-332	600	Ductile Iron	0.68
P-419	Raw water tank	PMP-3	80	PVC	2.15
P-42	J-92	J-420	600	Ductile Iron	0.68
P-420	J-329	J-321	100	PVC	0.68
P-421	J-330	J-320	100	PVC	1.68
P-422	J-331	J-326	100	PVC	3.78
P-423	J-321	J-335	100	PVC	0.68
P-424	J-335	J-325	100	PVC	0.68
P-425	J-328	J-336	100	PVC	1.68

P-428	J-116	J-74	150	PVC	0.01
P-429	J-313	Hospital Reservoir	100	PVC	1.13
P-43	J-420	J-418	80	PVC	0.85
P-430	J-277	J-337	80	PVC	0.59
P-431	J-337	J-279	100	PVC	0.61
P-434	J-59	J-60	100	PVC	1.69
P-435	J-60	J-430	600	Ductile Iron	1.69
P-436	J-421	J-432	600	Ductile Iron	1.13
P-437	J-432	J-431	600	Ductile Iron	1.13
P-438	J-431	J-433	600	Ductile Iron	1.13
P-44	J-478	J-452	600	Ductile Iron	2.13
P-440	J-338	New treatment plant	600	Ductile Iron	19.58
P-441	J-582	J-339	600	Ductile Iron	1.83
P-442	J-339	J-1	150	DCI	1.83
P-447	J-341	J-251	150	DCI	8.78
P-45	J-452	J-461	150	DCI	1.87
P-453	New tp clearwater tank	PMP-7	150	DCI	2.74
P-455	J-342	J-343	150	DCI	1.54
P-456	J-343	T-3	150	DCI	1.54
P-459	J-345	J-582	150	DCI	1.83
P-46	J-461	J-463	150	DCI	1.73
P-465	J-336	Boye WTP (Old TP)	150	DCI	1.68
P-468	J-65	J-87	150	DCI	1.27
P-47	J-455	J-449	150	DCI	1.53
P-470	J-445	J-531	150	DCI	2.13
P-471	J-531	J-444	150	DCI	2.13
P-472	J-444	J-413	150	DCI	1.27
P-473	J-131	J-444	150	DCI	1.68
P-474	J-478	J-138	150	DCI	2.13
P-475	J-44	J-146	150	DCI	1.02
P-476	J-49	J-97	150	DCI	0.01
P-478	J-75	J-76	150	DCI	0.81
P-479	J-69	J-114	500	Ductile Iron	1.51
P-48	J-449	J-466	500	Ductile Iron	1.8
P-480	J-111	J-346	500	Ductile Iron	0.01
P-481	J-346	J-347	350	Ductile Iron	0.01
P-482	J-347	J-348	350	Ductile Iron	0.02
P-483	J-348	J-349	500	Ductile Iron	0.03
P-484	J-349	J-350	500	Ductile Iron	0.04
P-485	J-76	J-103	500	Ductile Iron	0.84
P-486	J-103	J-113	350	Ductile Iron	0.72

P-487	J-350	J-103	500	Ductile Iron	0.06
P-488	J-351	J-352	500	Ductile Iron	0.13
P-489	J-434	J-353	500	Ductile Iron	0.04
P-49	J-467	J-139	500	Ductile Iron	2.98
P-490	J-353	J-354	300	Ductile Iron	0.05
P-491	J-435	J-355	350	Ductile Iron	0.08
P-492	J-355	J-78	500	Ductile Iron	0.06
P-493	J-78	J-434	500	Ductile Iron	0.02
P-494	J-583	J-356	500	Ductile Iron	0.08
P-495	J-356	J-115	350	Ductile Iron	0.09
P-496	J-115	J-357	500	Ductile Iron	0.11
P-497	J-78	J-98	500	Ductile Iron	0.04
P-498	J-358	J-359	500	Ductile Iron	0.02
P-499	J-352	J-435	500	Ductile Iron	0.11
P-5	J-121	J-155	500	Ductile Iron	1.88
P-50	J-139	J-44	500	Ductile Iron	1.3
P-500	J-435	J-358	300	Ductile Iron	0.03
P-501	J-13	J-77	500	Ductile Iron	0.31
P-502	J-117	J-118	500	Ductile Iron	16.92
P-503	J-361	J-532	500	Ductile Iron	1.37
P-504	J-532	J-533	500	Ductile Iron	1.29
P-506	J-534	J-360	350	Ductile Iron	1.1
P-507	J-360	J-362	500	Ductile Iron	1.1
P-508	J-362	J-363	500	Ductile Iron	1.1
P-509	J-363	J-535	500	Ductile Iron	1.1
P-51	J-466	J-468	350	Ductile Iron	1.93
P-510	J-535	J-364	500	Ductile Iron	1.1
P-511	J-364	J-536	350	Ductile Iron	1.1
P-512	J-536	J-488	500	Ductile Iron	1.1
P-513	J-488	J-365	400	Ductile Iron	0.98
P-514	J-365	J-436	500	Ductile Iron	0.36
P-515	J-361	J-504	400	Ductile Iron	0.82
P-516	J-534	J-369	500	Ductile Iron	2.17
P-518	J-368	J-367	500	Ductile Iron	1.5
P-519	J-367	J-45	500	Ductile Iron	1.26
P-52	J-449	J-450	500	Ductile Iron	1.04
P-520	J-366	J-489	400	Ductile Iron	0.63
P-521	J-537	J-370	400	Ductile Iron	1.5
P-522	J-370	J-371	400	Ductile Iron	1.02
P-523	J-371	J-437	500	Ductile Iron	0.49
P-524	J-538	J-539	400	Ductile Iron	0.93

P-525	J-539	J-564	500	Ductile Iron	0.03
P-526	J-539	J-540	500	Ductile Iron	0.85
P-527	J-540	J-372	500	Ductile Iron	0.73
P-528	J-372	J-541	400	Ductile Iron	0.65
P-529	J-541	J-542	500	Ductile Iron	0.66
P-53	J-450	J-451	400	Ductile Iron	1.04
P-530	J-542	J-565	400	Ductile Iron	0.89
P-531	J-475	J-538	500	Ductile Iron	0.81
P-532	J-538	J-373	500	Ductile Iron	0.65
P-533	J-373	J-543	400	Ductile Iron	0.71
P-534	J-543	J-544	500	Ductile Iron	0.61
P-535	J-544	J-374	500	Ductile Iron	0.66
P-536	J-374	J-375	200	PVC	0.68
P-537	J-375	J-545	350	Ductile Iron	0.68
P-538	J-545	J-546	150	Ductile Iron	0.68
P-539	J-546	J-547	150	Ductile Iron	0.62
P-54	J-451	J-452	300	Ductile Iron	1.04
P-540	J-547	J-548	150	DCI	0.67
P-541	J-548	J-376	100	PVC	0.92
P-542	J-376	J-567	100	PVC	0.75
P-543	J-530	J-549	250	Ductile Iron	0.67
P-544	J-549	J-550	250	Ductile Iron	0.74
P-545	J-550	J-551	250	Ductile Iron	0.64
P-546	J-551	J-552	500	Ductile Iron	0.64
P-547	J-552	J-377	500	Ductile Iron	0.69
P-548	J-377	J-378	400	PVC	0.67
P-549	J-378	J-379	400	PVC	0.68
P-550	J-379	J-380	600	Ductile Iron	1.27
P-551	J-380	J-562	350	GS	0.6
P-552	J-57	J-55	350	GS	1.69
P-553	J-55	J-58	250	GS	1.69
P-554	J-77	J-351	600	Ductile Iron	0.15
P-555	J-583	J-354	250	GS	0.07
P-556	J-152	J-381	350	GS	0.29
P-557	J-381	J-70	250	GS	0.72
P-56	J-466	J-571	150	GS	0.99
P-560	J-382	J-384	150	GS	0.68
P-562	J-238	J-385	200	Ductile Iron	0.87
P-563	J-385	J-32	200	Ductile Iron	0.87
P-564	J-266	J-386	500	GS	0.67
P-565	J-386	J-17	300	GS	0.75

P-566	J-32	J-33	400	PVC	0.89
P-567	J-387	J-266	300	GS	0.61
P-568	J-33	J-388	300	GS	0.89
P-569	J-388	J-39	300	GS	0.91
P-570	J-256	J-389	300	GS	0.67
P-571	J-389	J-387	300	GS	0.75
P-572	J-40	J-237	400	Ductile Iron	1.05
P-573	J-262	J-390	300	Ductile Iron	0.82
P-574	J-390	J-391	400	PVC	0.7
P-575	J-391	J-256	400	PVC	0.81
P-580	J-234	J-393	250	PVC	1.69
P-581	J-393	J-394	500	PVC	1.69
P-582	J-394	J-54	400	Ductile Iron	1.69
P-583	J-430	J-61	250	PVC	1.69
P-584	J-61	J-46	100	PVC	1.69
P-585	J-153	J-395	100	PVC	0.69
P-586	J-395	J-381	150	PVC	0.99
P-587	J-396	J-72	50	PVC	0.4
P-588	J-397	J-396	50	PVC	0.4
P-589	J-50	J-398	50	PVC	0.62
P-59	J-467	J-469	50	PVC	1.89
P-590	J-398	J-397	50	PVC	0.62
P-591	J-204	J-79	150	PVC	0.4
P-592	J-79	J-198	150	PVC	0.4
P-593	J-51	J-399	50	PVC	0.39
P-594	J-399	J-69	100	PVC	0.6
P-595	J-463	J-553	50	PVC	1.15
P-596	J-553	J-465	50	PVC	1.15
P-597	J-468	J-400	100	PVC	1.83
P-598	J-400	J-467	100	PVC	1.53
P-599	J-480	J-400	100	PVC	0.77
P-60	J-469	J-470	50	PVC	1.89
P-600	J-104	J-105	50	PVC	0.22
P-601	J-105	J-106	100	PVC	0.54
P-602	J-97	J-401	100	PVC	0.02
P-603	J-401	J-76	50	PVC	0.02
P-604	J-76	J-110	100	PVC	0.01
P-605	J-357	J-77	50	PVC	0.13
P-606	J-67	J-403	100	PVC	1.05
P-607	J-403	J-404	600	Ductile Iron	0.04
P-608	J-404	J-402	200	PVC	0.04

P-609	J-402	J-405	200	PVC	0.04
P-61	J-470	J-471	200	PVC	1.89
P-610	J-405	J-112	200	PVC	0.04
P-611	J-112	J-80	200	PVC	0.03
P-612	J-7	J-232	200	PVC	0.6
P-613	J-232	J-180	200	PVC	0.59
P-614	J-80	J-232	200	PVC	0.03
P-615	J-192	J-454	200	PVC	0.15
P-616	J-454	J-193	200	PVC	0.94
P-617	J-194	J-556	200	PVC	0.71
P-618	J-556	J-486	200	PVC	0.71
P-619	J-537	J-406	80	PVC	1.32
P-62	J-471	J-463	80	PVC	1.89
P-620	J-406	J-366	80	PVC	1.89
P-621	J-45	J-407	80	PVC	0.96
P-622	J-407	J-409	80	PVC	1.5
P-623	J-409	J-537	50	PVC	0.83
P-624	J-223	J-224	50	PVC	2.44
P-625	J-214	J-411	50	PVC	1.06
P-626	J-411	J-528	80	PVC	1.06
P-627	J-517	J-557	80	HDPE	0.77
P-628	J-557	J-558	80	PVC	0.77
P-629	J-558	J-511	80	PVC	0.77
P-63	J-463	J-472	80	PVC	0.62
P-630	J-505	J-559	80	PVC	1
P-631	J-559	J-555	80	PVC	0.85
P-632	J-433	J-408	80	PVC	1.13
P-633	J-408	J-46	80	PVC	1.13
P-634	J-416	J-438	80	PVC	1.27
P-635	J-438	J-133	80	PVC	1.27
P-636	J-137	J-446	80	PVC	1.84
P-637	J-125	J-126	80	PVC	1.18
P-638	J-571	J-410	80	PVC	0.99
P-639	J-410	J-461	80	PVC	0.99
P-64	J-472	J-473	80	PVC	0.62
P-640	J-420	J-439	80	PVC	2.53
P-641	J-439	J-423	80	PVC	1.62
P-642	J-107	J-412	80	PVC	0.82
P-643	J-412	J-108	50	HDPE	0.82
P-644	J-548	J-566	50	HDPE	0.2
P-65	J-473	J-474	50	HDPE	0.62

P-66	J-44	J-572	50	HDPE	1.94
P-67	J-572	J-140	50	HDPE	1.94
P-68	J-140	J-465	50	HDPE	1.1
P-69	J-465	J-141	50	HDPE	0.76
P-7	J-156	JK PR Tank	50	HDPE	1.88
P-70	J-141	J-475	50	HDPE	0.81
P-71	J-474	J-563	80	PVC	0.62
P-72	J-44	J-142	80	PVC	1.16
P-73	J-142	J-143	100	PVC	1.16
P-74	J-143	J-144	50	PVC	1.15
P-75	J-144	J-145	200	PVC	1.15
P-76	J-145	J-146	200	Ductile Iron	1.17
P-77	J-146	J-147	150	DCI	2.84
P-78	J-147	J-573	150	DCI	2.04
P-79	J-573	J-148	150	DCI	2.04
P-80	J-148	J-149	100	PVC	2.04
P-81	J-149	J-150	100	PVC	0.63
P-82	J-150	J-151	150	DCI	0.6
P-84	J-65	J-88	150	DCI	1.27
P-85	J-88	J-89	100	PVC	1.27
P-87	J-20	J-154	150	DCI	0.1
P-88	J-154	J-511	100	PVC	0.13
P-89	J-89	J-90	100	PVC	1.27
P-9	J-122	J-123	150	DCI	1.18
P-91	J-418	J-422	150	DCI	3.77
P-92	J-422	J-161	100	PVC	1.67
P-93	J-161	J-480	150	DCI	1.68
P-94	J-480	J-162	150	DCI	1.6
P-95	J-162	J-484	150	DCI	1.57
P-96	J-484	J-163	100	PVC	1.02
P-97	J-163	J-153	100	PVC	1
P-98	J-423	J-468	150	DCI	1.62
P-99	J-482	J-164	150	DCI	0.04
P-517	J-369	J-368	200	PVC	1.82
P-250	J-486	J-190	200	PVC	0.71
P-411	J-322	J-327	200	PVC	1.68
P-258	J-222	J-579	100	PVC	0.04
P-257	J-509	J-221	100	PVC	0.03
P-439	J-338	AERATOR	200	PVC	19.58
P-446	PMP-1	J-341	200	PVC	0
P-450	PMP-5	J-341	200	PVC	9.96

P-454	J-342	PMP-7	200	PVC	2.74
P-462	PMP-9	J-345	200	PVC	1.62
P-464	PMP-10	J-345	200	PVC	1.62
P-415	PMP-3	J-331	200	PVC	2.15
P-25	New treatment plant	New tp clearwater tank	200	PVC	21.79
P-433	Ginjo Reservoir	PMP-2	200	PVC	0.27
P-432	J-285	Ginjo Reservoir	200	PVC	0.91
P-447	PMP-6	J-341	300	PVC	9.8
P-1	Jiren Kela Reservoir 1	J-117	300	PVC	16.92
P-32	J-248	Jiren Kela Reservoir 1	400	PVC	8.69
P-33	J-248	Jiren Kela Reservoir 2	400	PVC	13.29
P-41	J-3	Jiren Kela Reservoir 2	150	PVC	0.71
P-6	J-155	J-156	100	PVC	1.88
P-46	J-59	J-58	100	PVC	1.69
P-47	J-57	J-56	100	PVC	1.69
P-48	J-56	J-64	100	PVC	1.69
P-49	J-64	J-54	80	PVC	1.69
P-50	J-234	J-53	50	PVC	6.78
P-51	J-53	J-306	200	PVC	0.75
P-52	J-37	J-237	200	PVC	1.06
P-576	J-39	J-6	200	PVC	1.03
P-577	J-6	J-40	130	PVC	1.03
P-55	J-563	J-564	150	PVC	0.03
P-56	J-527	J-526	150	PVC	0.13
P-57	J-238	J-30	300	PVC	0.86
P-58	J-30	J-235	300	PVC	0.85
P-60	J-25	J-245	150	PVC	0.84
P-61	J-245	J-27	80	PVC	0.87
P-62	J-27	J-41	80	PVC	0.86
P-63	J-41	J-244	150	PVC	0.86
P-64	J-24	J-246	150	PVC	0.86
P-65	J-247	J-241	80	PVC	0.73
P-71	J-23	J-38	80	PVC	0.83
P-72	J-38	J-239	80	PVC	0.85
P-75	J-236	J-43	80	PVC	0.86
P-334	J-31	J-383	80	PVC	0.72
P-313	J-208	J-37	250	PVC	1.09
P-561	J-266	J-384	200	PVC	0.65
P-218	J-487	J-490	200	PVC	0.86
P-219	J-490	J-568	200	PVC	0.83

P-84	J-489	J-488	200	PVC	0.73
P-93	J-382	J-23	200	PVC	1.04
P-94	PMP-2	J-208	80	PVC	0.27
P-458	PMP-4	J-341	80	PVC	0
P-458	PMP-8	BOYE	250	Ductile Iron	1.43
P-461	PMP-9	BOYE	250	Ductile Iron	1.62
P-463	PMP-10	BOYE	250	PVC	1.62
P-646	PMP-12	BOYE	250	PVC	1.48
P-645	PMP-11	BOYE	400	PVC	1.59
P-110	PMP-8	J-7	600	Ductile Iron	0.64
P-111	J-7	Jiren Kela Reservoir 1	150	PVC	0.64
P-112	PMP-12	J-8	150	PVC	0.66
P-113	J-8	Jiren Kela Reservoir 1	100	PVC	0.66
P-114	PMP-11	J-9	100	PVC	0.71
P-115	J-9	J-3	100	PVC	0.71
P-116	New TP clear water tank	J-340	100	PVC	8.78
P-449	J-340	PMP-5	50	PVC	9.96
P-445	J-340	PMP-4	400	Ductile Iron	0
P-444	J-340	PMP-1	400	Ductile Iron	0
P-448	J-340	PMP-6	400	Ductile Iron	9.8
P-322	J-26	J-13	150	Ductile Iron	0.85
P-325	J-13	J-36	150	Ductile Iron	0.83
P-339	J-236	J-15	150	Ductile Iron	0.85
P-331	J-15	J-239	150	Ductile Iron	0.85

Appendix C; 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 D; Representation of flow value

Sampling point	Observed flow (m/s)	Computed flow (m/s)	Difference
P-113	0.63	0.66	0.03
P-408	0.85	0.68	0.17
P-419	2.5	2.15	0.35
P-453	2.67	2.74	0.37
P-112	0.96	0.66	0.2