JIMMA UNIVERSITY

JIMMA INSTITUTES OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDRAULIC ENGINEERING MASTER PROGRAM

EVALUATING HYDRAULIC PERFORMANCE OF EXISTING WATER SUPPLY DISTRIBUTION SYSTEM: A CASE STUDY ON ADDIS ZEMEN TOWN

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 HYDRAULIC ENGINEERING

By

BIRHAN ADDIS MULAT

OCTOBER, 2016

JIMMA, ETHIOPIA

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OCTOBER, 2016

JIMMA, ETHIOPIA

DECLARATION

I hereby declare that this thesis: "Evaluating hydraulic performance of existing water distribution supply system: The Case of Addis Zemen Town, Amhara Region, Ethiopia" is my own work and has not been submitted for any degree in any other university. It is being submitted for the degree of Master of Science in Hydraulic Engineering, and all sources of material used for this thesis have been dully acknowledged.

Name of candidate	Signature	Date

This thesis has been submitted for examination with my approval as University Supervisor

Name of Chairperson	Signature	Date
Name of Major Advisor	Signature	Date
Name of Co-Advisor	Signature	Date
Name of Internal Examiner	Signature	Date
Name of External Examiner	Signature	Date

ABSTRACT

Water distribution network (WDN) is the components of water supply system that needs to design carefully because of cost involved and its significance. However, in many of the developing countries, the hydraulic and physical performance of water distribution network is inadequate to meet consumers' demands and losses in system. Addis Zemen has been experiencing frequent and regular disruption of water supplies for days to a week. This study was conducted in Addis Zemen, to evaluate hydraulic performance of existing water supply distribution system of the town. Both primary and secondary data sources were used in this study. Primary data were collected though face-to-face interview with Addis Zemen Water Supply and Sewerage enterprise (AZWSSE) experts, field observations, photographs of relevant sites and infrastructures were taken. For secondary data collection, document review was used to collect valuable information. To analyze the data which is collected from different sources, both qualitative and quantitative methods was used. The computer software application that is Origin8 and excel was used to analyze the data obtained from office. The field survey data for distribution system was evaluated by using the engineering software called WaterCADv8i. The per capita domestic water consumption of Addis Zemen Town was found to be 12.98 l/c/d in the year 2015. The average water loss in Addis Zemen Town was 25.6%, showing that needs a matter of concern. 11.6% of the junctions were (>70 m) located around Michael area and Hospital due to low elevation. 1.9% of the junction was (<15 m) recorded 14 m around Hana due to high elevation.86.5% of the town that is the majority of the area has pressure within the optimum range (15-70 m) and the lowest velocity recorded was zero and the highest was 2.12 m/s during steady state analysis. 13.5% of the analyzed nodes get water at low pressure (<15 m), none of the node has pressure above 70m and only 86.5% have pressure within recommended limit (15 to 70 m) and velocity in major pipe parts was below 0.6 m/s during extended period simulation. The current water demand is 1398.68 m^3/day and the demand at end of design period of 2025 years would be around 2926.33 m^3/day. In order to achieve a 15 m minimum and 70 m maximum pressure, it is necessary to provide pressure controlling valve and establishing boosting station. Securing additional water supplies becomes an essential issue to meet the current water demand future demand.

Key words: *Hydraulic performance, Simulation, Water demand, Water distribution system and water losses.*

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ACRONYMES

ADSWE	Amhara Design and Supervision Works Enterprise
AWRDB	Amhara Water Resources Development Bureau
AWUP	African Water Utility Partnership
AWW	Amhara Water Works
AZTWDS	Addis Zemen Town Water Distribution System
AZWSSE	Addis Zemen Town Water Supply and Sewerage Enterprise
CIWD	Commercial and Institutional Water Demand
CSA	Central Statistical Agency
C^0	Degree Centigrade
DI	Ductile Iron
DOH	Development of Health
DWD	Domestic Water Demand
FWD	Fire Water Demand
GI	Galvanized Iron
GIS	Geographic Information System
GPS	Global Position System
HC	House Connection
HF	Head Friction
M.A.S.L	Mean above Sea Level
MDF	Maximum Day Factor
MM	Mile Meter
MOWR	Ministry Of Water Resource
MOWIE	Ministry OF Water, Irrigation and Electricity
NGOS	Non-Governmental Organizations

PHF	Peak Hour Factor
PTU	Public Tab User
PVC	Polyvinyl Chloride
PWS	Public Water System
TWD	Total water Demand
UFW	Unaccounted For Water
UWD	Unaccounted Water Demand
WDN	Water Distribution Network
WHO	World Health Organization
YCS	Yared connection Share

CHAPTER ONE

INTRODUCTION

1.1 Background

The distribution network is responsible for delivering water from the source or treatment facilities to its consumers at serviceable pressures and mainly consists of pipes, pumps, junctions (nodes), valves, fittings, and storage tanks. Water distribution networks play an important role in modern societies being its proper operation directly related to the population's well-being. However, water supply activities tend to be natural monopolies, so to guarantee good service levels in a sustainable way the water supply systems performance must be evaluated (Muranho et al., 2013). WDN is one of the components of water supply system that needs to design carefully because of cost involved and its significance. The main purpose of design of WDNs is to supply the required quantity of water at required time with sufficient pressure. But, in many of the developing countries, drinking water considered as probability of a node being connected to supplies are inadequate to meet consumers' demands. Water supply systems designed and operated as intermittent systems (Gottipati and Nanduri, 2014).

A completely satisfactory water distribution system should fulfill its basic requirements such as providing the expected quality and quantity of water during its entire lifetime for the expected loading conditions with the desired residual pressures (Misirdali, 2003).

WDS are required to supply water to domestic, commercial, and industrial entities above or at a threshold pressure with consumer demands that vary throughout the day, weak, season and year. The minimum pressure that should be observed at junctions throughout the system varies depending on the type of water consuming sector and regulations governing the distribution system (Hopkins, 2012).

Water distribution systems can be either looped or branched. Looped systems are generally more desirable than branched system because, in the looped system, breaking of pipe can be isolated and repaired with little impact on consumers outside the immediate area. On the other hand, in the branched system, all the consumers downstream from the break will have their water supply interrupted until the repairs are finished (Atiquzzaman, 2004).

Water supply and distribution systems serve many critical functions and play a large part in achieving human and economic health. Despite this, the performance of these systems often goes unnoticed until there is a major disruption or operational failure. While failure events are likely inevitable and often dramatic and costly, the day-to-day inefficient performance of a water distribution system. WDS also entails great economic, social and environmental burdens. Performance measurement is a key issue in engineering the behavior and control of any WDS. The most common challenges in water distribution networks include water quality degradation, capacity shortages, infrastructure aging and deterioration, demand increases, and their ever- increasing energy consumption coupled to the global energy crisis (Jalal, 2008).

In water utility systems, significant amount of water is lost as leakage while in transport from source up to consumers. Water loss represents inefficiency in water delivery and measurement operations in rising main and distribution networks. By acquiring a continuous water supply, cities in the developing world must ensure that their water systems become more efficient and effective by reducing water losses, gradually increasing water tariffs, improving revenue Collection, increasing staff productivity, and securing safe and reliable water supplies. When the productivity increased, investments in new infrastructure will lead to more effective and efficient water services (Dighade et al., 2014).

Because of rapid population growth and high water losses from the distribution network, the total water demand of the system in many developing countries exceeds available production capacity. To limit total demand and provide an equitable distribution of available water, intermittent water supplies with reduced system pressures are often introduce (Petingeduld and Zdeneksvitak, 2006).

1.2. Statement of the problem

The primary goal of all water distribution system is the delivery of water to meet the demands on quantity and pressure. Unfortunately, as a water distribution system ages, its ability to transport water diminishes and the demands placed upon it typically increase. In addition to the unsatisfactory performance of a deteriorated network, there are direct economic impacts of a failing system (Utkarshnigam et al., 2015).

Because of significant development of urbanized areas and construction of thousands of small and large-scale water supply and distribution systems in recent decades, many people have access to clean water and adequate sanitation. However, the quality of service in terms of optimum pressure and velocity, which provided by water utilities, is often difficult (Jalal, 2008). The level of service provided by water supply and distribution systems is one of the key issues facing the water industry today (Tamminen et al., 2008).

Mostly problems that occurred in developing countries are intermittent, erratic pressure is not acceptable, inequalities in service provision between the rich and the poor, high rate of water losses from the distribution systems, Population growth and urbanization, Growing urban water demand, Infrastructure is aging and deteriorating (jalal,2008).

A serious problem arising from intermittent supplies, which generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system (Zyoud, 2003). There are different problems that affect the performance of the public water utilities, for example, many public utilities in developing countries including Ethiopia, experience high (UfW) rate, which often average between 40 - 60%, meaning that about half of the potable water produced is lost somewhere in the supply process. Moreover, the public utilities often face financial challenges due to a combination of low tariffs, poor services, poor consumer records and inefficient billing and collection practice (Kimey et al., 2008).

Addis Zemen is a town in South Gondar Zone that passed through various socioeconomic progresses. The study area has been experiencing frequent and regular disruption of water supplies for days to a week. Although the town water supply and sewerage enterprise trying to curb the problem, delivering sufficient water without any interruption to the dwellers remains dream. Unprecedented rate of population growth, urbanization and the need for repair and maintenance of very old and outdated structures widen the gap between demand and supply of water in the town. The source of the existing water supply for Addis Zemen Town is ground water.

Earlier studies conducted on water supply both at international and national levels focused mainly on rural areas and big cities. However, in small and medium towns like Addis Zemen no adequate research yet carried out. Furthermore, the town is one of the medium level towns in the country with recent rapid urbanization and high population growth. This clearly calls for the expansion and improvement of water supply system service through research based estimation of water demand and appropriate hydraulic networking. Therefore, this research attempts to evaluate the present status of distribution system performance and its outlook to provide base line information for decision makers and further research.

1.3. Objectives of the Study:

1.3.1. Main objective:

The main objective of this research was to evaluate hydraulic performance of the existing water distribution system of Addis Zemen Town.

1.3.2. Specific objectives:

- To evaluate the existing water supply situation of the town
- To evaluate water losses of existing water distribution system
- To simulate hydraulic parameters of existing distribution system
- To evaluate the present water demand and forecast future demand

1.4. Research Question

The research questions that were addressed in this research are:

1. How is the present condition of water supply in Addis Zemen?

2. How much water losses is in the water distribution network?

3. How is the performance of water supply network of the Addis Zemen Town?

4. Is the existing water supply satisfied current demand and future demand for the next decade?

1.5. Organization of Study

This thesis was organized into five major parts. Chapter 1 included the introduction, which focused mainly on the background, statement of the problem, objectives, research questions, significance, the scope and limitation of the study as well as the organization of the thesis. Chapter 2 dealt with review of different literatures related to the performance, demand and losses of water in urban supply distribution system. Research methodology constituted chapter three of the thesis and includes description of the study area, research design, data collection and analysis methods. Chapter four contained results and discussion, which describe the main findings of the study. Chapter five included conclusion of the study and recommendation.

1.6. Limitations

Problem faced in the course of this study was associated with getting sufficient updated secondary data. For example, there was shortage of well-documented data sources and adequate report especially in the study area from Addis Zemen Town water office and due to resource constraints in terms of the research experiment materials coupled with cost to be incurred on the research to study water quality.

1.7. Significance of the study

Poor performance of water supply distribution network is the main problems in whole world predominantly in poor countries like Ethiopia. The study result shows the existing water supply situation of the urban dwellers by investigating the water demand, water losses and identifying factors that affect the performance of water distribution network. It also provide insight to policy makers, NGOs, community based organizations and other stakeholders who are concerned with urban water supply problems. This thesis also adds to the literature of urban water supply issue, which are currently the global challenge. It also serves as the base line for other researchers who will be interested in the area.

1.8. Scope of the study

The scope of the research focuses on performance the water supply distribution system of the urban places of Ethiopia particularly in the Addis Zemen Town. This study primarily focus on evaluating performance of water supply distribution system in terms of pressure, flow or velocity, demand meeting (not included livestock water demand and industrial demand) and water loss. This research was used hydraulic network analysis software Bentley WaterCADV8i. The performance of the system was observed under peak consumption and minimum time consumption and its performance was evaluated based on hydraulic conditions not including water quality.

CHAPTER TWO

LITERATURE REVIEW

2.1. Urban water supply

Safe drinking water is the birthright of all humankind as much a birthright as clean air (Rao, 2002) while access to clean water can be considered as one of the basic needs and rights of a human being. Health of people and dignified life is based on access to clean water (Korkeakoski, 2006).

Water is important in a number of ways; these include domestic and productive uses. Domestic water use takes the form of drinking, washing, cooking and sanitation, while productive water uses includes those for agriculture, Beer brewing, brick making, etc. Safe drinking water matched with improved sanitation contributes to the overall well-being of people; it has significant bearing on infant mortality rate, longevity and productivity.

However, the majority of the world's population in both rural and urban settlements does not have access to safe drinking water (Alaci, 2009). According to WHO (2006), only 16% of people in sub-Saharan Africa had access to drinking water through a household connection (an indoor tap or a tap in the yard).

The primary goal of all water supply utilities is to provide customers with a private connection to the piped water supply network. For many public officials, policy makers and politicians a household or yard connection (here after referred to as a private connection) is considered the most satisfactory way to meet the following key objectives; Public health objectives: by ensuring better quality and access. Commercial objectives: by facilitating cost recovery and revenue generation. Social objectives: by improving access for the poorest and enhancing security and safety. Environmental objectives: by enabling better demand management and water conservation (AWUP, 2003).

2.2. Water supply distribution network

Water distribution Networks are very important lifeline infrastructure systems, where failures are inevitable. A typical WDNs consists of network of pipes, nodes linking the pipes, storage tanks, reservoirs, pumps, additional appurtenances like valves. Water distribution systems represent a major portion of the investment in urban infrastructure and a critical component of public works. The main goal is to design water distribution systems to deliver potable water over spatially extensive areas in required quantities and under satisfactory pressures. Therefore, hydraulic models for water distribution networks have become indispensable tools for understanding system behavior by simulating pressures and flows at different locations and times in the networks (Byakika, 2012). The design of water distribution systems in general based on the assumption of continuous supply. However, in most of the developing countries, the water supply system is not continuous but intermittent (Khatri and Vairavamoorthy, 2007). A well-planned water distribution network is very essential in the development of urban areas. The network is built to satisfy various consumer demands while meeting minimum pressure requirements at certain nodes (Atiquzzaman, 2004). For lower pressures, there cannot be a water delivery and for higher pressures, there can be excessive amount of leakage. To provide this, the service area is divided into different pressure zones. One of the main criteria determining the number of zones is the topology. A system serving to a highly elevated hilly area has more pressure zones than a relatively flat area (Misirdali, 2003).

2.3. Problems of water distribution system

Water flow is a function of several things, including the size and shape of the opening, and the pressure at the opening (Rossman etal. 2003). Typically, city water supplies are at 40 to 70m, (static pressure). Older private systems are set to maintain water pressure between 20m and 40m, which is too low for some lifestyles; plumbers can set systems higher if the pump is capable of delivering higher pressure (MOWR, 2006b).

2.3.1 Water pressure drops due to gravity

Gravity is another source of pressure loss in a residential plumbing system. Energy is required to push the water uphill. For every 0.305m of elevation increase in a pipe, approximately 0.434 m is lost. With no water flowing, the static pressure available at the street main may be 60 psi, but the static pressure at the second floor basin would be 52 m (Ilesenim, 2006).

2.3.2 Water pressure drops due to corrosion

When the water pressure is poor in the distribution system, the most common cause is corroded galvanized steel piping. The common 12.7 mm diameter piping can close down so that the opening is only 3.18 mm diameter or even less. The only solution is to replace this pipe typically with copper. It is wise to replace with a larger diameter pipe on the main feeds at least to improve pressure. When galvanized steel pipe is present, and pressure is low, it is common for accessible pipes running across the basement ceiling to be replace first (Hutton etal, 2007).

2.3.3. Water pressure drops due to distance from the source

If more water is flowing, the pressure drops more at each point along the pipe (Hutton etal, 2007). The more fixtures flowing at once, the greater the pressure drop at all fixtures and the lower the flow at each fixture (Rossman etal, 2003).

2.3.4. Other causes of poor water pressure

The supply line from the street to the house may be undersized, damaged or leaking. Long runs of relatively small (13 mm diameter) pipe within a house will result in considerable pressure drop. Clogged pipe within the house will adversely affect pressure. In addition, defective, undersized or poorly adjusted pump will result in poor pressure (Rossman etal, 2003).

2.4. Performance evaluation of urban water distribution system

Performance of a water distribution network can be defined as its ability to deliver a required quantity of water under sufficient pressure and an acceptable level of quality during different normal and abnormal operational situations (Tabesh and Dolatkhahi, 2006). Evaluating the performance of water supply systems is an important for water industry to deliver competent levels of service .A good distribution system should be a capable of supplying water at all intended place within the city with reasonably sufficient pressure head and the requisite amount of water for various types of demand (Garg, 2010). The performance of urban water supply scheme can be evaluate based on four performance measures: Hydraulic, Structural, Water quality and Customers perception. The performance of urban water distribution network can be categorized in Figure 2.1.

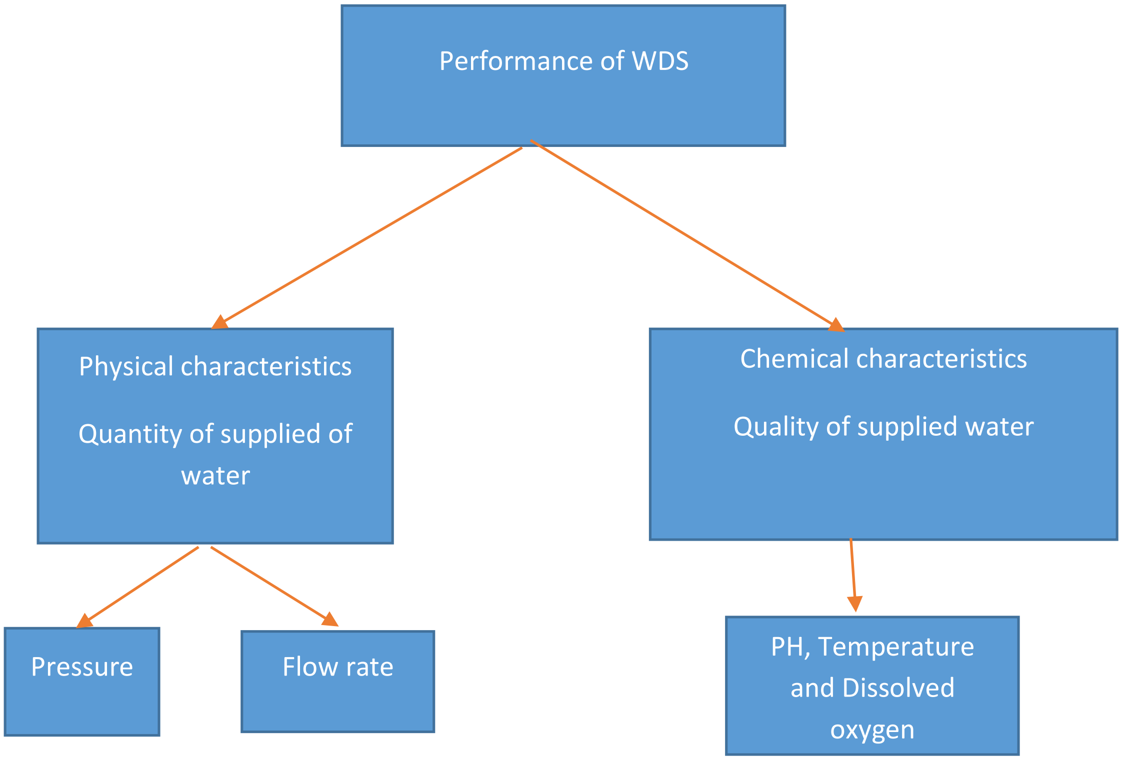

Figure 2.1: Performance Classification of WDS (Jalal, 2008)

2.4.1. Hydraulic performance

The hydraulic performance of a water distribution system is the ability to provide a reliable water supply at an acceptable level of service that is, meeting all demands placed upon the system with provisions for adequate pressure, fire protection, and reliability of uninterrupted supply (Tiwari and Gulati, 2011). Thus, hydraulic simulation modeling is now a days the most common tool used by water supply engineers and managers, as a complement to their experience and insight, at the process of establishing a diagnosis, defining the remedies and implementing them (Tabesh etal., 2011).

2.4.2. Structural (physical) performance

Water mains generally comprise a variety of pipe work and fittings, and which over time are subject to various episodes of augmentation, refurbishment, renewal, replacement, repair and extension. Physical performance of water supply system is the ability of the distribution system to act as a physical barrier that prevents external contamination from affecting the quality of the internal, drinking water supply (Tabesh and Dolatkhahi, 2006).

The most obvious indication of the physical deterioration and failure of the pipe network is leakage. Analysis of a pipe network is essential to evaluate a physical system of water supply systems. The annual volume of water lost is an important indicator of water distribution efficiency, both in individual years, and as a trend over a period of years. High and increasing water losses are an indicator of ineffective planning and construction, and of low operational maintenance activities (Mckenzi etal., 2006). The other indicator is the volumetric efficiency which is the ratio of the registered volume and the total supplied volume during a certain reference period of time a value above 75% is considered to be acceptable.

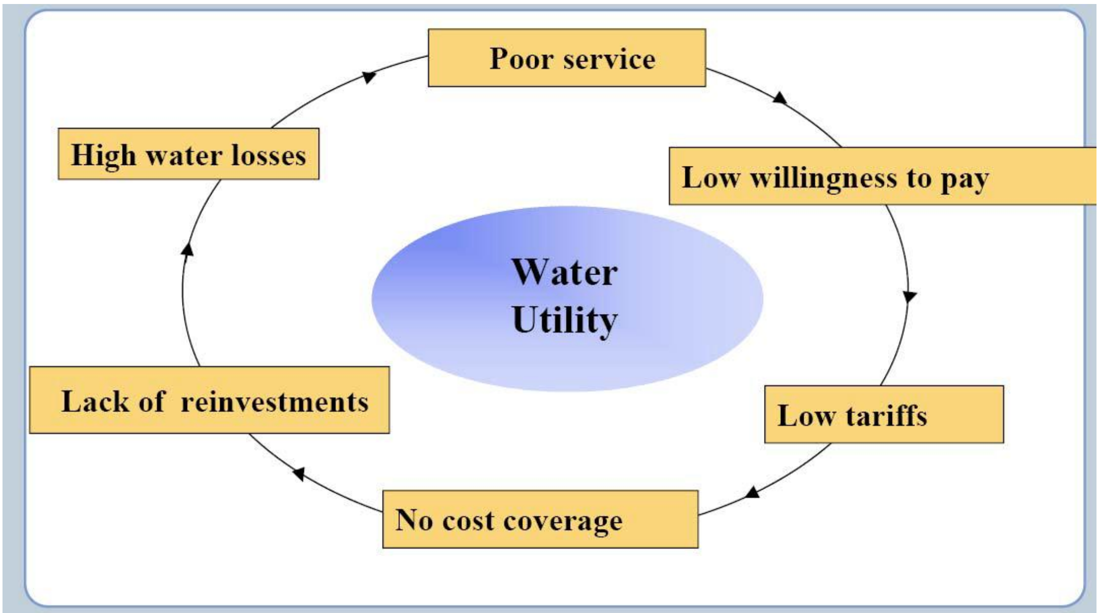

Figure 2. 2: Performance of urban water supply service source (Sharma, 2008)

2.4.3. Customer perception

It is important to maintain the public's confidence in the quality of drinking water and the services provided by a utility. Satisfied customers will pay their bills promptly and will provide political support for necessary rate increases or bond issues. In order to evaluate a WDS, it would be ideal to identify all major customers with their preferences, expectations, needs and requirements and then to explore the ways of meeting their expectations with consideration to associated consequences. Major customers may need those facilities that constitute significant portion of supply demand in a region (e.g., residential, Industrial, and firefighting users, public health officials). An ideal approach might be to investigate the quantity of water needed for each Individual customer, the period they need water for, and the appropriate level of water quality that is suitable for their need. The estimation of the quantity of water should reflect customer preferences and expectations efficiently. The more closely customer needs are met, the higher the level of satisfaction for customers and the better the water utility is managed (Jalal, 2008).

2.5. Water supply mode in distribution system

2.5.1. Continuous system

In the continuous supply systems, water directly conveyed through the distribution network continuously without interruptions. The consumers use water at any time without any need for individual roof.

2.5.2. Intermittent supply system

The distribution system usually designed as a continuous system based on the assumption of continuous supply. However, in most developing countries water supply is not continuous but intermittent. A serious problem arising from intermittent supplies, which generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system. During the Supply period, the water is stored in all sorts of vessels for use in non-supply hours and when the supply resumed, the stored water is wasted and fresh water again stored. During non-supply hours, polluted water may enter the supply mains through leaking joints, pollute the supplies, and create the health related problem. Intermittent systems, which require frequent valve operations, are likely to affect equitable distribution of water mostly due to operator negligence. Intermittency generates inequitable water distribution due to pressure dependent flow conditions, with obvious disadvantages for consumers located far away from the supplying points or at higher altitudes in the area (Totsuka etal, 2004).

2.6 Types of water distribution systems

2.6.1 Branching systems

This type of distribution networks is the most economical system and common in the developing countries due to its low cost. In this system, when there is need for developing the network, new branches follow that development and new dead ends will constructed. The branching systems may have limitation of the dead ends cause accumulation of sediments, which increasing contamination of distribution system.

2.6.2 Grid systems

There are no dead ends in this type of distribution networks. The maintenance operation not affect the interruption of the system as in the branching system.

2.7 Methods of water distribution

There are three methods of water distribution system delivered from the source to consumers' house (Zyoud, 2003). These are as follows:

2.7.1. Gravity distribution

This is possible, when the source of water is elevated, so that sufficient pressure can be maintained in the systems. The main important of this method of water distribution system is saving power that needed for pumping.

2.7.2. Distribution by pumping without storage

In this method of distribution, water can pumped directly into the main distribution lines without transfer water to service reservoir. The pumping rate should be sufficient to satisfy the demand. An advantage of direct pumping is that a large fire service pump may be used which can run up the pressure to any desired amount permitted by the construction of mains.

2.7.3. Distribution by means of pumps with storage

This method used when there is an elevated reservoirs used to maintain the excess water pumped during periods of low consumption, and these stored quantities of water may use during the periods of high consumption

2.8 Principles of pipe network hydraulics

Flow in a pipe network satisfies two basic principles, conservation of mass, and conservation of energy.

2.8.1. Conservation of mass

For steady state condition, Conservation of mass states that the flow into and out of the system must be the same. It assumed that water is incompressible (Hopkins, 2012).

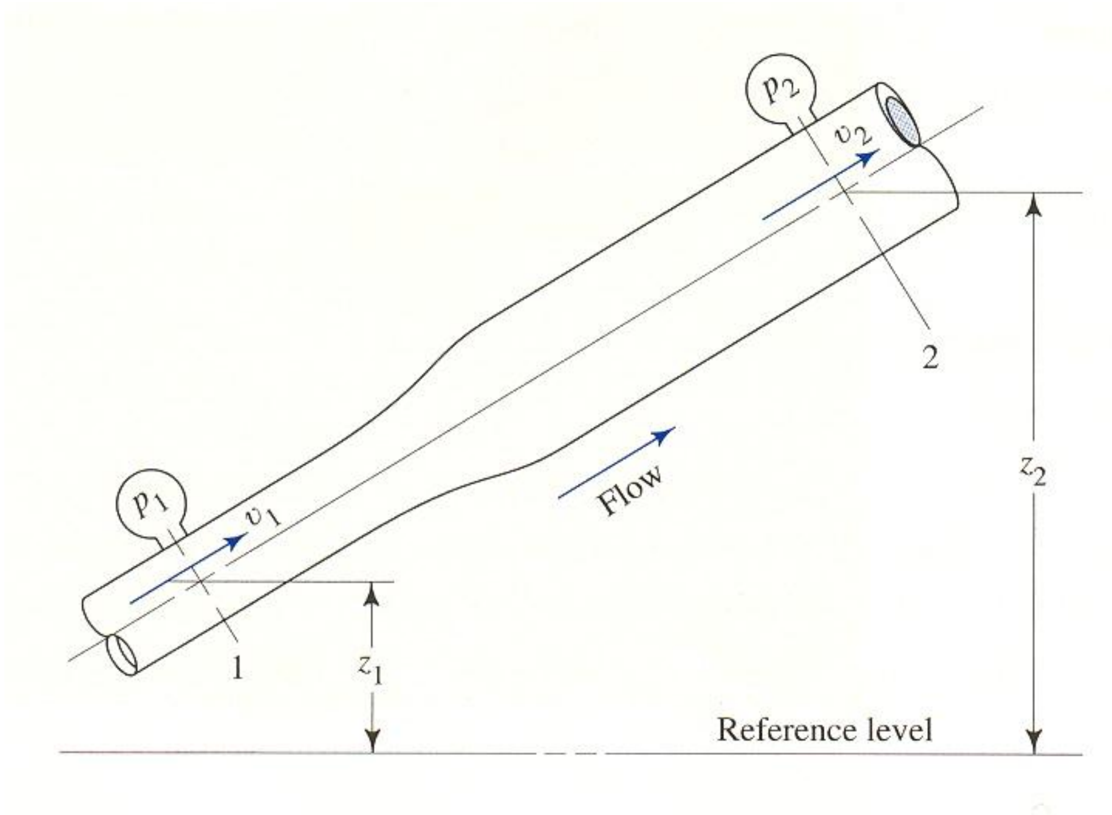

Figure 2. 3 Continuity diagram (Conservation of mass)

Mass of fluid at section 1 = Mass of fluid at section 2

Principle of conservation of mass

$$A1V1 = A2V2 = Q1 = Q2 \qquad 2.1$$

Where, V = average velocity (ft. /sec); A = cross-sectional area (ft^2) and Q = Discharge (ft^3 /sec).

2.8.2. Conservation of energy

The principle of conservation of energy states energy can neither created nor destroyed. Thus, the energy difference between two points is the same regardless of the path taken. The energy in pipe flow typically described in terms of head. The energy at any point in a distribution system is the sum of three components, pressure head, velocity head, and elevation head.

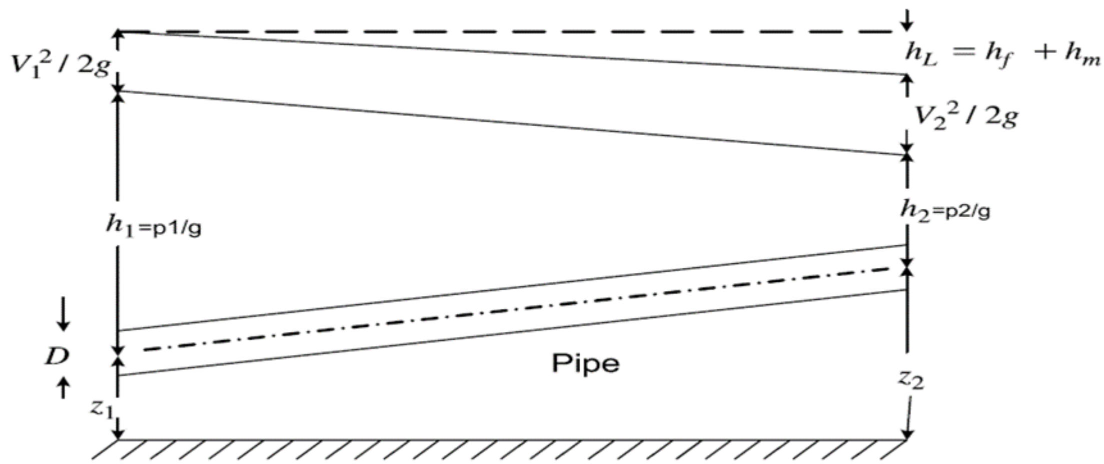

Figure 2. 4 Conservation of energy (Sharma, 2008)

$$\frac{P1}{\Upsilon} + \frac{V12}{2g} + z1 = \frac{P2}{\Upsilon} + \frac{V22}{2g} + z2 + HL \qquad 2.2$$

Where, P = Pressure (Pa); V = Velocity (ft. /se); z = Elevation; g = gravitational acceleration constant (32.2 ft. /sec^2); γ = Specific weight of water (lb. /ft.) and HL = Head losses (m).

2.9 Head losses

There are different factors that cause the energy losses. The main reason of the energy loss is due to internal friction between fluid particles traveling at different velocities (Zyoud, 2003).

2.9.1. Friction losses

Hazen-Williams equation and the Darcy-Weisbach equation are the most commonly methods used for determining head losses in pressure piping Systems. The assumptions for a pressure pipe system can describe as the following: Pressure piping is usually circular, so the area of flow, wetted perimeter, and the hydraulic radius can directly related to diameter. Through a given length of a pipe in a pressure piping system, flow is full, so the friction slope is constant for a certain flow rate.

2.9.2. Minor losses

Minor losses are a result of localized areas of increased turbulence and are Frictional head losses, which cause energy losses within a pipe. A drop in the energy and hydraulic grades caused by valves, meters, and fittings, the value of these minor losses is often negligible.

2.9.3. Water hammer

When the velocity of flow in a pipe changes suddenly, surge pressures are generated as some, or all, of the kinetic energy of the fluid is converted to potential energy and stored temporarily via elastic deformation of the system. It generally occurs when valve opened or closed suddenly, or when pumps started or stopped.

2.10 Urban water demand

Water demand is the volume of water requested by users to satisfy their needs. In a simplified way, it is often considered equal to water consumption, although the two terms conceptually do not have the same meaning (Wallingford, 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use (Berhe, 2005). (Maher and Trifunovic, 2013) noted that, water demand is the algebraic sum of the quantity of water utilized by consumer (consumption) and the amount of water physically lost from the system (leakage). It usually expressed as per capita demand. Per capita water usage varies widely due to the differences in climatic conditions, standard of living, population growth, type of commercial and industrial activity and water pricing. Water demand increases with time due mainly to population growth. Therefore, new water resources ought to be developed in order to meet the increasing water demand at present and in future (Abdo, 2009).

2.10.1. Types of urban water demand

It is usual to classify water demand in various sorts depending on the characteristics of the consumers' .The most common types are domestic, commercial, industrial, firefighting and unaccounted water demand.

2.10.1.1. Domestic water demand

Domestic demand includes the water required in private building for drinking, cooking, bathing, flushing and washing clothes (WHO, 2002). Garg (2010) indicated that the domestic consumption varies according to the living conditions of the consumers, economic status of the community, climatic condition, mode of service and affordability and accessibility of the service. Daily per capita water consumption in Ethiopia is generally very low throughout the country. DWD is suppressed in almost all towns in the country because of supply shortages. Actual demand is expected to be greater than present consumption if greater supplies were available to the community (MOWE, 2011).

2.10.1.2. Non-domestic demand

Non-domestic demand comprises Industrial, Commercial, and Institutional, Firefighting demands, Unaccounted Water Demand (UWD).

Industrial water demand: represents the amounts of water demand required by industries and factories in the cities. According to Garg (2010), the ordinary per capita consumption of industries is 50l/c/d. but due to the modernization of technology in reusing waste water the amount of water require for industry getting reduced.

Commercial and institutional water demand (CIWD): In addition to those of household consumers, the water requirements of towns include the needs of such commercial and institutional consumers as public schools, clinics, hospitals, offices, shops, bars, restaurants, and hotels. CIWD is usually linked directly to population size. For medium town, the CIWD estimate is taken as 10 per cent of DWD (MOWE, 2011).

Unaccounted water demand: is the amount of water physically lost from the system and theft (Motiee etal, 2007). Losses from water supply systems vary considerably according to diverse factors. According to MoWR (2011), water losses is a function of the quality of construction, the type and age of the pipes in the distribution network, and pressure within the system. Losses can also originate in treatment plants. Loss for urban scheme is taken as 25 per cent of the total domestic, commercial and institutional, and industrial water demand. It can be obtained as the difference between the supplied volume and the metered volume.

2.11. Urban water demand forecasting

Water demand should forecasted in time. Many water resource projects have a relatively long useful life. Therefore, in studies of water demand forecasting the plan should extended to about 50 years for long term. In medium scale development plans, a lead-time of 15 to 25 years may apply (Karamouz etal, 2003).

2.12. Water losses in distribution system

There are two types of water losses in distribution system (Dighade, 2014).These are real losses and apparent losses. Real losses consist of water lost through burst pipes, leaking joints, fittings, service pipes, and connections. A high level of real loss reduces the amount of precious water reaching to customers and increases the operating costs of the utility. Apparent losses result from illegal connections, under-registration of customers meters, inaccurate meters, stopped meters, vandalized meters, by passed meters, billing errors, inadequate meter reading policy, bribery and corruption of meter readers.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Description of study Area

3.1.1. Location

Addis Zemen is a town in Northern Ethiopia, located south Gondar Zone of Amhara Regional state, on the road connecting Gondar and Bahir Dar. It is far 645 km from Addis Ababa and 85 km to the capital of Amhara Nation Regional State, Bahir Dar. Addis Zemen has latitude and longitude of 12°07′24.84″N and 37°46′47.44″ E respectively and average elevation of 1943 m above sea level. It is the administrative center of Kemekem Woreda. The map of study area is given in Figure (3.1).

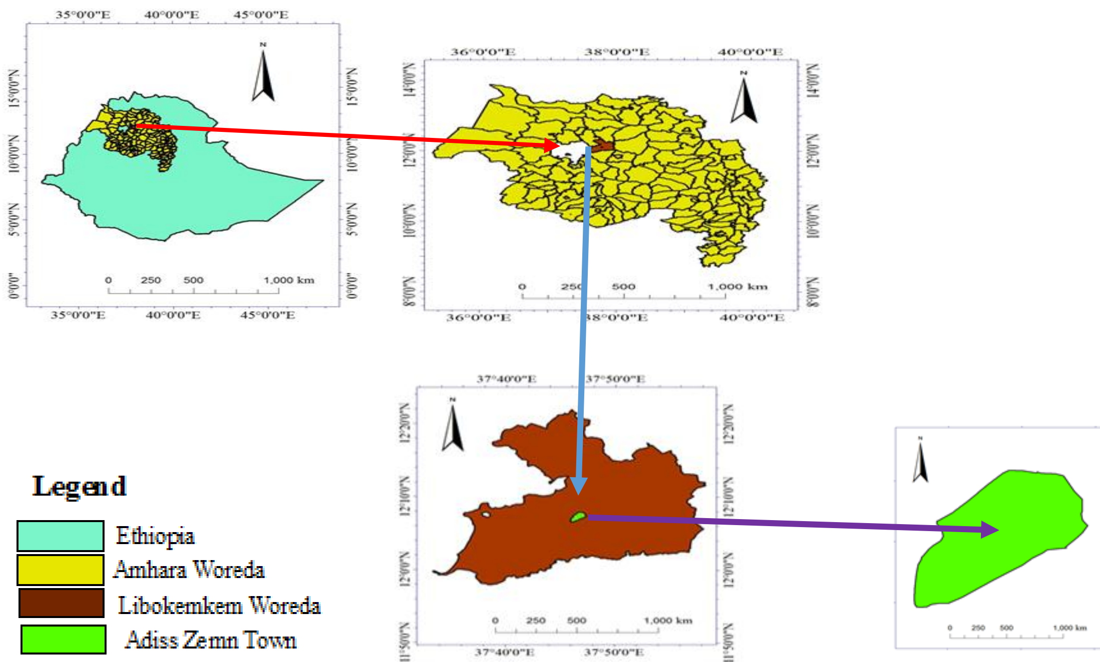

Figure 3. 1 Map of Addis Zemen Town

3.1.2. Population

Based on the figures from CSA in 2007, Addis Zemen town has an estimated total population of 16113 of whom 8166 were males and 7947 were females.

3.1.3. Climate

The wet period runs from June/July to August/September. Maximum temperatures are observed in March-April while minimum are recorded in July- August. The minimum temperature of the town is 15^0C and maximum temperature 24^0C. The mean annual rainfall of the town is about 1038 mm.

3.1.4. Material

This research was conducted on evaluating hydraulic performance of existing water supply in distribution system. To achieve the goal of the research the materials that were used are computer, endnote, Arc GIS Version 9.3, WaterCADV8i, origin8 and GPS Garmin72.

3.1.5. The Research design

The water per capita consumption supply of the town was first evaluated with annual consumption with in specific year. After evaluating the water per capita consumption, the percentage of the water loss was estimated. The total water produced and actual water consumption as aggregated from the individual contracts (customer meters) was used as an input for water losses analysis. After evaluating the total water losses, the possible causes of water losses were tried to be identified. Then the performance of water distribution network was evaluated. Lastly, estimating the current and future water demand of the town was conducted by considering per mode of service.

3.1.6 The town water source system

3.1.6.1. Existing water source

The town's main source of drinking water is borehole with the design yield of 1879 m^3/day. This ground water supplied to the population is abstracted from the well by pump. After the water is pumped to service reservoir, then the storage reservoir water is distributed to the costumer by gravity.

3.1.6.2. Existing distribution system

The existing water distribution system of the town is both pump and gravity system. The water from the source is taken to relief tank by pump and the water from the relief tank is taken to storage reservoir by pump. Then, the stored water is distributed (PVC, DI and GI) to the town by gravity. The water distribution network of the town consists of about 16 km and 840 m of water pipes ranging in diameter from 2 to 8 inches. The existing distribution system consists of a variety of pipe types: ductile iron, PVC and galvanized iron. The town supplied by water intermittently by water Staff who is managing the system mainly by using controlling valves in order to supply all customers at least twice a week.

3.2 Data Collection

3.2.1. Primary data collection

Primary data were collected though face-to-face interview with AZWSSE experts, field observations and measurement, photographs of relevant sites and infrastructures were taken.

3.2.2. Secondary data collection

Secondary data were collected from reviewing of documents from AZWSSE, Amhara water design and supervision office, journals, reports, and internet.

3.2.2.1. The town existing water distribution network

The entire town water supply network including their attribute like pipe length, diameter, material types, roughness coefficient of the pipes, Junction point, pumps characteristics, reservoir and tank section has been collected from the Amhara design and supervision works office.

3.2.2.2. Water production

The water production has been evaluated as a total annual water supplied to the water distribution system (WDS). The production of water depends on four-supply system, which are administrated by Addis Zemen Town water service office. The designed gross water production capacity of these boreholes is 29 liters per second (l/s) or (1879 m^3 /day) average working for 18 hours per a day.

Table 3. 1 Description of existing boreholes (AZWSSE, 2014)

Name of source	Constructed by	Drilled year	Distance from the town (km)	yield (l/s)	Elevation (m)	Daily production(m^3)
Alabo	AWW	1981	2	4	1928	259
Angot-1	AWW	2009	5	2	1937	130
Angot-2	AWW	2009	5	3	1869	194
Bora	AWW	2012	12	20	1806	1296

3.2.2.3. Water consumption

In order to evaluate the water loss in the distribution system, consumption data of each customer were collected from billed data. The rate of water consumption at a node depends on the population served by that node, type of the demand (domestic, public, commercial, etc.), time of the year and the time of the day. Even for the existing water distribution systems, the nodal demands change due to many factors, such as new users or an increase in the number of existing users (Misirdali, 2003).

3.2.2.4. Population data

Based on the CSA (2007), the numbers of the population figures the year 2016 has been also collected from planning commission of the town.

3.3. Data analysis

To analyze the data which is collected from different sources, both qualitative and quantitative methods was used. From the quantitative methods, the descriptive statistical methods like percentage, graphs and cross tabulation was used in order to come up with the appropriate result. In addition to this, qualitative methods like narration were employed in the study. The computer software application origin8 and excel was used to analyze the data obtained from office. The field survey data for distribution system was evaluated by using the engineering software called Water CADV8i.

3.3.1. Analysis of Existing Water Supply System of the town

3.3.1.1. Estimation of domestic water consumption

Average per capita consumption was used to assess the domestic water supply coverage of the town. Data on individual domestic water consumptions, total water consumption (m^3) and total production (m^3) were collected from Addis Zemen Town Water Supply and sewerage Enterprise bill documents for analyzing average per capita consumption. The following formula was applied for the determination of per capita consumption (liter/person/day) (Desalegn, 2005).

$$Domestic\ consumption = \frac{Annual\ consumption\ (m^3)\times 1000L/m^3}{Population\ number\times 365} \qquad 3.1$$

3.3.2. Water loss analysis

The total annual water produced and distributed to distribution system and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water losses of the town (EPA, 2010).

$$\text{Unaccounted Water\%} = \frac{\text{Water prduced by PWS} - \text{Metered water used x 100}}{\text{Water produced by PWS}} \qquad 3.2$$

3.3.3. Network Simulation

3.3.3.1 Steady-state simulation

It is the simplest simulation type and solves the system of equations as if the system Junction demands and tank elevations kept constant.

3.3.3.2. Extended-period simulations

Demand patterns: - the amount of water that consumed in the morning when everyone is getting ready for work is different at midnight. The extended-period simulation was chose for this analysis because of its capability to model varying demands. The total simulation time was 24 hours with a one-hour time-step. Analysis at peak and minimum time consumption was simulated to identify the current problems of the system.

3.3.4. Hydraulic Parameters

The main hydraulic parameters in water distribution networks are the Pressure and the flow rate, other relevant design factors are the pipe diameters, velocities, and the hydraulic gradients.

3.3.4.1 Pressure

The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network. The minimum pressure should maintained to ensure that consumers' demand provided at all times. The maximum pressure also contain limitation of leakage and lead to water losses in distribution system. The operating pressure in the distribution network is given in Table 3.2.

Table 3. 2 The operating pressures in the distribution network (MOWR, 2006b)

Normal condition		Exceptional conditions
Minimum	15 m	10 m
Maximum	60 m	70 m

3.3.4.2 Flow

It is the quantity of water passes within a certain time through certain section. Velocity is directly proportional to the flow rate. For a known pipe diameter and a known velocity, the flow rate through a section can estimated. Low velocities affect water consumption and severe to diseases problem.

$$V = \frac{4Q}{\pi D^2} \qquad 3.3$$

$$D = \sqrt{\frac{4Q}{\pi V}}$$

Where, D= diameter of the pipe (m); Q= discharge (m^3/se) and V= velocity (m/sec)

• Maximum velocities in distribution system 2 m/s and minimum 0.6 m/s.

3.3.5. Modeling the existing distribution system

3.3.5.1. Water CADV8i

Water CAD is a powerful tool for design, analysis and improve the existing urban water distribution system. A model was developed utilizing Water CAD software (Water CADV8i for Auto CAD 2007 software). Water CAD is selected for this study because of it is aided with good quality of manual, integration with other external software's, like Auto CAD, GIS background support and Microsoft excel, requires less effort and shorter time to build a model than others do, rule-based controls and ground elevation extraction from shape files and CAD drawings. The other capabilities of the Water CAD software are evaluate the hydraulics for different demands at a single node with varying time patterns, Solve for different frictional head losses using Hazen-William, DarcyWeisbach or the Chezy-Manning equation, determine fire flow capacities for hydrants, model tanks, including those, which are not circular and model various valve operations (Bhadbhade, 2004). In order to analyze the distribution network system, the available data and plan of the distribution network of water supply system was reviewed. The modeling process are input data collection, model building in Bentley Water Cad, data entry (Elevations, XY coordinates, base demand, pump data, tank data and pipe data),model testing and hydraulic modelling and problem analysis.

Input data for the analysis of distribution system included:-

- Nodes:- Elevations and base demand
- Pipes: - Pipe diameters, lengths, material type and the friction coefficient factors
- Tanks:- Base , minimum and maximum elevation and diameter of the tank
- Pumps: - The most important parameter defining the pump operation is the pump curve. Other input needed is the elevation of the pump
- Reservoir:- Elevation

After all the parameters required to running, the out puts of the simulation model are-

- Flows at every point of time in the system
- Velocities in the pipes
- Levels in the tanks
- Pump curve
- Water age and quality
- Pressure head at node
- Head losses

i. Junctions

Junctions are points in the network where links join and where water enters or leaves the network (Rossman, 2000). The basic input data required for junctions are elevation above some reference (usually mean sea level), location (X-coordinate, Y-coordinate) and water demand (rate of withdrawal from the network).

ii. Reservoirs

Reservoirs are nodes that represent an infinite external source or sink of water to the network. The primary input property for a reservoir is its hydraulic head. Because a reservoir is a boundary point to a network, its head cannot be affected by what happens within the network. Therefore, it has no computed output properties.

iii. Pipes

Pipes are links that convey water from one point in the network to another. Flow direction is from the end at higher hydraulic head to that at lower head. The principal hydraulic input parameters for pipes during analysis were start and end nodes, diameter, length, roughness coefficient and status (open or closed). The computed outputs for pipes included head loss, velocity and flow. To compute friction head losses, Hazen-Williams equation were used with the assumption that viscosity is constant. Hazen William equation to compute friction head loses was as follows:

$$Hf= \frac{10.68LQ^{1.852}}{C^{1.852}D^{4.87}} \quad 3.4$$

Where, Hf= Head friction; Q= discharge (m^3/s); L=Length of the pipe (m); D=Diameter (mm) and C= Roughness coefficient which varies for different pipe materials and age.

The pipe roughness coefficient refers to a value that defines the roughness of the interior of a pipe. The Hazen William roughness coefficients value of different pipe materials are given in Table 3.3.

Table 3.3 Hazen-William roughness coefficients for pipe material (Chase etal, 2003)

Pipe Age (years)	Pipe Type		
	PVC	GI	DI
New	150	120	130
10 -20	125	105	105
> 20	105	96	96

3.3.5.2. Need for hydraulic simulation

Most small and medium towns do not have very complex networks as compared to Cities; however, they have poor data and records regarding their systems. In such cases, when one has to evaluate the hydraulics and the water quality of the distribution systems, it is advantageous to use computer models. Computer models making use of hydraulic simulation software are capable of representing the behavior of a real time system and have the capability of predicting the performance of the same system for future ‘what if ‘scenarios (Hasted, 2003). Simulation can be used for analysis of the existing system to improve the supply in terms of pressure / flows/ and minimize leakage. Simulation of a network is also important to make decisions about the network augmentation requirements due to increase in water demand or expansion of a water servicing area. The understanding of pipe network flows and pressures is important for making such decisions for a water supply system (Swamee, 2008).

3.3.6. Addis Zemen Town population projection

Several models are used to forecast the population. In projecting the future population, geometric increase method and regional population growth rate was used to all towns in Ethiopia for every five years interval (Amdework, 2012). Therefore, the geometric increase method was adopted for this scenario for the purpose of future population forecast of Addis Zemen Town. Because this, method is mostly applicable for growing towns having vast scope of expansion, like Addis Zemen Town. The urban population growth rate of Amhara Region is given in Table 3.4.

Table 3. 4 Growth rate (%) of urban population of Amhara Region (CSA, 2007)

Years	2000-2005	2005-2010	2010- 2015	2015-2020	2020-2025	2025-2030
Growth rate (%)	4.5	4.5	4.3	4.1	4	3.8

Population for the next ten (until 2025) years is projected using geometric increase method as follows.

$$Pn = \mathrm{Po}(1 + \frac{r}{100})^{n} \quad 3.5$$

Where, Po= initial known population i.e. the population at the end of last known census; Pn= population after n years; r= growth rate and n= number of years of the concerned period

3.3.7. Present and future water demand forecasting

For this study, water demand is classified in to two major categories as domestic and non-domestic water demand. Domestic water demand is water that is required for cooking, toilet flushing, bathing, drinking, and washing of face, clothes and utensils, etc. Non-domestic water demand includes Industrial demand, institutional demand, firefighting demand, water lost and waste, and public demand.

3.3.7.1. Domestic water demand forecasting

The domestic water demand is the portion of that municipal water supply, which is used in home and largest portion of total demand for most water system (DOH, 2009). It includes toilet flash, cooking, drinking, washing, bathing, and other uses. There are four modes of services identified for domestic water consumers of Addis Zemen Town. These are house connection (HC), yard connection own (YCO), Neighborhood connection (NC) and public tap user (PTU). The per capita water demand for various demand categories of Addis Zemen Town was adopted by taking into account the different development factors and standards used by the Ministry of Water Resources (MOWR, 2006b). In projecting the domestic water demand of the town, the following procedures were used.

3.3.7.1.1 Population percentage distribution by mode of service

Although the standard approach for formulating the percentage of population served by different modes would normally involve a detail analysis of past consumption trends based on office expert household survey, the base year (2015) percentage of population by mode of service was adopted from Addis Zemen Town records and documents. The distribution of population for each mode of service was determined by considering socio-economic situation and living standard of the town. After establishing the population, distribution for the base year a forecast was made.

3.3.7.1.2. Establishment of per-capita water demand (l/c/d) for each mode of service

The per capita water demand is the most important parameter to estimate the total water demand of the town. The per capita water demand varies with the level of water service, mode of service, affordability, climatic condition and socio- economic factors. The values in 3.5 Table were used to establish domestic per capita water demand by mode of services of Addis Zemen Town.

Table 3. 5 Water consumption by mode of services (AWRDB, 2012)

Mode of service	Per capita water demand (l/c/d)
House connection(HC)	70
Yard connection own(YCO)	40
Yard connection shared (YCS)	30
Public tap users (PTU)	25

These values were given for the year of 2012; to convert into base year that is 2015, the annual rate of projection of 2% for public tape users, while for house connection and yard connection 3% was adopted by considering the living standard and socio-economic activities of the town.

3.3.7.1.3. Projection of consumption by mode of service

Distributions of mode of service were established based on available data. The forecast envisages decrease in the public tap and neighborhood users. The assumption was that more people would have yard connection. Besides, the number of house connection would increase in certain amount. Due to this, a significant increase of yard connections was estimated.

3.3.7.1.4. Adjustment for climate and socio-economic activity

In order to account change in climate, which affects water demand of a given area, the value of average per capita domestic demand were factored for climatic changes using the climatic factor. The demand adjustment factor due to climatic effect is given in Table 3.6.

Table 3. 6 Demand adjustment factor due to climatic effects (AWRDB, 2012)

Group	Mean annual precipitation(mm)	Factor
A	900 or less	1.1
B	900 – 1200	1.0
C	1200 or more	0.9

According to the National Meteorological Service Agency, the mean annual rainfall of Addis Zemen is 1038mm, the correction factor was taken as 1.0.

The domestic water demand also depends on the socio-economic situation of the area. Thus, per capita domestic water demand was modified using appropriate factor. The demand adjustment factor for socio-economic situation is given in Table 3.7.

Table 3. 7 Demand adjustment factor for socio-economic situation (AWRDB, 2012)

Group	Description	Factor
A	Town enjoying high living standard and high potential for development	1.10
B	Town with high potential for development but lower living standards at present	1.05
C	Town under normal Ethiopian conditions	1.00
D	Advanced rural towns	0.95

Considering the socio-economic situation of Addis Zemen town, the town can be categorized under group C. Consequently, a socio-economic factor of 1.0 was used.

3.3.7.1.5. Projection of domestic water demand

Estimation of water demand per mode of service and estimation of population by mode of service was used to calculate the average per capita water demand. The average per capita domestic water demand for each year was computed by combining water demand by mode of service and population percentage distribution by mode of service for the year 2015 to 2025.

3.3.7.2. Nondomestic water demand

3.3.7.2.1. Commercial and institutional water demand (CIWD)

This category includes water required for various public water utility purposes like hotels, hospitals, parks, playground, gardening sprinkling on road street foundation, banks, mosques Churches, etc. This demand is recommended 10% of the domestic demand. Therefore, in this study institutional demand was taken as 10% of the domestic demand.

$$ICWD = 10\% * \text{DWD} \qquad 3.6$$

3.3.7.2.2 Fire demand

Fire demand is the quantity of water required for fighting a fire that may break out at commercial center, stores, cities etc. For this study, it was take as 5%.

3.3.7.2.3. Unaccounted water demand

This includes the quantity of water due to wastage, losses, etc. Losses from water supply systems vary considerably according to diverse factors. Loses are a function of the quality of construction, the type and age of the pipes in the distribution network, and pressure within the system (MOWE, 2011). For urban schemes, losses equivalent to 25 per cent of the total domestic, commercial and institutional, and industrial water demand was assumed.

Total water demand Total water demand for the town is the sum of all the demands calculated above. i.e.

$$\text{Total water demand(TWD)} = \text{DWD} + \text{CIWD} + \text{FWD} + \text{UWD} \quad 3.7$$

3.3.7.3. Variation of water use

The rate of water use varies from season to season, from day to day and hour to hour. Water requirements in the dry season are more than in wet season. The use of water is also more during weekends than working days. More water is also required at rush hours when people come back from work than on normal working hours. Therefore, to satisfy this variation of demand the average day demand is scaled up by certain factors to get the maximum day demand and peak hour demand. These scaled up water demand figures are used to size or determine the capacities of pump stations, rising main and pipe distribution networks.

3.3.7.3.1. Maximum day demand

The maximum day demand is the highest demand of any one 24-hour period over any specific year. It represents the change in demand with season. The maximum day factor utilized to calculate the maximum day demand is dependent on the population of the town.

3.3.7.3.2. Peak hour demand

The peak hour demand is the highest demand of any one hour over the maximum day. It represents the diurnal variation in water demand resulting from the behavioral pattern of the local population. The peak hour factor (PHF) utilized to calculate the peak hour demand shows similar dependencies as the maximum day factor for the maximum day demand. The maximum daily factor and peak hour factor are given in Table 3.8.

Table 3. 8 Maximum daily factor and peak hour factor (AWRDB, 2012)

Total population	MDF	PHF
0 to 20000	1.3	2
20001 to 50000	1.25	1.9
50001 and above	1.2	1.7

For Addis Zemen Town the population is 23536 in 2016. Hence 1.25 MDF and 1.9 PHF taken to calculate maximum day demand and peak hour demand respectively. In demand, analysis knowing maximum daily demand and peak hour demand are very crucial (AWRDB, 2012). The maximum daily demand is based on the average daily water required and peak hour demand is greatly influenced by population size.

3.4 Study variables

Dependent variables

The dependent variable is the output of independent variables, which directly related to the general objectives.

- Leakage of pipe in fitting and water losses
- Water consumption

Independent variables

These independent variables are more relating with specific objectives. The independent variables are affect the dependent variables.

- Pressure variation
- Family size

3.5 Ethical consideration

Before conducting the data collection activity, the researcher tell the purpose and informed for concern bodies. Thus, collection of data will undertake after obtaining permission from the concern offices. With regard to data collection in different concerned bodies, First study objectives clearly explain. Each concerned bodies will tell that the information provide will be confidential and use only for the research purpose.

3.6 Data quality assurance

In order to increase the quality of the data, the researcher prepared a fieldwork manual to check every day progress the data handling good. The researcher has checked the reliability and the accuracy of the data as well.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Evaluating the current water supply of Addis Zemen Town

4.1.1 Coverage of potable water

In order to evaluate the potable water supply coverage, the quantity of per capita water consumption was used. The average percapita water consumption was derived from the yearly consumption of the town that have been aggregated from the individual water meter and public tap. Thus, the annual water consumption data was converted to average daily per capita consumption using the population data of Addis Zemen Town (using equation 3.1). As shown in Table 4.1, the per capita domestic water consumption of Addis Zemen Town was found to be 12.98 l/c/d in the year 2015. According to WHO (2008), the minimum quantity of domestic water required in urban areas of developing country is taken as 20 l/c/day. Regarding to this value, the domestic water supply of Addis Zemen Town only satisfies 65% of the standard value and the quantity of domestic water required in urban areas of Ethiopia is taken as 50 l/c/day (MOWIE, 2015). According to this value, the domestic water supply of Addis Zemen Town only satisfies 26% of the standard value. As it is indicated in Table 4.1, the per capita water consumption of town is showing a decreasing trend. The main reasons for decrease in the town's per capita water consumption as time goes is the increase in the population number of the town, pump failure and seasonal fluctuation of the source. The population number of the town is increasing from time to time with increasing demand on the existing water supply system of the town. As a result, the per capita domestic water consumption of the town gets lower and lower. Thus, it is advisable to develop the public preferred nearby source with supply and install new pump to improve the per capita water consumption of the town.

Table 4. 1: Annual water consumption of Addis Zemen Town

Year	Population	Annual domestic Consumption (m^3)	Per capita Consumption (l/c/d)
2014	21718	134146	16.9
2015	22609	107177	12.98

4.2 Water losses analysis

The current production of water supply for Addis Zemen Town depends on Angot1and Bora boreholes, which are administrated by Addis Zemen Town Water Supply and Sewerage Enterprise. The designed water production capacity of this system is (1879 m^3/d). However, the actual production of water has been lower than the maximum capacity. Production data computed for Bura and Angot boreholes shows that actual average production of water at present from the system was 950.4 m^3/day, which is 50.6% of its capacity (1879 m^3/d). The volume of the water supplied and billed water (consumption) for seven consecutive years was depicted in Figure 4.1.

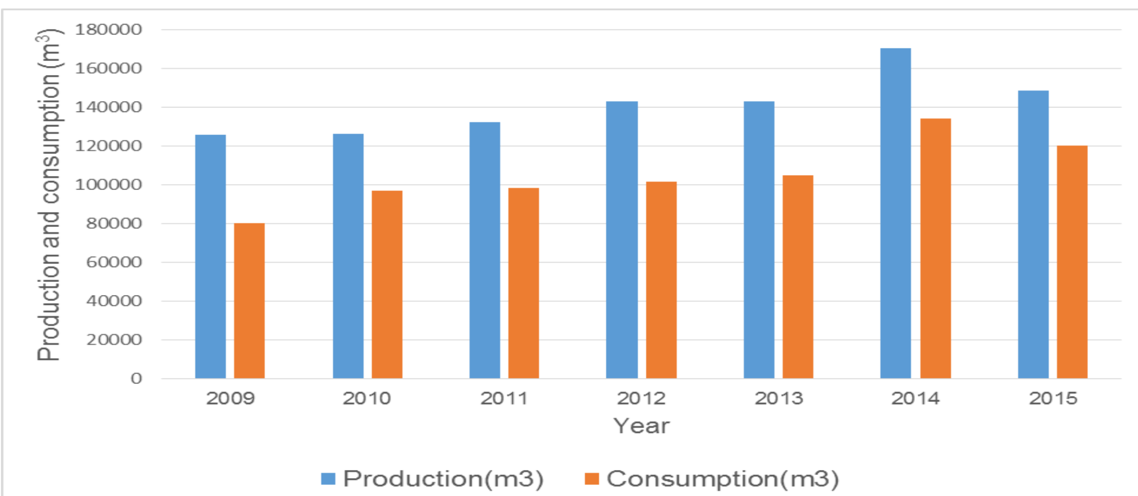

Figure 4. 1 Water production and consumption for Addis Zemen Town water supply service

Water loss from water distribution systems (WDSs) has long been a feature of the WDS operations management. According to Motie etal (2007), total water loss or unaccounted for water (UFW) is the difference between the volume of water produced, and the volume that is billed or consumed. The percentage of water loss in the town water distribution system is given in Figure 4.2. According to Figure 4.2, the water loss in 2015 (19.2%) is lower than in 2014 (21.3) due to pump failure, power shortage, and decrease production. The average amount of water, which actually reached the consumers, therefore accounts for only 74.4% of the total water produced. According to Mckenzie et al (2006), the system efficiency is good (acceptable) if above 75% of water produced reaches the consumer. Thus, Addis Zemen Town water supply system is not good. As it can be seen from Figure 4.2 non-revenue water from the system is vary from year to year due to the aging of pipe that leads to leakage, pipe bursting, installation (exestation of network in new area) and illegal connection.

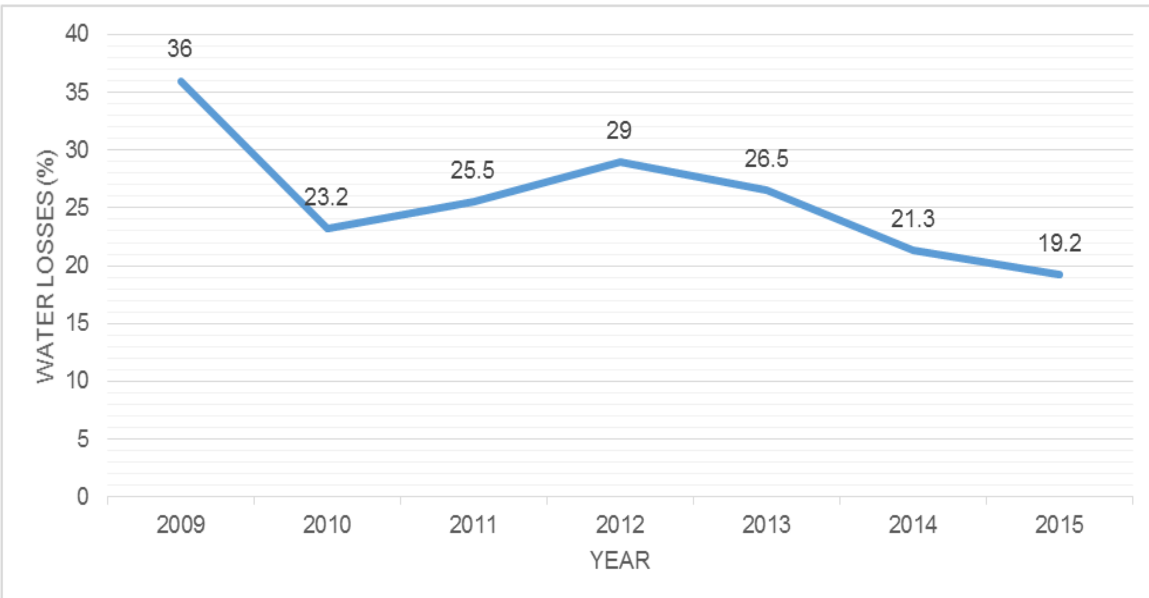

Figure 4. 2 water lost in percentage

4.2.1 Total Water Loss Expressed as Percentage (UFW)

The total annual water produced and consumed within the specified year (2009 to 2015) have been 989851 and 736491 m^3 respectively and the annual total water loss was 253360 m^3 that accounts to 25.6%. Saroj (2008) gives classification and descriptions of UFW as acceptable, which could be monitored and controlled, when the loss is < 10%, as intermediate, which could be control when the loss is 10-25% and as a matter of concern that reduces the water supply when the loss is > 25%. According to this study, based on above expression average water loss in Addis Zemen Town was 25.6%, showing that needs a matter of concern.

4.24. Pipe type and length of AZTWDS

Input parameters for pipes during analysis were start and end nodes, diameter, length, roughness coefficient and status. As depicted in Table 4.2, 33.72% of the distribution system covered by pipe of 50 mm and 17.38% of 80 mm diameter . Pipe of 65 mm diameter is the lowest. It is only 8.24%. The water distribution network length and diameter of town is given in Table 4.2.

Table 4. 2: Pipe size distribution in diameter

Diameter (mm)	Length(m)	%
200	2,345	13.92
150	2,427	14.41
100	2,077	12.33
80	2,926	17.38
65	1,387	8.24
50	5,678	33.72
Total	16840	100

In terms of material type, Galvanize Iron (GI) is the major pipe type in distribution system. As depicted in table 4.3, 65.94% is Galvanize iron. Polyvinyl chloride (PVC) pipes and Ductile Iron are used in smaller percentage 18.74 and 15.31% respectively. Distribution network of town in material type is given in Table 4.3.

Table 4. 3: Distribution of pipe material types at Addis Zemen Town

Pipe type	Length (m)	% in Length
DI	2,579	15.31
PVC	3,156	18.74
GI	11,105	65.94
Total	16,840	100

4.2 Water distribution network simulation

Distribution work starts from the point of water production, where water is produced and made ready to be used (Wonduante, 2013). Figure 4.3 shows the distribution network of the Addis Zemen Town.

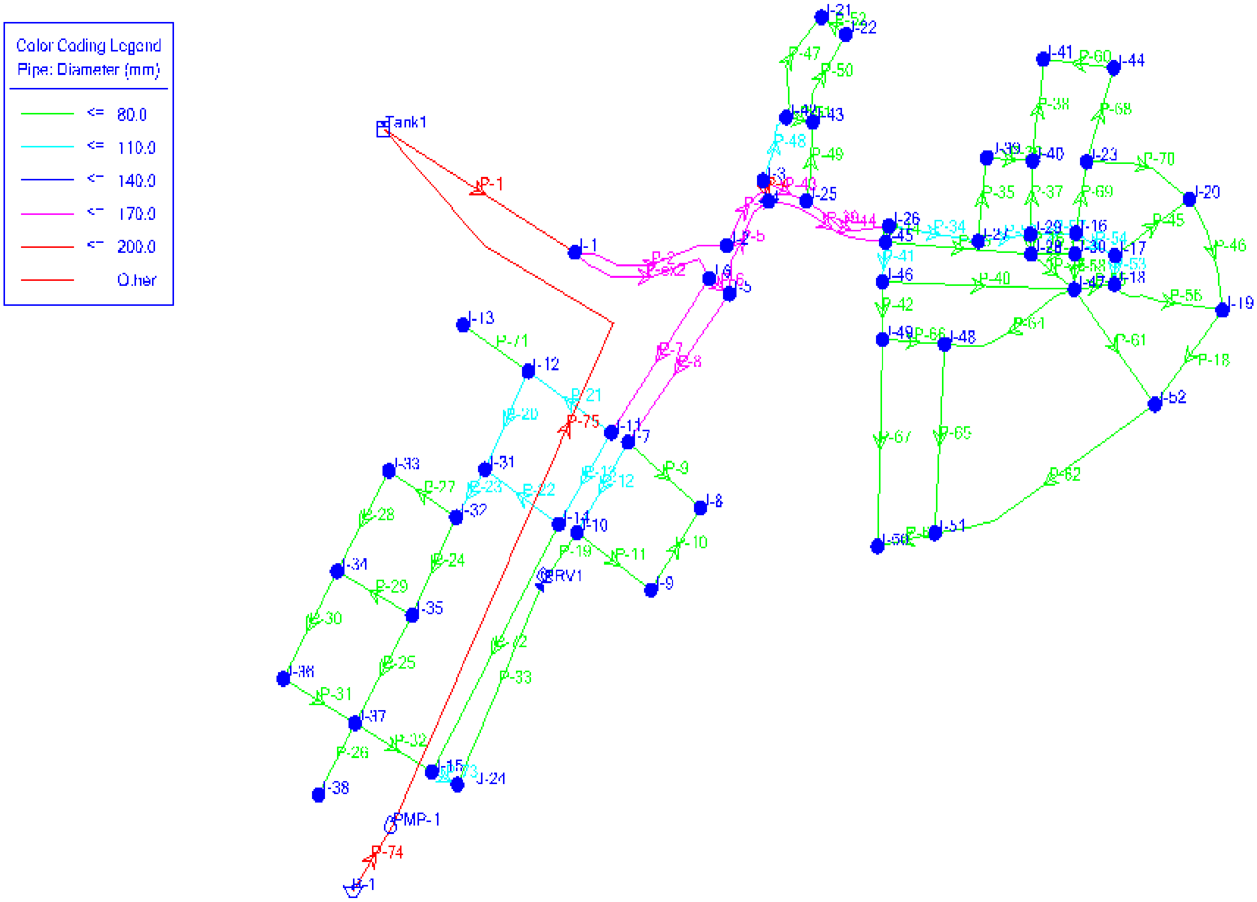

Figure 4. 3 Water distribution network map of Addis Zemen Town

4.3.1 Pressure

During hydraulic modeling of water pressure of Addis Zemen Town, 52 (junctions) nods and 76 pipes were identified. Specific area and nodes distribution in town is given in Table 4.4.

Table 4.4: The area and junction distribution for Addis Zemen Town

No	Area	Nodes
1	Michael Church	4,5,7,8,9,10,14,15,24,45,46,48,49,50 and 51
2	Hana Mariam	16,17,18,19,20,23,27,28,29,30,35,39,41,44,47 and 52
3	Medhanialem	1,2,3,6,11,12,13,21,22,25,26,31,42 and 43
4	Hospital	32,33,34,35,36,37 and 38

The contour map of pressure clearly shows the pressure difference in the whole systems. As it is shown in the Figure 4.4, 11.6% of the higher pressures in the town (>70 m) were observed at 4 junctions (9, 10, 15 and 24) located around Michael suffer and 2 junctions (37 and 38) around Hospital due to low elevation. 86.5% of pressure junction that is the majority of the area has pressure within the optimum range during steady state analysis. 1.9% the lowest pressure recorded was junction 19 about 14 m around Hana church at steady state due to high elevation. The lowest velocity recorded was zero and the highest 2.12 m/s. With regard to steady state simulation the pressure and velocity was summarized in Appendix A1 and A2 respectively. Pressure contour of Addis Zemen Town is given in Figure 4.4.

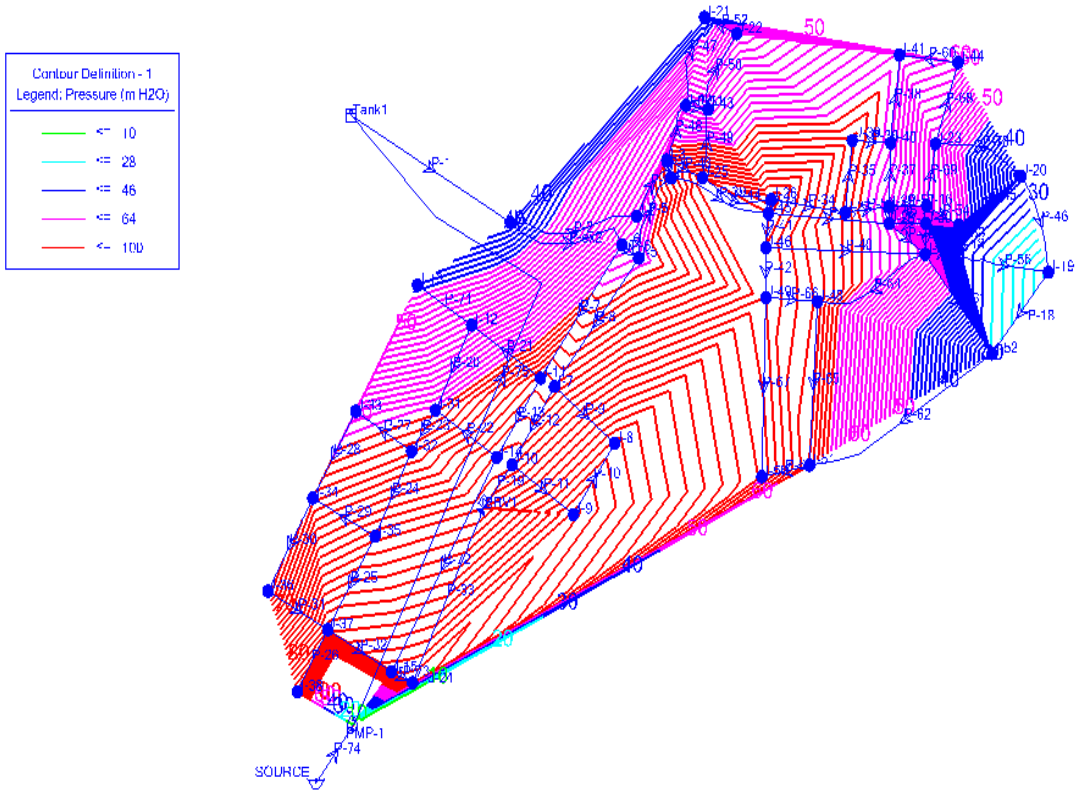

Figure 4. 4 Pressure map of water distribution at steady state (0:0 hour)

The pressure distribution systems affects the capacity of water supply to the town. The Ethiopian guideline criteria for the minimum and maximum operating pressure value in the distribution network are 15 and 70 m respectively (MOWR, 2006).

After hydraulic analysis using Bentley Water CadV8i, as shown in table 4.5, 13.5% of the identified nodes have pressure below 15 m (17, 18, 19,20,23,30 and 52) around Hana Suffer. Specifically junction 18,19,20,52 were negative pressure at peak time consumption and none of the nodes has pressure above 70 m. Thus, only 86.6% of the areas have pressure within the recommended limit (15 to70 m) during peak hour consumption. Lower pressure can cause reduction of quantities of water supplied to the consumer and entry of a contaminant or selfdeterioration of water quality within the network itself a severe damage to public health (Geldreich, 1991). The lowest pressures recorded then was about -19 m at junction 19 during peak consumption. With regard to current simulation, result for pressure at peak consumption is summarized in Table 4.5 and detailed in appendix B1.

Table 4. 5 Distribution of pressure at peak hour consumption

Pressure (m)	Nodes	%
>70	0	0
60-70	1	1.9
50-60	4	7.7
40-50	11	21.2
30-40	12	23.1
20-30	8	15.4
15-20	9	17.3
<15	7	13.5
Total	52	100

As shown in Figure 4.5, the pressure distribution of junction 18, 19 and 52 were negative pressure at peak hour consumption. Booster tank with pump is required to access the water to the consumer at peak consumption.

The pressure distribution of selected nodes at peak hour consumption is given in Figure 4.5.

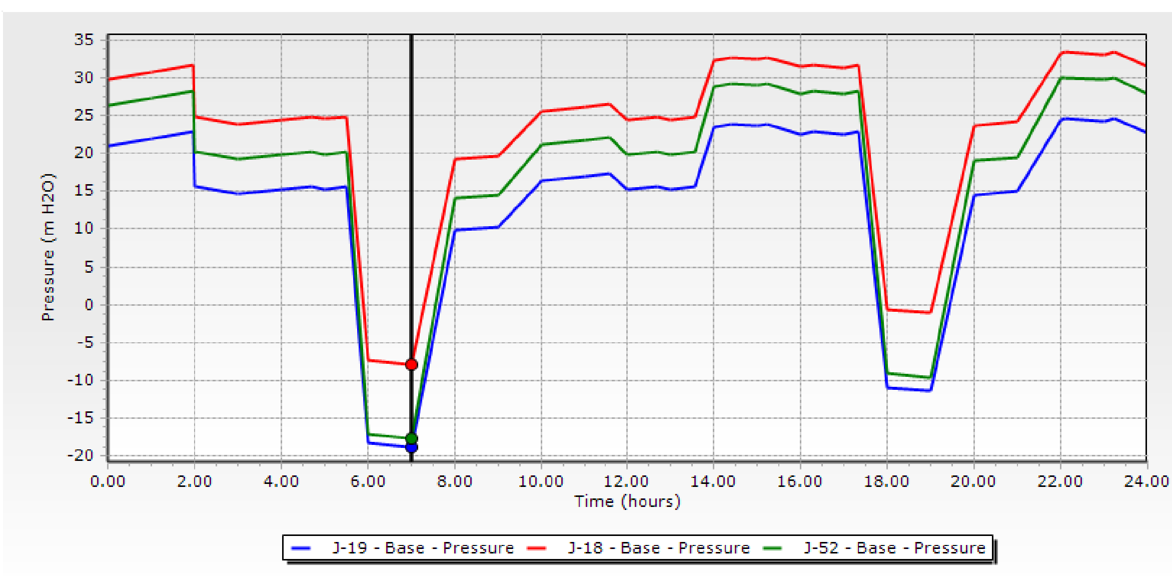

Figure 4. 5 Pressure distribution for selected junction at peak consumption

Households located on higher elevations and close to reservoir site have get water at low water pressure (Ermias, 2014). Variations of pressure during day and night can create operational problems, resulting in increased leakage and malfunctioning of water appliances. Reducing the pressure fluctuations in the system is therefore required (Byakika, 2012).The effects of distance and elevation in pressure distribution in selected nodes is given Figure 4.6.

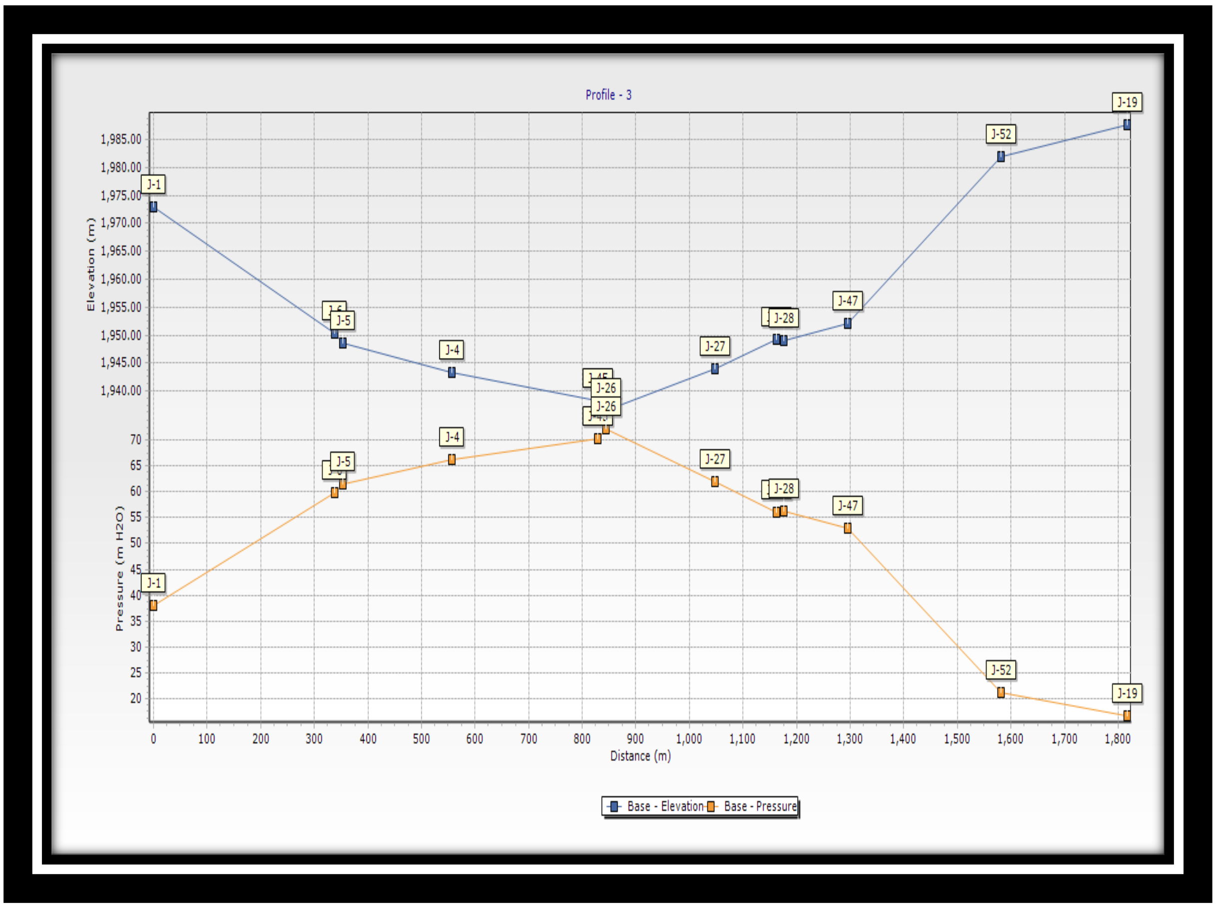

Figure 4. 6 pressure distribution far from service reservoir

According to Totsuka.etal.,(2004), those consumers furthest away from supply points will always collect less water than those nearer to the source due to pressure losses in the network is increasing as far from the source. The Figure 4.6 shows how distance and elevation affect pressure distribution in selected nodes. In Addis Zemen Town residents living in Hana Mariam church get water at low pressure and low water pressure creates a low level of reliability of water users on a water supply system. As shown in Table 4.6, none of the identified nodes has pressure below 15 m and 34.7% of the nodes have pressure above 70 m. Thus, only 65.3% of the areas have pressure within the recommended limit (15 to70 m) during minimum consumption. Higher pressure may cause pipe burst. However, most nodes around Michael area, Addis Zemen hospital, some nodes of Medhanialem church and Hana area, get water above standard pressure (>70m) due to low consumption at mid-night when most of the customers are sleep and not using water. With regard to current simulation, result for pressure at low consumption hour is summarized in Table 4.6 and detailed in appendix B2.

Table 4. 6 Distribution of pressure at minimum consumption time

Pressure(m)	Nodes	%
>70	18	34.7
60-70	17	32.7
50-60	8	15.4
40-50	4	7.7
30-40	3	5.7
20-30	2	3.8
15-20	0	0
<15	0	0
Total	52	100

In general the pressure contour distribution for the town in minimum consumption at midnight is given in Figure 4.7.

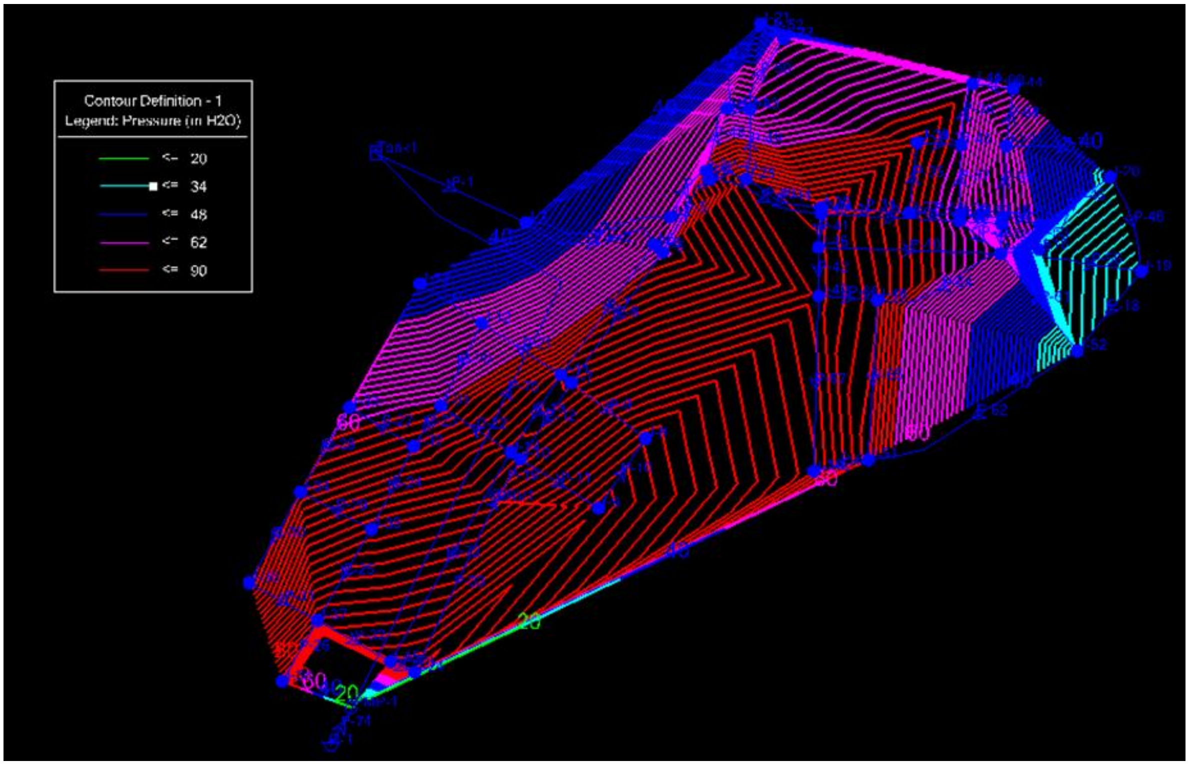

Figure 4. 7 Pressure contour map of Addis Zemen Town at minimum hour consumption

In the case of Addis Zemen Town, the main cause of water supply interruption was water shortage of water from the source, lack of maintenance, improper function of pump and interruption of electric power in pumped pressure system.

4.3.2 Velocity

Control on the flow velocities in water distribution networks should be maintained in order to avoid structural problems or undesirable hydraulic regimes caused by high velocities, or in order to minimize the unfavorable consequences of too low velocities on the quality of the transported water (Tamminen etal, 2008). Velocity range can also be adopted as a design criterion. Low velocities are not preferred for hygienic reasons, while too high velocities cause exceptional head-losses. Figure 4.8, shows velocity is decreasing from the main line to the sub distribution line (for selected pipe).

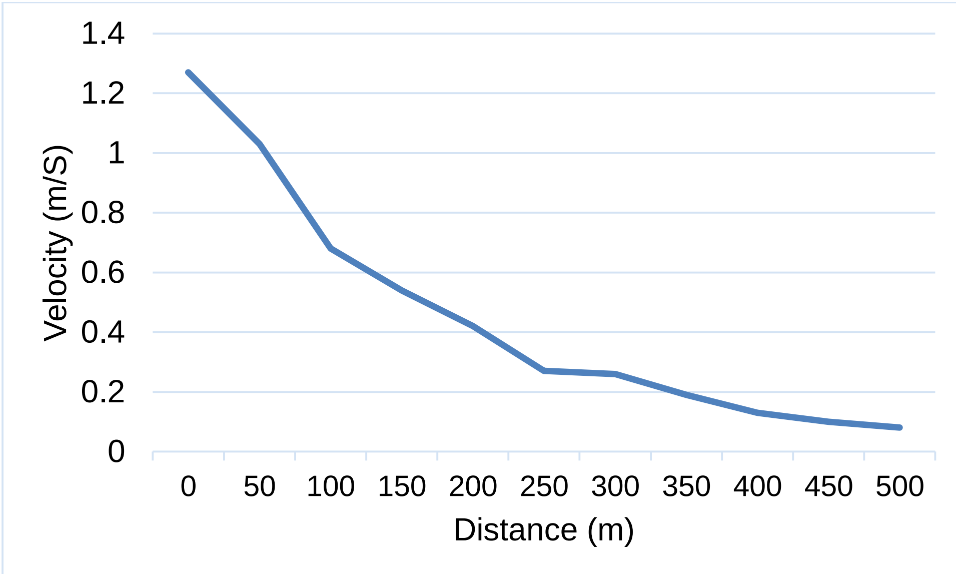

Figure 4. 8 Velocity variation between the node at the main line and sub distribution line

According to Besner et al (2005), velocity of flow in the pipe below 0.6 m/s causes sediment accumulation. Town distribution system velocity in pipe was also inadequate. Velocity in major pipe parts was below 0.6 m/s. Figure 4.9 and detailed in appendix B3 shows velocity in distribution network is in high consumption time for selected pipe.

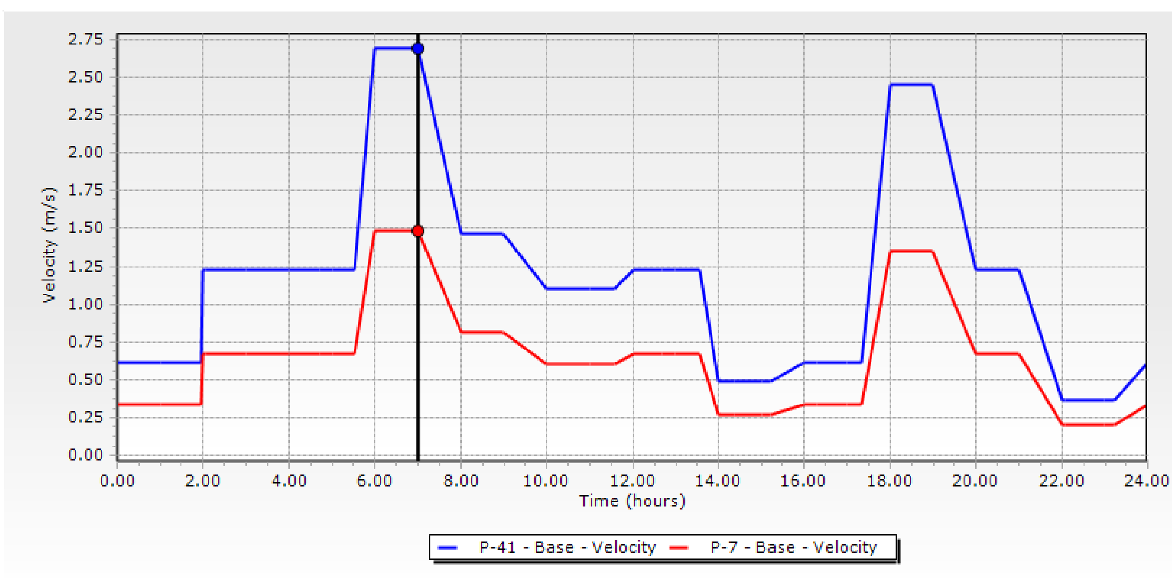

Figure 4. 9 Velocity distribution for selected pipe

4.3.3 Pump curve

A pump curve represents the relationship between the head and flow rate that a pump can deliver water. Pump head is the head gain imparted to the water by the pump and plotted on the vertical of the curve in meter. Flow rate is plotted on the horizontal in litter per second. A valid pump curve must have decreasing head with increasing flow. An efficiency curve determines pump efficiency in vertical percent as a function of pump flow rate in horizontal flow.

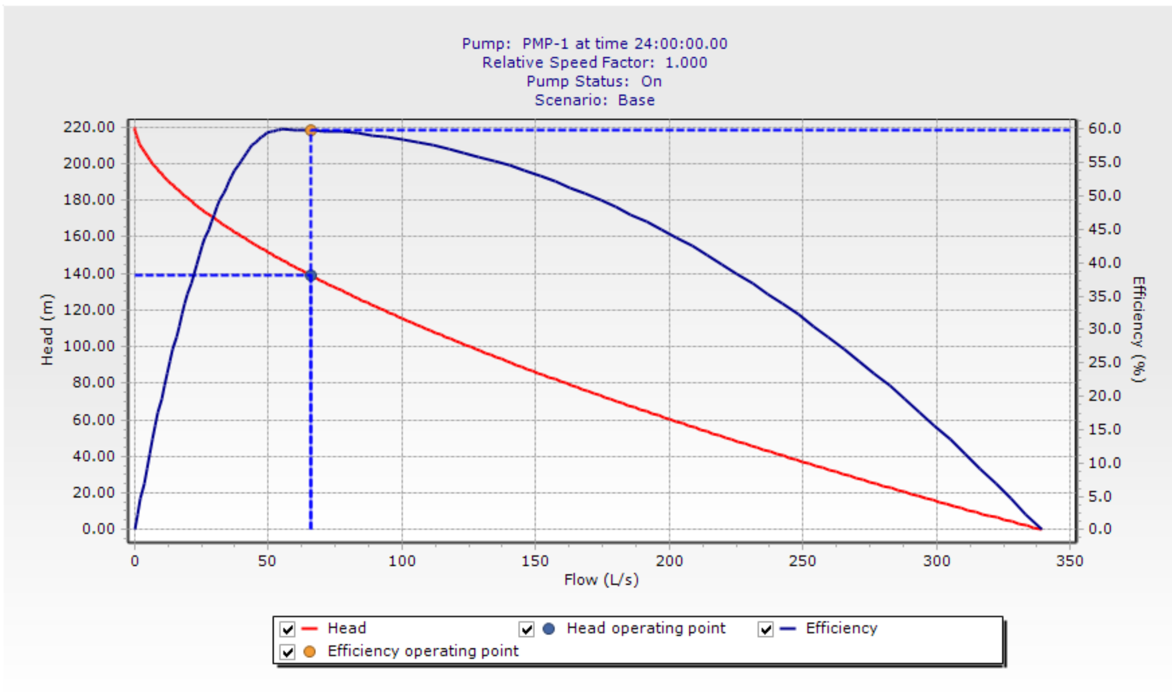

Figure 4. 10 Pump curve

4.4 Population and water demand projection

4.4.1 Population projection

In the 2007 census analytical report, CSA has established growth rates for all regions in the country. The rate that CSA has set for urban population projection of Amhara Regional State is shown in Table 3.4 (section 3.3.6). This was considered for population projection. The population of Addis Zemen Town was estimated to reasonably quantify the inhabitants of the area until the end of the design period (2025). Using geometric mean formula the population of Addis Zemen Town was forecasted and the detail is presented in the Appendix C1 and using chart as follows.

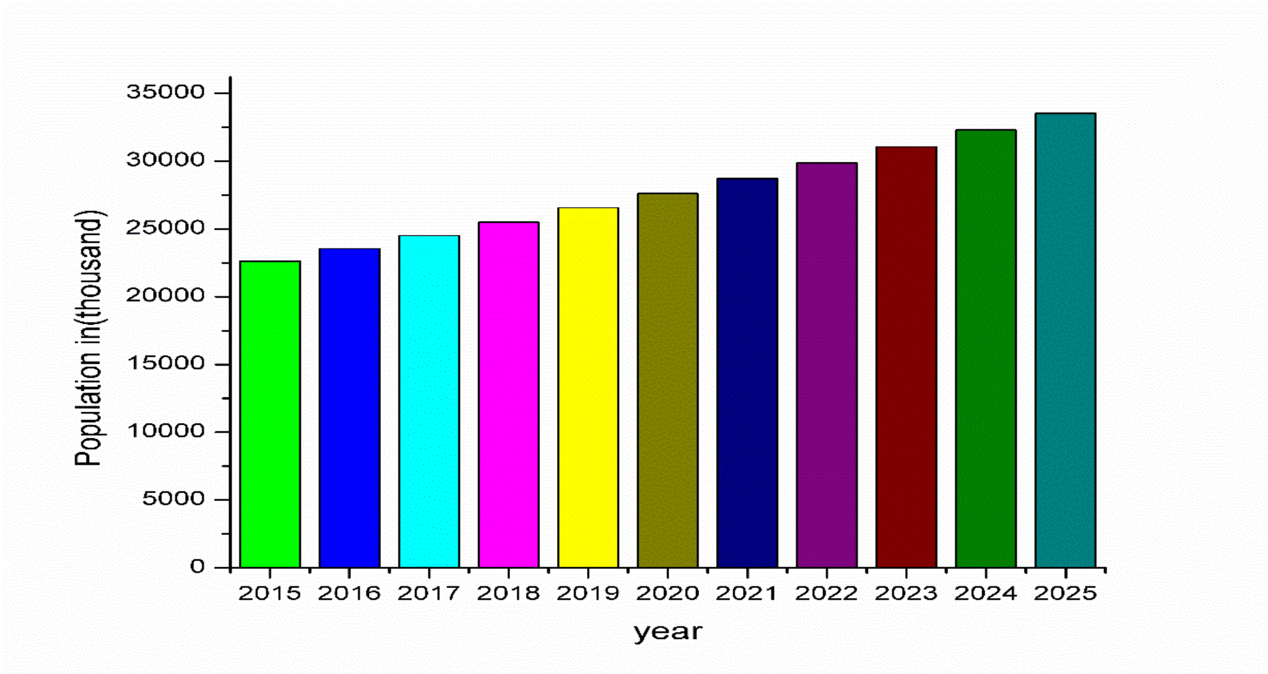

Figure 4. 11 Population projection of Addis Zemen Town for the design period (2015-2025)

4.4.2 Water demand projection

Water managers forecast future water demand for a variety of purposes. These analysis can help managers understand spatial and temporal patterns of future water use to optimize system operations, plan for future water purchases or system expansion, or for future revenue and expenditures. There are several mathematical methods in use for estimating future demand. For this particular study, per capita use approach was employed due to the availability of data and the simplicity of the method. Thus, population was projected from 2015 to 2025 using geometric increases by using regional growth rate and the corresponding water demand per mode of service was estimated till 2025.

According to MOWR (2006), a plan was prepared and entered in to action to improve the water supply schemes of Ethiopian Towns. As the schemes are changed to modern technology, the quality of the water and system of supply also become better than the existing one. This change in quality and supply system makes the people to consume more water that makes the per capita water demand high in the coming years. Population growth influences water demand through increased demand by households, but also indirectly through uses in maintaining particular lifestyles (Pretoriou and Shutte, 1997).

4.4.2.1 Population Projection per Mode of Services

To estimate per capita water demand, the population for each mode of service should be first determined. The distribution of population for each mode of service was determined by considering socio-economic situation and living standard of the town. After establishing the population distribution for the base year a forecast was made. The population projection per mode of service for the design period is given in Table 4.7.

Table 4. 7: Population projection per mode of services

Item	unit	2015	2017	2019	2021	2023	2025
Total population serves	No	22609	24501	26551	28718	31061	33531
➢ HC	%	4.4	4.8	5.4	5.7	6.3	6.77
➢ YCO	%	37.9	42.4	46.34	50.9	55.8	61.23
➢ YCS	%	36.3	33.4	30.26	27	22.6	18
➢ PTU	%	21.4	19.4	18	16.4	15.3	14
Population served	No						
➢ HC	No	995	1176	1434	1637	1957	2270
➢ YCO	No	8569	10388	12304	14617	17332	20531
➢ YCS	No	8207	8183	8034	7754	7020	6036
➢ PTU	No	4838	4753	4779	4710	4752	4694

4.4.2.2 Per capita demand establishment

Based on working standard of the town the per capita demand of water per mode of service is 70, 40, 30 and 25 for HT, YCO, YCS and PCU respectively (AWRDR, 2012). Based on the town master plan and the past trends, the growth rate of water demand in each mode of services assumed is 2% per annum for public tap users and 3% per annum for yard and house connection users. Based on these standards as a base line value, the per capita demand of water was projected till 2025 and presented in Table 4.8 .

Table 4.8: Per Capita Water Demand by mode of service (l/c/d)

Year	2014	2015	2017	2019	2021	2023	2025
HC	82.02	84.48	89.62	95.07	100.86	107.01	113.53
YCO	46.87	48.28	51.22	54.34	57.65	61.16	64.88
YCS	35.15	36.2	38.4	40.74	43.22	45.86	48.66
PTU	25.38	25.88	27.73	28.85	30.02	31.23	32.49

4.4.2.3 Projection of Domestic Water Demand

Estimation of water demand per mode of service and estimation of population by mode of service was used to calculate the average per capita water demand. The average per capita domestic water demand for each year was computed by combining water demand by mode of service and population percentage distribution by mode of service for the year 2015 to 2025 (Appendix C5). After the per capita water demand for each mode of water service has been determined, it was adjusted for climate and socio economic factor. Once the total domestic water is projected, the other demand categories were predicted as per the standard. The detail of adjustment and domestic water demand for each mode of service is presented in Table 4.9.

Table 4.9: Water demand projection of Addis Zemen Town

Year	2015	2017	2019	2021	2023	2025
Population	22609	24501	26551	28718	31061	33531
Total domestic water demand	920.06	1084.2	1270.09	1484.29	1739.79	2035.68
Average per capita domestic demand (l/c/d)	40.69	44.25	47.84	51.69	56.01	60.71
Climatic adjustment factor	1	1	1	1	1	1
Socio-economic Adjustment factor	1	1	1	1	1	1
Adjusted Average Domestic Demand (l/c/d)	40.69	44.25	47.84	51.69	56.01	60.71
Adjusted Domestic Water Demand (m^3/d)	920.06	1084.2	1270.09	1484.29	1739.79	2035.68
Institutional and commercial water demand (10%)	92.006	108.4	127.01	148.43	173.98	203.6
Fire demand (5%)	46.03	54.21	63.5	74.21	86.99	101.78
Average daily water demand(m^3/d)	1058.09	1246.81	1460.6	1706.93	2000.76	2341.06
Uncounted water (25% of average water demand)	264.52	311.7	365.15	426.73	500.19	585.27
Projected average water demand (m^3/day)	1322.61	1558.51	1825.75	2133.66	2500.95	2926.33
Maximum day factor	1.25	1.25	1.25	1.25	1.25	1.25
Maximum daily Water Demand (m^3/day)	1653.26	1948.14	2282.19	2667.08	3126.18	3657.91
Peak hour factor	1.9	1.9	1.9	1.9	1.9	1.9
Peak hour demand(m^3/h)	130.9	123.38	144.54	168.91	197.99	231.67

The total water demand of the town was determined by summing up the adjusted domestic water demand and Non-domestic water demands as shown in Table 4.10. In estimating the overall water demand of water for Addis Zemen town, 25% of total water demand was allowed for losses and wastes. The current demand is 1398.68 m^3/day and water demand at the end of the design period (2025) is 2926.33 m^3/day. The design maximum water production capacity of the source is (1879 m^3/day) but the current average daily production is 950.4 (m^3/day) which is very low due to less working hour, reduction of water from the source, pump failure and lack of maintenance. It is far lower than the demand.

Currently the gap between existing supply and demand is 448.28 m^3/day. The gap will be 1047.33 m^3/day for coming 10 years period. This indicate the need for the development of additional water sources to satisfy the 1047.33 m^3/day water demand of Addis Zemen Town for coming 10 years period.

4.5 Challenges of water supply system in Addis Zemen Town

There are a number of challenges of water supply the study area. The major problems of water supply in the town are rapid population growth, urbanization and socio-economic change of the people. In the town, the demand for water is far outpacing its availability in terms quantity. The provision and expansion of urban water supply requires huge investment. According to discussion with AZWSSE manger lack of sufficient fund has limited for quantity of water supply service in the town. This is exacerbated by technical problems and under estimation of population growth. Besides, lack of skilled labor, non function of pump, lack of power supply to take water from the source to the service reservoir and lack of staff motivation are the constraints to service delivery of Addis Zemen Town. These constraints are the most limiting factors in the implementation of the desired service provision.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The findings of this study revealed that:-

- The average per capita domestic water consumption of the town was found to be 12.98 L/c/d for the base year which only satisfies 26% of the minimum urban water consumption value set by (MOWIE, 2015) and 65% value set by (WHO,2008).
- None revenue water is also high (25%) in the study area through illegal connection (theft), leakage, during installation and pipe bursting.
- 11.6% of the higher pressures in the town (>70 m) were observed at 4 junctions located around Michael suffer and 2 junctions around Hospital due to low elevation. 86.5% of pressure junction that is the majority of the area has pressure within the optimum range during steady state analysis. 1.9% the lowest pressure recorded was junction 19 about 14 m around Hana church at steady state due to high elevation.
- During peak hour consumption, parts of the distribution system receive water with low pressure and under some circumstances risk of obtaining no water is observed because of the pressure in the distribution system is below permissible minimum requirement. 13.5% of the identified nodes have pressure below 15 m were negative pressure at peak time consumption and none of the nodes has pressure above 70 m. 86.6% of the areas have pressure within the recommended limit (15 to70 m) during peak hour consumption. The lowest pressures recorded was about -19 m at junction 19 during peak consumption. For the parts of the system that are located far away from the sources, or have high elevation, it is clearly obvious that they are suffering from low-pressure values. During low consumption time, none of the identified nodes have pressure below 15 m and 34.7% of the nodes have pressure above 70 m. Thus, only 65.3% of the areas have pressure within the recommended limit (15 to70 m). Velocity in distribution network is high in peak consumption time. Velocity of water is decreasing from the main line to the sub distribution line and velocity in major pipe parts was below 0.6 m/s.
- After ten years the water demand for Addis Zemen Town will be 1296.33m^3 /day. Currently the gap between existing supply and demand is 448.28 m3/day. The gap will be 1047.33 m^3/day for coming 10 years period.

5.2. Recommendation

Based on the findings, the following recommendations are made:

- The development of new sources having the production capacity at least 1047.33 m^3/day and expansion of the existing sources should be done to meet increasing water demand.
- Manage the demand by controlling waste or loss from pipe leakage and consumption through the use of meters and tariffs that are set in accordance with the volume of water consumption.
- In order to achieve (15- 70 m), uses of pressure sustaining valves are recommended as to control the occurrences of minimum pressures. These valves start closing if the pressure falls below the preset value as to guarantee allowable minimum pressure for isolated parts of area and also establishing boosting station is recommended. Pressure reducing valve devices which decrease pressure are recommended as solution to control occurrences of maximum pressures for parts of high elevation network.
- A planned and scheduled rationing system should be implemented to supply water equally for residents of the town.

REFERENCES

Abdo (2009) Evaluation of urban water supply options using Weap: The case of Nablus city.

Alaci & Alehegn (2009) Infrastructure Provision and the Attainment of Millennium Development Goals (MDG) in Decentralized Systems of Africa; Experiences from Ethiopia and Nigeria. Abuja, Nigeria.

Amedework (2012) Hydraulic network modeling and upgrading of legedadi subsystem water supply: A case study of Addis Ababa city. MSc Thesis. Addis Ababa University, Addis Ababa, Ethiopia.

Andey & Kelkar (2007) Performance of water distribution system during intermittent versus continuous water supply.

Atiquzzaman (2004) water distribution network modeling :hydroinformatics approach:at io nal university of singapore.

AWRDB (2012) Water supply design guideline.

AWUP (2003) Better water and sanitation for the urban poor; Good Practice from Sub-Saharan Africa, Kenya.

AZWSSE (2014) Addis Zemen Town Water Supply and Sewerage Enterprise Annual Report. Addis Zemen, Ethiopia.

Berhe (2005) Water supply coverage and losses in distribution system: The case of Addis Ababa, Addis Ababa University.

Bhadbhade (2004) Performance evaluation of a drinking water distribution system using Hydraulic simulation software. oilton, pune.

Chase, Dsavic, Grayman, Beckwith & Koelle (2003) Advanced water distribution modeling and management. Haestad Methods, Waterbury, CT.

CSA (2007) Population and Housing Census of Ethiopia. Results for Amhara Regional State, Vol. 1.

Desalegn (2005) Water supply coverage and water losses in distribution system: the case of Addis Ababa , Ethiopia.

Dighade, Kadu & Pande (2014) Challenges in water loss management of water distribution systems in developing countries internatinal journal innovative reseach in science engineering technology, 3, 1-2.

DOH (2009) Water system design manual. Washington State departments of health, division of environmental health of drinking water.

EPA (2010) Control and mitigation of drinking water losses in distribution systems.

Ermias (2014) Assessment of urban water supply and sanitation: the case of Bedesa Town, Damot Woyde woreda,SNNP. MSc Thesis. Hawassa University.

Garg (2010) Water supply Engineering. Twenteeth revised edition,Delhi.

Geldreich (1991) Investigating the outbreak in Cabool, Missouri for a watersupply connection. Proceedings of the AWWARF/EPA Conference on Water Quality Modeling in Distribution Systems, Cincinnati, Ohio.**,** 55-56.

Gottipati & Nanduri (2014) Equity in water supply in intermittent water distribution networks.Water and environment journal promoting sustainable solutions.

Haestad (2003) Water CAD design manual.

Hopkins (2012) Critical node analysis for water distribution system using flow distribution.

Hutton, Haller & Bartram (2007) Global cost benefit analysis of water supply and sanitation, journal of water and health. 5**,** 481-502.

Ilesenim (2006) Pre-feasibility assessment of onsite and decentralized sanitation systems for new satellite settlements in Abuja, Nigeria. PhD Thesis. Hamburg University of Technology.

Jalal (2008) Performance measurment of water distribution systems. Civil Engineering. Toronto.

Karamouz, Szidarovszky & Zahraie (2003) Water resources system analysis lewis publisher. Boca Raton London,Nework Washington,DC.

Khatri & Vairavamoorthy (2007) Challenges for urban water supply and sanitation in the developing countries, discussion draft paper for the session on urbanization delft, The Netherlands.

Kimey, Hoko & Mashauri (2008) Performance of urban water supply utilities. Water Resource Engineering. Deressalaam, Deressalaam University.

Korkeakoski (2006) A guide to sanitation and hygiene for those working in developing countries global dry toilet club.

Maher Abu-Madi & Trifunovic (2013) Impacts of supply duration on the design and performance of intermittent distribution systems in West Bank. journal of water international, 38**,** 263-282.

Mckenzi, Hamilton & Seago (2006) A review of performance indicators for real losses from water supply systems.

Misirdali (2003) A methodology for calculating hydraulic system reliability of water distribution networks

Motiee, Emcbean & Amotiei (2007) Estimating physical unaccounted for water (UFW) in distribution networks using simulation models and GIS. Urban Water Journal, 4**,** 43-42.

MOWE (2011) Urban Water Supply Universal Access Plan PART III (2011-2015), Addis Ababa, Ethiopia.

MOWIE (2015) Second Growth and Transformation National Plan for the Water Supply and

Sanitation Sub-sector.

MOWR (2006a) Universal Access Program for Water Supply and Sanitation Services 2006 to 2012, International Calendar (1999 to 2005 Ethiopian Calendar).

MOWR (2006b) Urban Water Supply Design Criteria.Water Resources Administration Urban Water Supply and Sanitation Department.

Muranho, Ferreira, Gomes & Marques (2013) Technical performance evaluation of water distribution networks based on EPANET. 12th International Conference on Computing and Control for the Water Industry.

Nyende-Byakika, Gaddi Ngirane-Katashaye &Ndambuki (2012a) Comparative analysis of approaches to modeling water distribution. . Civil Engineering and Environmental.

Nyende-Byakika, Ngirane-Katashaya & Ndambuki (2012b) The hydraulic impact of water supply network expansions.

Petingeduld & Zdeneksvitak (2006) Modellng intermittent water supply systems with EPANET.

Piyush Tiwari & Gulati, (2011) Efficiency of urban water supply utilites. International journal of water resources development, 27**,** 361-374.

Prabhata & Sharma (2008) Desgin of water supply pipe networks.

Pretoriou & Shutte (1997) Water Demand and Population Growth. 3**,** 127-133.

Rao (2002) A guide to sanitation and hygiene for those working in developing countries global dry toilet club.

Rossman (2000) EPANET 2 Users Manuel. Water supply and water resources division national risk management research laboratory.

Rossman, Boulos & Altman (2003) The discrete volume element method for modeling water quality in pipe networks, journal of water resources planning and management. 119**,** 56-67.

Sharma, (2008) Performance indicators of water losses in distribution:Delft, the Netherlands.

Tabesh & Dolatkhahi (2006) Effect of pressure dependent analysis on water quality performance assessment of distribution network. Iranian Journal of Science & Technology. 30**,** 119-127.

Tabesh, Jamasb & Moeini (2011) Calibration of wtaer distribution hydraulic model. A comparation between pressure dependent and demand driven analaysis. Urban water journal, 8, 93-102.

Tamminen, Ramos & Covas (2008) water supply system performance for different pipe materials part i. water quality analysis, 8.

Totsuka, Trifunovic & Vairavamoorthy (2004) Intermittent urban water supply under water starving situations.

utkarshnigam, kaoustubhtiwari & darshanmehta (2015) water distribution network re-design for Svnit Surat campus. International Journal of Advance Research in Engineering, Science & Technology, 2**,** 3.

Wallingford (2003) Hand book for assessment of cachment water demand and use.

WHO (2002) Health systems: improving performance. Geneva, Switzerland

Wonduante (2013) Assessing the challenges of sustainable water supply in Gonder Town. MSc thesis, Addis Ababa university.

Zyoud (2003) Hydraulic performance of Palestinian water distribution system. Nablus, An-Najah National University.

APPENDICES

Appendix A 1: Steady state at 0:0 hour Analysis Table for Nodes (Junctions)

Node ID	Northing(m)	Easting(m)	Elevation (m)	Pressure(m)	Demand calculated(l/s)
Junction1	1,340,656.75	366,596.08	1,973.00	37	0
Junction2	1,340,681.12	366,928.42	1,951.66	56	0
Junction3	1,340,771.10	367,013.75	1,943.61	63	2
Junction4	1,340,742.96	367,037.39	1,943.20	63	0
Junction 5	1,340,580.63	366,915.29	1,948.52	58	0
Junction6	1,340,596.38	366,883.07	1,950.44	56	0
Junction7	1,340,278.16	366,706.52	1,940.30	66	1
Junction8	1,340,154.06	366,871.37	1,928.65	76	2
Junction9	1,339,993.33	366,762.75	1,925.99	80	1
Junction10	1,340,099.96	366,588.88	1,936.62	70	0
Junction11	1,340,300.53	366,675.66	1,939.75	66	1
Junction12	1,340,420.29	366,493.76	1,956.01	48	2
Junction13	1,340,510.04	366,351.66	1,965.84	38	0
Junction14	1,340,121.88	366,560.43	1936.56	67	1
Junction15	1,339,639.04	366,283.06	1,921.66	77	2
Junction16	1,340,668.57	367,692.76	1,955.00	47	0
Junction17	1,340,656.33	367,772.20	1,960.73	41	0
Junction18	1,340,540.60	368,046.88	1,978.90	23	0
Junction19	1,340,512.41	368,140.59	1,987.65	14	1
Junction20	1,340,755.47	367,940.41	1,977.83	24	1
Junction21	1,341,113.16	367,136.87	1,967.93	37	1
Junction22	1,341,075.60	367,190.37	1,958.40	46	1
Junction23	1,340,828.30	367,703.09	1,956.65	45	0
Junction24	1,339,620.44	366,304.99	1,921.57	77	1
Junction25	1,340,754.42	367,104.51	1,938.58	67	0
Junction26	1,340,713.83	367,159.79	1,936.50	69	0
Junction27	1,340,678.32	367,479.25	1,943.93	59	2
Junction28	1,340,624.68	367,758.12	1,949.04	53	1
Junction29	1,340,674.44	367,592.73	1,949.23	53	1
Junction30	1,340,355.23	367,866.28	1,963.15	39	0
Junction31	1,340,228.83	366,398.94	1,946.17	57	0
Junction32	1,340,135.08	366,335.71	1,942.74	60	1
Junction33	1,340,226.22	366,188.96	1,947.84	53	1
Junction34	1,340,030.54	366,075.31	1,941.27	59	0
Junction35	1,339,945.12	366,236.81	1,934.33	66	1
Junction36	1,339,820.72	365,957.40	1,943.58	56	0
Junction37	1,339,733.89	366,114.82	1,926.88	73	1
Junction38	1,339,594.30	366,033.90	1,923.26	76	1
Junction39	1,340,834.78	367,497.72	1,942.70	58	0
Junction 40	1,340,830.27	367,598.26	1,946.65	54	2

Junction41	1,340,971.64	367,624.46	1,946.62	54	0
Junction42	1,340,915.61	367,059.34	1,953.84	52	0
Junction43	1,340,912.17	367,112.12	1,954.55	51	0
Junction44	1,340,960.33	367,718.26	1,949.31	51	1
Junction45	1,340,665.47	367,273.76	1,938.34	67	0
Junction46	1,340,594.46	367,269.64	1,938.06	66	2
Junction47	1,340,581.69	367,691.08	1,952.07	50	2
Junction 48	1,340,473.94	367,404.88	1,940.50	61	2
Junction49	1,340,482.18	367,268.11	1,937.43	65	2
Junction50	1,340,077.23	367,259.07	1934.55	64	1
Junction51	1,340,103.01	367,386.01	1,940.44	58	2
Junction52	1,340,108.04	367,390.06	1,982.05	18	1

Appendix A1: Steady state at 0:0 hour Analysis Table for Links

Link ID	Length (m)	Diameter (mm)	Material	Flow (l/s)	Roughness	Velocity (m/s)	Head loss (m/km)
Pipe 1	141	200.0	DI	42	130.0	1.34	9.354
Pipe 2	341	150.0	PVC	21	150.0	1.18	7.900
Pipe 3	138	150.0	PVC	21	150.0	1.18	7.886
Pipe 4	20	200.0	GI	7	120.0	0.21	0.357
Pipe 5	203	150.0	PVC	5	150.0	0.30	0.640
Pipe 6	16	150.0	PVC	9	150.0	0.51	1.656
Pipe 7	367	150.0	PVC	-12	150.0	0.68	2.813
Pipe 8	367	150.0	PVC	3	150.0	0.19	0.256
Pipe 9	213	50.0	GI	1	120.0	0.46	7.496
Pipe 10	194	50.0	GI	-1	120.0	0.40	5.857
Pipe 11	213	80.0	GI	-1	120.0	0.26	1.495
Pipe 12	213	100.0	GI	-2	120.0	0.19	0.666
Pipe 13	213	100.0	GI	6	120.0	0.72	7.608
Pipe 14	16	80.0	GI	0	120.0	0.02	0.009
Pipe 15	318	50	GI	2	120.0	0.66	10.726
Pipe 16	13	80.0	GI	1	120.0	0.14	0.481
Pipe 17	98	50	GI	1	120.0	0.19	1.040
Pipe 18	236	50.0	GI	1	120.0	0.34	4.355
Pipe 19	112	80.0	GI	0	120.0	0.00	0.000
Pipe 20	213	100.0	GI	3	120.0	0.41	2.722
Pipe 21	217	100.0	GI	5	120.0	0.65	6.276
Pipe 22	194	100.0	GI	-2	120.0	0.31	1.656
Pipe 23	112	100.0	GI	5	120.0	0.67	6.664
Pipe 24	213	80.0	GI	-4	120.0	0.71	9.665
Pipe 25	243	80.0	GI	2	120.0	0.44	4.056
Pipe 26	161	50.0	GI	0	120.0	0.00	0.000
Pipe 27	174	50.0	GI	1	120.0	0.59	12.107

Pipe 28	226	50.0	GI	0	120.0	0.18	1.282
Pipe 29	184	50.0	GI	0	120.0	0.21	1.834
Pipe 30	240	50.0	GI	-1	120.0	0.26	2.694
Pipe 31	180	80.0	GI	0	120.0	0.02	0.008
Pipe 32	194	50	GI	1	120.0	0.32	2.846
Pipe 33	444	80.0	GI	0	120.0	0.00	0.000
Pipe 34	203	100.0	PVC	9	150.0	1.19	12.977
Pipe 35	161	50.0	GI	1	120.0	0.57	11.300
Pipe 36	102	50.0	GI	1	120.0	0.41	6.077
Pipe 37	161	50.0	GI	-1	120.0	0.55	10.363
Pipe 38	144	50.0	GI	0	120.0	0.18	1.354
Pipe 39	272	150.0	PVC	12	150.0	0.68	2.880
Pipe40	420	80.0	GI	3	120.0	0.55	5.961
Pipe41	77	100.0	PVC	10	150.0	1.23	13.615
Pipe42	112	80.0	GI	-5	120.0	1.00	18.306
Pipe43	95	150.0	PVC	10	150.0	0.59	2.178
Pipe44	290	150.0	PVC	10	150.0	0.56	2.012
Pipe45	197	80.0	GI	-1	120.0	0.26	1.492
Pipe46	233	50.0	GI	0	120.0	0.14	0.835
Pipe47	226	50.0	GI	1	120.0	0.40	5.923
Pipe48	157	100.0	PVC	2	150.0	0.27	0.799
Pipe49	161	50.0	GI	0	120.0	0.08	0.265
Pipe50	187	50.0	GI	-1	120.0	0.42	6.391
Pipe51	52	50	GI	1	120.0	0.29	2.387
Pipe52	66	50.0	GI	0	120.0	0.08	0.293
Pipe53	56	100.0	GI	0	120.0	0.06	0.080
Pipe54	89	100.0	PVC	-2	150.0	0.26	0.749
Pipe55	89	80.0	GI	1	120.0	0.30	1.936
Pipe56	249	80.0	GI	1	120.0	0.30	1.944
Pipe57	98	100.0	PVC	-4	150.0	0.49	2.533
Pipe58	69	50.0	PVC	0	150.0	0.14	0.563
Pipe59	115	100.0	PVC	7	150.0	0.84	6.701
Pipe60	95	50.0	GI	0	120.0	0.05	0.133
Pipe61	285	50.0	GI	1	120.0	0.40	5.910
Pipe62	548	50.0	GI	-1	120.0	0.29	3.153
Pipe63	128	50.0	GI	0	120.0	0.01	0.008
Pipe64	315	50.0	GI	0	120.0	0.11	0.564
Pipe65	371	50.0	GI	1	120.0	0.50	8.718
Pipe66	138	80.0	GI	2	120.0	0.47	4.572
Pipe67	404	50.0	GI	-1	120.0	0.52	9.570
Pipe68	135	50.0	GI	-1	120.0	0.52	9.302
Pipe69	167	80.0	GI	-2	120.0	0.31	2.076
Pipe70	259	50.0	PVC	0	150.0	0.04	0.053
Pipe71	167	50	GI	0	120.0	0.00	0.000
Pipe72	558	50	GI	-2	120.0	0.57	8.359
Pipe73	120	100.0	GI	1	120.0	0.08	0.117

Pipe74	84	200.0	GI	67	120.0	2.12	25.361
Pipe75	2,100	200.0	GI	67	120.0	2.12	21.867
Pipe76	120	80.0	GI	1	120.0	0.23	1.173

B1: Extended period state Analysis Table for Nodes (Junctions) at peak hour consumption

Node ID	Northing(m)	Easting(m)	Elevation (m)	Pressure (mH_20)	Demand calculated(l/s)
Junction1	1,340,656.75	366,596.08	1,973.00	34	0
Junction2	1,340,681.12	366,928.42	1,951.66	43	0
Junction3	1,340,771.10	367,013.75	1,943.61	47	1
Junction4	1,340,742.96	367,037.39	1,943.20	47	0
Junction 5	1,340,580.63	366,915.29	1,948.52	42	0
Junction6	1,340,596.38	366,883.07	1,950.44	41	0
Junction7	1,340,278.16	366,706.52	1,940.30	50	0
Junction8	1,340,154.06	366,871.37	1,928.65	55	1
Junction9	1,339,993.33	366,762.75	1,925.99	62	0
Junction10	1,340,099.96	366,588.88	1,936.62	53	0
Junction11	1,340,300.53	366,675.66	1,939.75	47	0
Junction12	1,340,420.29	366,493.76	1,956.01	25	1
Junction13	1,340,510.04	366,351.66	1,965.84	15	0
Junction14	1,340,121.88	366,560.43	1936.56	43	1
Junction15	1,339,639.04	366,283.06	1,921.66	38	1
Junction16	1,340,668.57	367,692.76	1,955.00	16	0
Junction17	1,340,656.33	367,772.20	1,960.73	10	0
Junction18	1,340,540.60	368,046.88	1,978.90	-8	0
Junction19	1,340,512.41	368,140.59	1,987.65	-19	0
Junction20	1,340,755.47	367,940.41	1,977.83	-8	0
Junction21	1,341,113.16	367,136.87	1,967.93	16	0
Junction22	1,341,075.60	367,190.37	1,958.40	26	0
Junction23	1,340,828.30	367,703.09	1,956.65	13	0
Junction24	1,339,620.44	366,304.99	1,921.57	38	0
Junction25	1,340,754.42	367,104.51	1,938.58	51	0
Junction26	1,340,713.83	367,159.79	1,936.50	50	0
Junction27	1,340,678.32	367,479.25	1,943.93	32	1
Junction28	1,340,624.68	367,758.12	1,949.04	23	0
Junction29	1,340,674.44	367,592.73	1,949.23	23	0
Junction30	1,340,355.23	367,866.28	1,963.15	9	0
Junction31	1,340,228.83	366,398.94	1,946.17	32	0
Junction32	1,340,135.08	366,335.71	1,942.74	32	0
Junction33	1,340,226.22	366,188.96	1,947.84	18	0
Junction34	1,340,030.54	366,075.31	1,941.27	23	0
Junction35	1,339,945.12	366,236.81	1,934.33	32	0
Junction36	1,339,820.72	365,957.40	1,943.58	18	0
Junction37	1,339,733.89	366,114.82	1,926.88	35	0
Junction38	1,339,594.30	366,033.90	1,923.26	39	0

Junction39	1,340,834.78	367,497.72	1,942.70	25	0
Junction 40	1,340,830.27	367,598.26	1,946.65	19	1
Junction41	1,340,971.64	367,624.46	1,946.62	18	0
Junction42	1,340,915.61	367,059.34	1,953.84	36	0
Junction43	1,340,912.17	367,112.12	1,954.55	35	0
Junction44	1,340,960.33	367,718.26	1,949.31	15	0
Junction45	1,340,665.47	367,273.76	1,938.34	49	0
Junction46	1,340,594.46	367,269.64	1,938.06	44	1
Junction47	1,340,581.69	367,691.08	1,952.07	20	1
Junction 48	1,340,473.94	367,404.88	1,940.50	30	1
Junction49	1,340,482.18	367,268.11	1,937.43	36	1
Junction50	1,340,077.23	367,259.07	1934.55	22	0
Junction51	1,340,103.01	367,386.01	1,940.44	17	1
Junction52	1,340,108.04	367,390.06	1,982.05	-18	0

B2 : Extended period state Analysis Table for Nodes (Junctions) at minimum hour consumption

Node ID	Northing(m)	Easting(m)	Elevation (m)	Pressure (mH_20)	Demand calculated(l/s)
Junction1	1,340,656.75	366,596.08	1,973.00	40	0
Junction2	1,340,681.12	366,928.42	1,951.66	60	0
Junction3	1,340,771.10	367,013.75	1,943.61	68	1
Junction4	1,340,742.96	367,037.39	1,943.20	69	0
Junction 5	1,340,580.63	366,915.29	1,948.52	63	0
Junction6	1,340,596.38	366,883.07	1,950.44	61	0
Junction7	1,340,278.16	366,706.52	1,940.30	72	0
Junction8	1,340,154.06	366,871.37	1,928.65	83	1
Junction9	1,339,993.33	366,762.75	1,925.99	86	0
Junction10	1,340,099.96	366,588.88	1,936.62	75	0
Junction11	1,340,300.53	366,675.66	1,939.75	72	1
Junction12	1,340,420.29	366,493.76	1,956.01	55	1
Junction13	1,340,510.04	366,351.66	1,965.84	46	0
Junction14	1,340,121.88	366,560.43	1936.56	75	1
Junction15	1,339,639.04	366,283.06	1,921.66	89	1
Junction16	1,340,668.57	367,692.76	1,955.00	56	0
Junction17	1,340,656.33	367,772.20	1,960.73	50	0
Junction18	1,340,540.60	368,046.88	1,978.90	32	0
Junction19	1,340,512.41	368,140.59	1,987.65	23	1
Junction20	1,340,755.47	367,940.41	1,977.83	33	1
Junction21	1,341,113.16	367,136.87	1,967.93	44	0
Junction22	1,341,075.60	367,190.37	1,958.40	53	0
Junction23	1,340,828.30	367,703.09	1,956.65	54	0
Junction24	1,339,620.44	366,304.99	1,921.57	89	0
Junction25	1,340,754.42	367,104.51	1,938.58	73	0
Junction26	1,340,713.83	367,159.79	1,936.50	75	0
Junction27	1,340,678.32	367,479.25	1,943.93	67	1

Junction28	1,340,624.68	367,758.12	1,949.04	62	1
Junction29	1,340,674.44	367,592.73	1,949.23	62	0
Junction30	1,340,355.23	367,866.28	1,963.15	48	0
Junction31	1,340,228.83	366,398.94	1,946.17	65	0
Junction32	1,340,135.08	366,335.71	1,942.74	68	0
Junction33	1,340,226.22	366,188.96	1,947.84	63	0
Junction34	1,340,030.54	366,075.31	1,941.27	70	0
Junction35	1,339,945.12	366,236.81	1,934.33	77	0
Junction36	1,339,820.72	365,957.40	1,943.58	67	0
Junction37	1,339,733.89	366,114.82	1,926.88	84	1
Junction38	1,339,594.30	366,033.90	1,923.26	87	0
Junction39	1,340,834.78	367,497.72	1,942.70	68	0
Junction 40	1,340,830.27	367,598.26	1,946.65	64	1
Junction41	1,340,971.64	367,624.46	1,946.62	64	0
Junction42	1,340,915.61	367,059.34	1,953.84	58	0
Junction43	1,340,912.17	367,112.12	1,954.55	57	0
Junction44	1,340,960.33	367,718.26	1,949.31	61	0
Junction45	1,340,665.47	367,273.76	1,938.34	73	0
Junction46	1,340,594.46	367,269.64	1,938.06	73	1
Junction47	1,340,581.69	367,691.08	1,952.07	59	1
Junction 48	1,340,473.94	367,404.88	1,940.50	71	1
Junction49	1,340,482.18	367,268.11	1,937.43	74	1
Junction50	1,340,077.23	367,259.07	1934.55	76	1
Junction51	1,340,103.01	367,386.01	1,940.44	70	1
Junction52	1,340,108.04	367,390.06	1,982.05	20	0

B3 : Extended period state Analysis Table for Link at peak hour consumption

Link ID	Length (m)	Diameter (mm)	Material	Roughness	Flow (l/s)	Velocity(m/s)	Head loss (m/km)
Pipe 1	141	200.0	DI	130.0	93	2.95	40.288
Pipe 2	341	150.0	PVC	150.0	46	2.59	34.024
Pipe 3	138	150.0	PVC	150.0	46	2.59	33.964
Pipe 4	20	200.0	GI	120.0	15	0.47	1.555
Pipe 5	203	150.0	PVC	150.0	12	0.67	2.757
Pipe 6	16	150.0	PVC	150.0	20	1.11	7.116
Pipe 7	367	150.0	PVC	150.0	-26	1.49	12.114
Pipe 8	367	150.0	PVC	150.0	7	0.41	1.102
Pipe 9	213	50.0	GI	120.0	2	1.01	32.297
Pipe 10	194	50.0	GI	120.0	-2	0.88	25.241
Pipe 11	213	80.0	GI	120.0	-3	0.57	6.441
Pipe 12	213	100.0	GI	120.0	-3	0.42	2.867
Pipe 13	213	100.0	GI	120.0	12	1.57	32.767
Pipe 14	16	80.0	GI	120.0	0	0.05	0.074
Pipe 15	318	65.0	GI	120.0	5	1.45	46.196
Pipe 16	13	80.0	GI	120.0	2	0.31	2.038
Pipe 17	98	65.0	GI	120.0	1	0.41	4.482

Pipe 18	236	50.0	GI	120.0	1	0.75	18.759
Pipe 19	112	80.0	GI	120.0	0	0.00	0.000
Pipe 20	213	100.0	GI	120.0	7	0.90	11.721
Pipe 21	217	100.0	GI	120.0	11	1.42	27.030
Pipe 22	194	100.0	GI	120.0	-5	0.69	7.128
Pipe 23	112	100.0	GI	120.0	12	1.47	28.705
Pipe 24	213	80.0	GI	120.0	-8	1.56	41.626
Pipe 25	243	80.0	GI	120.0	5	0.97	17.471
Pipe 26	161	50.0	GI	120.0	0	0.00	0.000
Pipe 27	243	50.0	GI	120.0	3	1.31	52.143
Pipe 28	161	50.0	GI	120.0	1	0.39	5.520
Pipe 29	184	50.0	GI	120.0	-1	0.47	7.902
Pipe 30	240	50.0	GI	120.0	-1	0.58	11.605
Pipe 31	180	80.0	GI	120.0	0	0.03	0.036
Pipe 32	194	65.0	GI	120.0	2	0.71	12.257
Pipe 33	444	80.0	GI	120.0	0	0.00	0.000
Pipe 34	203	100.0	PVC	150.0	21	2.63	55.892
Pipe 35	161	50.0	GI	120.0	2	1.26	48.666
Pipe 36	102	50.0	GI	120.0	2	0.90	26.175
Pipe 37	161	50.0	GI	120.0	-2	1.20	44.634
Pipe 38	144	50.0	GI	120.0	1	0.40	5.831
Pipe 39	272	150.0	PVC	150.0	27	1.50	12.406
Pipe40	77	80.0	GI	120.0	6	1.20	25.671
Pipe41	420	100.0	PVC	150.0	21	2.70	58.638
Pipe42	77	80.0	GI	120.0	-11	2.20	78.839
Pipe43	95	150.0	PVC	150.0	23	1.29	9.384
Pipe44	190	150.0	PVC	150.0	22	1.24	8.665
Pipe45	197	80.0	GI	120.0	-3	0.57	6.427
Pipe46	233	50.0	GI	120.0	-1	0.31	3.597
Pipe47	226	50.0	GI	120.0	2	0.89	25.510
Pipe48	157	100.0	PVC	150.0	5	0.58	3.442
Pipe49	161	50.0	GI	120.0	0	0.17	1.141
Pipe50	187	50.0	GI	120.0	-2	0.93	27.524
Pipe51	52	65.0	GI	120.0	2	0.64	10.283
Pipe52	66	50.0	GI	120.0	0	0.18	1.265
Pipe53	56	100.0	GI	120.0	1	0.14	0.348
Pipe54	89	100.0	PVC	150.0	-4	0.56	3.226
Pipe55	89	80.0	GI	120.0	3	0.65	8.341
Pipe56	249	80.0	GI	120.0	3	0.65	8.373
Pipe57	98	100.0	PVC	150.0	-9	1.09	10.908
Pipe58	69	50.0	PVC	150.0	-1	0.31	2.429
pipe59	115	100.0	PVC	150.0	14	1.84	28.861
pipe60	95	50.0	GI	120.0	0	0.11	0.575
pipe61	285	50.0	GI	120.0	2	0.89	25.453
pipe62	548	50.0	GI	120.0	-1	0.63	13.580
pipe63	128	50.0	GI	120.0	0	0.02	0.034

pipe64	315	50.0	GI	120.0	0	0.25	2.429
pipe65	371	50.0	GI	120.0	2	1.10	37.549
pipe66	138	80.0	GI	120.0	5	1.04	19.690
pipe67	404	50.0	GI	120.0	-2	1.15	41.218
pipe68	135	50.0	GI	120.0	-2	1.13	40.066
pipe69	167	80.0	GI	120.0	-3	0.68	8.941
pipe70	259	50.0	PVC	150.0	0	0.09	0.232
pipe71	167	65.0	GI	120.0	0	0.00	0.000
pipe72	558	65.0	GI	120.0	-4	1.26	35.999
pipe73	120	100.0	GI	120.0	1	0.17	0.504
pipe74	84	100.0	GI	120.0	66	2.11	25.046
pipe75	124	100.0	GI	120.0	66	2.11	21.595
pipe76	120	80.0	GI	120.0	3	0.50	5.056

B4: Extended period state Analysis Table for Link at minimum hour demand

Link ID	Length(m)	Diameter (mm)	Material	Roughness	Flow (l/s)	Velocity (m/s)	Head loss (m/km)
Pipe 1	141	200.0	DI	130.0	17	0.54	1.714
Pipe 2	341	150.0	PVC	150.0	8	0.47	1.448
Pipe 3	138	150.0	PVC	150.0	8	0.47	1.445
Pipe 4	20	200.0	GI	120.0	3	0.09	0.067
Pipe 5	203	150.0	PVC	150.0	2	0.12	0.117
Pipe 6	16	150.0	PVC	150.0	4	0.20	0.307
Pipe 7	367	150.0	PVC	150.0	-5	0.27	0.515
Pipe 8	367	150.0	PVC	150.0	1	0.07	0.047
Pipe 9	213	50.0	GI	120.0	0	0.18	1.374
Pipe 10	194	50.0	GI	120.0	0	0.16	1.074
Pipe 11	213	80.0	GI	120.0	-1	0.10	0.274
Pipe 12	213	100.0	GI	120.0	-1	0.08	0.122
Pipe 13	213	100.0	GI	120.0	2	0.29	1.394
Pipe 14	16	80.0	GI	120.0	0	0.01	0.000
Pipe 15	318	65.0	GI	120.0	1	0.26	1.966
Pipe 16	13	80.0	GI	120.0	0	0.06	0.092
Pipe 17	98	65.0	GI	120.0	0	0.07	0.190
Pipe 18	236	50.0	GI	120.0	0	0.14	0.798
Pipe 19	112	80.0	GI	120.0	0	0.00	0.000
Pipe 20	213	100.0	GI	120.0	1	0.16	0.499
Pipe 21	217	100.0	GI	120.0	2	0.26	1.150
Pipe 22	194	100.0	GI	120.0	-1	0.13	0.304
Pipe 23	112	100.0	GI	120.0	2	0.27	1.221
Pipe 24	213	80.0	GI	120.0	-1	0.28	1.771
Pipe 25	243	80.0	GI	120.0	1	0.18	0.744
Pipe 26	161	50.0	GI	120.0	0	0.00	0.000
Pipe 27	243	50.0	GI	120.0	0	0.24	2.218
Pipe 28	161	50.0	GI	120.0	0	0.07	0.235

Pipe 29	184	50.0	GI	120.0	0	0.09	0.336
Pipe 30	240	50.0	GI	120.0	0	0.11	0.494
Pipe 31	180	80.0	GI	120.0	0	0.01	0.002
Pipe 32	194	65.0	GI	120.0	0	0.13	0.522
Pipe 33	444	80.0	GI	120.0	0	0.00	0.000
Pipe 34	203	100.0	PVC	150.0	4	0.48	2.378
Pipe 35	161	50.0	GI	120.0	0	0.23	2.071
Pipe 36	102	50.0	GI	120.0	0	0.16	1.113
Pipe 37	161	50.0	GI	120.0	0	0.22	1.899
Pipe 38	144	50.0	GI	120.0	0	0.07	0.248
Pipe 39	272	150.0	PVC	150.0	5	0.27	0.527
Pipe40	77	80.0	GI	120.0	1	0.22	1.092
Pipe41	420	100.0	PVC	150.0	4	0.49	2.495
Pipe42	77	80.0	GI	120.0	-2	0.40	3.354
Pipe43	95	150.0	PVC	150.0	4	0.24	0.398
Pipe44	190	150.0	PVC	150.0	4	0.23	0.369
Pipe45	197	80.0	GI	120.0	-1	0.10	0.273
Pipe46	233	50.0	GI	120.0	0	0.06	0.153
Pipe47	226	50.0	GI	120.0	0	0.16	1.085
Pipe48	157	100.0	PVC	150.0	1	0.11	0.146
Pipe49	161	50.0	GI	120.0	0	0.03	0.049
Pipe50	187	50.0	GI	120.0	0	0.17	1.171
Pipe51	52	65.0	GI	120.0	0	0.12	0.438
Pipe52	66	50.0	GI	120.0	0	0.03	0.054
Pipe53	56	100.0	GI	120.0	0	0.02	0.013
Pipe54	89	100.0	PVC	150.0	-1	0.10	0.137
Pipe55	89	80.0	GI	120.0	1	0.12	0.355
Pipe56	249	80.0	GI	120.0	1	0.12	0.356
Pipe57	98	100.0	PVC	150.0	-2	0.20	0.465
Pipe58	69	50.0	PVC	150.0	0	0.06	0.104
Pipe59	115	100.0	PVC	150.0	3	0.33	1.228
Pipe60	95	50.0	GI	120.0	0	0.02	0.023
Pipe61	285	50.0	GI	120.0	0	0.16	1.083
Pipe62	548	50.0	GI	120.0	0	0.11	0.578
Pipe63	128	50.0	GI	120.0	0	0.00	0.001
Pipe64	315	50.0	GI	120.0	0	0.05	0.103
Pipe65	371	50.0	GI	120.0	0	0.20	1.597
Pipe66	138	80.0	GI	120.0	1	0.19	0.838
Pipe67	404	50.0	GI	120.0	0	0.21	1.754
Pipe68	135	50.0	GI	120.0	0	0.21	1.704
Pipe69	167	80.0	GI	120.0	-1	0.12	0.381
Pipe70	259	50.0	PVC	150.0	0	0.02	0.010
Pipe71	167	65.0	GI	120.0	0	0.00	0.000
Pipe72	558	65.0	GI	120.0	-1	0.23	1.532
Pipe73	120	100.0	GI	120.0	0	0.03	0.021
Pipe74	84	100.0	GI	120.0	66	0.00	24.792

Pipe75	124	100.0	GI	120.0	66	0.00	21.376
Pipe76	120	80.0	GI	120.0	0	0.09	0.215

Appendix C 1: Population projection of Addis Zemen town

Year	Growth rate%	Population
2007	4.5	16113
2008	4.5	16838
2009	4.5	17596
2010	4.3	18353
2011	4.3	19142
2012	4.3	19965
2013	4.3	20823
2014	4.3	21718
2015	4.1	22609
2016	4.1	23536
2017	4.1	24501
2018	4.1	25505
2019	4.1	26551
2020	4	27613
2021	4	28718
2022	4	29866
2023	4	31061
2024	4	32303
2025	3.8	33531

Appendix C 2: Average per-capita water demand projection per mode of service

year	Per-capita water demand per mode of services(l/c/day)			
	HC	YCO	YCS	PT
2007	71.4	39.98	30.60	25.25
2008	72.83	40.8	31.21	25.50
2009	74.28	41.62	31.84	25.76
2010	75.77	42.45	32.47	26.02
2011	77.29	43.30	33.12	26.28
2012	78.83	44.16	33.78	26.54
2013	80.41	45.05	34.46	26.80
2014	82.02	45.95	35.15	27.07
2015	84.48	48.28	36.2	25.88
2016	87.01	49.73	37.29	26.92
2017	89.62	51.22	38.4	27.73
2018	92.3	52.76	39.55	28.28
2019	95.07	54.34	40.74	28.85
2020	97.92	55.97	41.96	29.43
2021	100.86	57.65	43.22	30.02

2022	103.89	59.38	44.52	30.62
2023	107.01	61.16	45.86	31.23
2024	110.22	62.99	47.24	31.85
2025	113.53	64.88	48.66	32.49

Appendix C3: Addis Zemen Town Population distribution (%) per each mode of service

year	HCU	YCO	YCS	PTU	Total
2007	2.7	22.3	47	28	100
2008	2.9	24.3	45.5	27.3	100
2009	3.1	26	44.3	26.6	100
2010	3.3	27.7	42.9	26.1	100
2011	3.53	29.73	41.6	25.14	100
2012	3.7	31.6	40.3	24.4	100
2013	3.9	33.5	39	23.6	100
2014	4.1	35.7	37.7	22.5	100
2015	4.4	37.9	36.3	21.4	100
2016	4.6	40	35.1	20.3	100
2017	4.8	42.4	33.4	19.4	100
2018	5.2	44.3	31.8	18.7	100
2019	5.4	46.34	30.26	18	100
2020	5.5	48.6	28.7	17.2	100
2021	5.7	50.9	27	16.4	100
2022	6	53.3	24.8	15.9	100
2023	6.3	55.8	22.6	15.3	100
2024	6.5	58.4	20.5	14.6	100
2025	6.77	61.23	18	14	100

Appendix C4: Population of Addis Zemen Town by mode of service for the year

year	HC	YCO	YCS	PTU	total
2007	435	3593	7573	4512	16113
2008	488	4092	7661	4597	16838
2009	545	4575	7795	4681	17596
2010	606	5084	7873	4790	18353
2011	676	5691	7963	4812	19142
2012	739	6309	8040	4871	19965
2013	812	6976	8121	4914	20823
2014	890	7753	8188	4887	21718
2015	995	8569	8207	4838	22609
2016	1083	9414	8261	4778	23536
2017	1176	10388	8183	4753	24501
2018	1326	11299	8111	4769	25505
2019	1434	12304	8034	4779	26551
2020	1519	13420	7925	4749	27613
2021	1637	14617	7754	4710	28718
2022	1792	15919	7407	4749	29866
2023	1957	17332	7020	4752	31061
2024	2010	18865	6622	4716	32303
2025	2270	20531	6036	4694	33531

Appendix C5: Domestic water demand per mode of service in m^3/day

year	HC	YCO	YCS	PTU	TOTAL	average	Adjusted percapita demand
2007	31.06	143.65	231.73	113.93	520.37	32.29	32.29
2008	35.54	166.95	239.09	117.22	558.8	33.19	33.19
2009	40.48	190.41	248.19	120.58	599.66	34.08	34.08
2010	45.91	215.82	255.64	124.64	642.01	34.98	34.98
2011	52.25	246.42	263.73	126.46	688.86	35.99	35.99
2012	58.26	278.6	271.59	19.28	737.73	36.95	36.95
2013	65.29	314.27	279.85	131.69	791.1	37.99	37.99
2014	72.99	356.25	287.8	133.61	850.65	39.17	39.17
2015	84.06	413.71	297.09	125.2	920.06	40.69	40.69
2016	94.23	468.16	308.05	128.62	999.06	42.45	42.45
2017	105.39	532.07	314.22	132.52	1084.2	42.95	42.95
2018	122.39	596.14	320.79	108.73	1148.05	45.01	45.01
2019	136.33	668.59	327.3	137.87	1270.08	47.84	47.84
2020	148.74	751.12	332.53	139.76	1372.15	49.69	49.69
2021	165.1	842.67	335.13	141.39	1484.29	51.69	51.69
2022	186.17	945.27	329.76	145.41	1606.61	53.79	53.79
2023	209.42	1060.03	321.94	148.4	1739.79	56.01	56.01
2024	221.54	1188.3	312.82	150.2	1872.86	57.98	57.98
2025	257.71	1332.05	293.42	152.5	2035.68	60.71	60.71

Appendix C6: Projected water demand for Addis Zemen Town

Year	DWD	ICWD	FWD	UWD	Total water demand
2007	520.37	52.04	26.01	130.09	728.51
2008	558.8	55.88	27.94	139.7	782.32
2009	599.66	59.97	29.98	149.92	839.53
2010	642.01	64.1	32.2	160.5	898.81
2011	688.86	68.89	34.44	172.22	964.41
2012	737.73	73.77	36.89	184.43	1032.82
2013	791.1	79.1	39.56	197.78	1107.54
2014	850.65	85.06	42.53	212.66	1190.87
2015	920.06	92.06	46.03	264.52	1322.51
2016	999.06	99.9	49.95	249.77	1398.68
2017	1084.2	108.4	54.21	311.7	1558.51
2018	1148.05	114.8	57.4	287.01	1607.26
2019	1270.09	127.01	63.5	365.15	1825.75
2020	1372.15	137.22	68.6	343.04	1921.01

2021	1484.29	148.43	74.2	426.73	2133.66
2022	1606.61	160.66	80.33	401.65	2249.25
2023	1739.79	173.98	86.99	500.19	2500.95
2024	1872.86	187.29	93.64	468.15	2621.94
2025	2035.68	203.6	101.78	585.27	2926.33