URBAN WATER SUPPLY SYSTEM PERFORMANCE ASSESMENT: THE CASE OF ASSOSA TOWN, ETHIOPIA.

By

ABEBE AMADO MENTOSEA

A THESIS SUBMITTED TO

THE FACULTY OF WATER RESOURCE AND IRRIGATION ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR DEGREE OF MASTER OF SCIENCE IN WATER RESOURCE ENGINEERING AND MANAGEMENT.

JULY 2022

HAWASSA, ETHIOPIA

HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY

SCHOOL OF RESEARCH AND GRADUATE STUDIES

FACULTY OF WATER RESOURCE AND IRRIGATION ENGINEERING

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M.SC. THESIS

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JULY 2022

HAWASSA, ETHIOPIA

Declaration

First, I declare that this thesis is my work and that all sources of materials used in this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirement for the degree of Master of Science in water resources engineering and management at Hawssa University. I confidently declare that I have not submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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We, the undersigned, members of the Board of examiners of the final open defense by ABEBE AMADO MANTOSE have read and evaluated his thesis entitled **"URBAN WATER SUPPLY SYSTEM PERFORMANCE ASSESMENT: THE CASE OF ASSOSA TOWN",** and examine the candidate.

This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree of **Master of Science in Water Resource Engineering and Management.**

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Abstract

Intermittent water disruption is the key problem of many water authorities in developing countries including Ethiopia. Water demand has been increasing significantly in most cities due to population growth and other factors. As a result, town water utilities are struggling to provide customers with adequate and reliable water supply service despite obstacles that hinder water utilities not to provide the required service. This study assesses the performance of Assosa town water supply system based on main performance indicators namely Demand and supply, water loss, water quality, customer satisfaction, and. operation and maintenance. These indicators have been cited as the main factors, which reflect the performance of many urban water supply systems. High water loss, customer complaints, and operation and maintenance problems indicate that there are deficiencies in the quality of the service. To conduct this research, data of water production and consumption, water supply system data were obtained from the water utility records, other data not found in the water utility records is collected using instruments. Hydraulic performance of the system is also evaluated by modeling the system. Water quality tests were conducted and compared with the national and international standards. Household interviews were made to understand customers' satisfaction towards the water supply. There is a frequent interruption of boreholes. The water quality test shows some parameters departed from the standard set on the Ethiopian and WHO water quality guidelines. In addition, there is customer's complaint towards continuous access of water. The operation and maintenance in the town is identified to be poor. In conclusion, the town's water supply system is poor in managing water loss, water quality, operation and maintenance with the worst condition of continuous generation of water from sources continuously interruption. It is recommended that the water utility develop a strategy and work hard on the indicated system deficiencies especially on operation and maintenance to improve the water supply system performance and provide customers with good quality service.

KEY WORD: water loss, operation and maintenance, hydraulic water CAD modeling, Assosa Town, Benishangul-Gumuz region, Ethiopia.

Acknowledgment

First, I would like to thank Almighty God for providing me with good health, wisdom and strength throughout my duty and help me to complete this thesis successfully. Secondly, my major advisors, Dr. Mihret Dananto (Ass.professer) and my co-advisor, Desalegn Jawisso (PhD) appreciation for constructive comment and suggestion to succeed this thesis. Thirdly, for Benishangul-Gumuz Regional State Water, Irrigation and Energy Resource Development Bureau to give this enjoyable chance with cooperative to Hawassa University thanks so much. Indeed, without their great dedication, the development and completion of this study would have been impossible. Moreover, I wish to express my deepest gratitude to my brother Tektel Amado and for all friends those of supporting financial and social ideal day to day activities by strengthen my motivation to success this alignment chance, I have deepest sense of gratitude and humble thanks to my loving wife Tigist Wasu and my sisters and brothers who are always helped me without any reward.

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List of Acronyms and Abbreviation

AASTU	Addis Ababa Science and Technology University
AWWA	American Water Works Association
CAPL	Current Annual Volume of Physical Losses
CSA	Central Statistics Agency
CWT	Clear Water Tank
CWPS	Clear Water Pumping Station
DN	Nominal Diameter
DCI	Ductile Cast Iron
DP	Distribution Point
EEP	Ethiopian Electric Power
EFC	Environmental Finance Center
EPA	Environmental protection Agency
ETB	Ethiopian Birr
EWRA	European Water Resources Association
FDRE	Federal democratic Republic of Ethiopia
Fig	Figure
GI	Galvanized Iron
G.C	Gregorian calendar
GIS	Geographical Information System
GPS	Global Position System
HH	House Hold
HDR	Henning sons Durham & Richardson (Architecture & Engineering Firm)
ILI	Infrastructure Leakage Index
IMF	International Monetary fund
ITCZ	Inter Tropical Convergence Zone
IWA	International Water Association
LCB	Lahore Cantonment Board
MAAPL	Minimum Achievable Annual Physical Losses
m.a.s.l.	Meter above sea level
Mg/l	Milligram per litre
Ml	Mili litre

MoWIE	Ministry of Water, Irrigation and Electric
NFFs	Needed Fire Flows
NRC	National Research Council
NRW	Non Revenue Water
NTU	Nephelometric Turbidity Units
RW	Non Revenue Water
BGWWCE	Benishangul Gumuz Water Works Construction Enterprise
PF	Public Fountain
PLC	Private Limited Company
PRVs	Pressure Release Valves
PVC	Polyvinyl Chloride
RC	Reinforced Concrete
RSWW	Standard for Water Works
RWPS	Raw Water Pumping Station
SI	System International
SPSS	Statistical Package for Social Science
SSF	Slow Sand Filter
UARL	Unavoidable Annual Real Loss
UfW	Unaccounted for Water
USAID	United States Agency for International Development
WDNs	Water Distribution Networks
WDS	Water Distribution System
WHO	World Health Organization
WUAM	Water Utility Asset Management
BGWSSE	Benshangul Gumuz Water Supply & Sewerage Enterprise

CHAPTER ONE

1. INTRODUCTION

1.1 Background and justification

Water is the primary need to sustain life; every citizen in the country has the right to have access to potable water. Provision of safe and adequate water supply services is necessary components for sustainable development. The provision of adequate supplies potable water for use in urban areas in developing countries is crucial for the well-being of the people. The demand for such supplies in the developing countries has been on the increase over time because of rising standards of living that occur with economic progress and population increase resulting from natural growth, and rural urban migration and rising per capital income. The estimated water supply service level of Ethiopia in terms of coverage, quantity, quality and reliability is very low. A well performing urban water supply system should provide water supply for human being and livestock consumption, for industrial and other uses in terms of coverage, quantity, reliability and acceptable quality taking the existing and future realities of the city in to consideration. This research paper assessed and evaluated the performance of Assosa water supply system in terms of for main performance indicators such as water supply coverage, water quality, water loss, operation and maintenance and customer satisfaction and recommend solutions for improving the water supply service. The research paper includes brief assessment of physical and social conditions of infrastructures, water sources and potentially existing and future water requirement of the town.

The overall objective of this project is to design sustainable and reliable water supply system for the studied area. This water supply system will improve quantity, quality and level of service for the 20 years projected population of Assosa town and rural kebles along pressure line in base year. Design report of Assosa town and rural kebeles along pressure line water supply project considers two design phases duration of which consists 20 years from year 2022-2031 and from year 2032-2041 for phase-1 and phase-2 respectively. Base population Assosa town in the year 2019 which is projected from CSA 2007 is 55583 and 12143 for rural Keble's along pressure line. Population projection has been made using geometrical increase method because of the fast increase of population of the town; accordingly, the total projected population at the end of the design period is calculated to be 16487 and 122,427 for rural Keble and Assosa town respectively. Demand projections were also made throughout the design periods. The major mode of levels of services considered in this project is yard tap users (YTU), house tap users and public tab users.

The maximum day demand and peak hour demand of the town at the end of the design period is estimated to be 15.04lit/sec and 30.08 lit/sec and 375.39 lit/sec and 675.97 lit/sec respectively for both rural Keble's and the town respectively. The proposed water supply structures for the project are distribution networks, pressure line with total length of 146.96km & 45km respectively, 3000m3 & 2000m3 reinforced concrete service reservoirs for zone-1 and zone-2 respectively.

1.2 Statement of the problem

Regarding coverage and water availability the capacity of the water supply system, which encompass sources, transmission, storage facilities, and distribution system should satisfy current and future demands. In case of Assosa Town, the sources do not satisfy the demand of present and future population and the distribution system do not cover the whole part of the town. The water supply coverage was not assessed before. There are villages in the town, which are out of the reach of distribution pipes, and villages with distribution pipes but unavailability of water most of the time. In addition to insufficient water supply coverage, high water loss and water quality issues are the major challenges of Assosa water supply system. As the water lost, is non-revenue water it has also economic effects because the water utility is losing revenue. High leakage also contributes to water quality risks due to possible infiltration of contaminated especially in areas of poor sanitation.

1.3 Objectives of the study

1.3.1 General objective

To assess the performance of Assosa Town water supply system in connection with water demand and supply, water loss, water quality, operation and maintenance, customer satisfaction.

1.3.2 Specific objectives

- To assess the existing water demand and supply balance in Assosa Town.
- To evaluate the hydraulic performance of the distribution network including water loss using the Water CAD software.
- To assess the water quality level with chemical, physical and biological aspects and compare the results with national and international standards.
- To know the level of customers satisfaction towards the water supply service.
- To evaluate the operation and maintenance status of the water supply system.

1.4 Research questions

- How is the water supply system accessibility and service reliability?
- What is the present water supply coverage of Assosa Town?
- How is the water quality compared with national and international standards?
- Are customers satisfied with the service?
- Does the water supply system have a system map and database of the system components?
- What are the main causes of water loss and distribution problems?
- What are the main operation and maintenance problems?

1.5 Significance of the study

It is expected that the deficiencies of the water supply system which encompass the estimate of unaccounted water and causes for the high water loss is assessed and known, water supply coverage and water quality level will be determined. Besides customer, satisfaction towards the service and operation and maintenance condition will also be analyzed. The assessed and analyzed results and estimates will in turn contribute to know the overall performance level of the system. Besides the results, help decision makers and especially the town water utility in planning of future expansions and to know areas of water loss and develop corrective measures to reduce the high water loss, improve coverage, service reliability and water quality to make the system more efficient and increase water supply service level. It may also give a clue for further research.

1.6 Scope of the study

This study is limited to existing water supply system and do not include the first Phase of water supply improvement project of the city which is under construction. This study also does not include the other incoming to the subsystem and outgoing from the subsystem but I consider the data of water incoming or out going. Besides the performance assessment, do not include tariff, billing system and management and financial aspect of the water utility.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Performance indicators of urban water supply systems

Before evaluating the performance of urban water supply system, it is important to develop appropriate performance indicators. The following are suggested performance indicators for evaluating urban distribution systems (EWRA Water Utility Journal 1:31-40, 2011). The indicators of urban water supply system are grouped under water resources performance, physical performance, and operational performance. Water resources availability and the availability of own water is mainly categorized under the water resource performance indicator. The capacity of storages, quality of the transmission and distribution lines and the density of the metered customers are taken as physical performance. On the other hand, loss management, the operation and maintenance as well as quality of water supplied fall under operational performance.

A study set out to assess the performance of two urban water supply utilities in Sudan shows there are serious water supply problems in the districts under study. The assessment was based on two main indicators, which are the quality of service and unaccounted for water. The quality of the service and UfW has been cited as some of the major factors, which reflect the performance of many water utilities. Poor service quality as measured by the water quality, billing efficiency and customer care, affects consumer willingness to pay and consequently the performance of the water supply utility. Methods used in the study included documentary review, household questionnaires, key informant interviews and field observations. The results show that accessibility and reliability of water supply in Muheza. Town is inadequate compared to Korogwe town. On average customers, receive water for 8 hours per day in Korogwe and 5 hours per day in Muheza. Water supplied by the respective utilities in the two districts is far below the total demand. More than 80% of customer complaints in both towns were about water quality, water shortage and customer relations. Poor billing practices and old infrastructure have resulted in high UfW of 42% in Korogwe and 47% in Muheza. The conclusion, therefore, was that the customers were not satisfied with quality of services and that the UfW was higher than the generally accepted value of 25% suggested by the World Bank. (Assessment of the Performance of Urban Water.

Supply Utilities:-By Victor Kimey June, 2008) However, this research paper will assess the performance of the Assosa Town water supply system not the water utility and the assessment is based on five main indicators which are, Water source availability, Hydraulic performance, water quality ,Customer satisfaction and operation and maintenance.

2.1.1 Urban Water Demand and Coverage

Water supply coverage provides a picture of the water supply situation of one specific country or city and helps to compare one country with others and the inter and intra city distribution with in specific country. The percentages of population with or without pipe water connection are a relevant indicator to compare the coverage of water supply in urban areas. Although the water supply coverage is better in urban areas while compared with the rural, the actual water supply coverage in cities of developing countries in general and African cities in particular is very low while compared to the demand. According to the Global Water Supply and Sanitation Assessment 2000 Report, the African largest cities are having 43% house connection or yard tap, 21 % served by public tap while 31% of the population are un-served (WHO, 2000). A household is considered to have access to improved drinking water if it has sufficient amount of water (201iters/person/day) for family use, at an affordable price (less than 10% of the total household income), available to household members without being subject to extreme effort (less than one hour) a day for the minimum sufficient quantity), especially to women and children) (UN-Habitat, 2003). On the other hand a minimum quantity of 25 liters of potable water per person per day provided at a minimum flow rate of not less than 10 liters per minute with the source being available within 200 meters from a household and the supply not interrupted for more than seven days per year (i.e. water should be available 98% of the time) is considered as a basic service for southern African cities‟ domestic water supply (Wallingford HR., 2003). Ethiopia has long been characterized by limited access to safe drinking water services. In 1990, for instance, only 19 percent of the country's population had access to a safe drinking water supply (Degnet Abebaw et al, 2011). By 2007, this figure had reached 52 percent.

Table 1.Percentage of Ethiopia's populations with access to safe drinking water, for selected

Year	1996	1998	2000	2004	2006	2007
Urban	72.0	84.0	92.0	92.0	78.8	82.0
Rural	10.0	14.0	17.0	25.0	41.2	46.4
Tota	19.0	24.0	28.0	36.0	47.3	52.5

(**Source**: MoFED 2007.)

2.1.2 Water Demand Management

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Wallingford HR., 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use. Water demand management refers to any socially beneficial action that reduces average or peak water withdrawals or consumption form either surface or ground water, consistent with the protection or enhancement of water quality (Tate, 2000). According to Rothert and Macy (2000), water demand management is the adaptation and implementation of a strategy by a water institution to influence the water demand and usage to meet any of the following objectives: economic efficiency, social development, social equity (Mwendera et al,, 2003). Urban water demand is classified in to different category that domestic water demand that includes in-house-use and out-of-house-use is among the others. In-house-use includes demands for drinking, cooking, sanitation, house cleaning, laundry and car washing while out-of-house-use includes like garden watering, swimming pools, public stand pipes for public uses and fountains, etc. Urban water demand is usually quoted in terms of liter per capita per day (1/cap/day). Despite the variation in residential indoor water use from household to household, a typical pattern (referred to as the water use profile) can be developed to provide a reasonable representation of indoor water use, based on the different indoor water use components (kitchen, bathroom, laundry, and toilet) and household occupancy. (Mitchell et al, 2000). In many African cities, urban water demands are often non- homogeneous owing to a range of levels of service occurring within the same urban area. Levels of service can vary from household connections to standpipes or no service at all. (Wallingford HR).

2.2 Water loss

Water losses occur in all water distribution networks, even new one and it is only the volume that varies. Thereby, the volume of these losses reflects the capacity of water authorities to manage their distribution networks (Dighade, et al., 2014). In general, „water losses consist of real and apparent losses. In addition, to most water utilities, the level of Non-Revenue Water (NRW) is a key performance indicator of efficiency. Utility managers should use the water balance to calculate each component and determine where water losses are occurring. By quantifying NRW from the water balance concept, volumes of lost water into system can be calculate and they will then prioritize and implement the required policy changes and operational practices which lead to the proper understood and take the required actions‟ (Farley, et al., 2008).

Therefore, the water balance can guides water loss estimation in the distribution system while also indicating the level of accuracy of the Non- Revenue Water calculation.

Table 2.Water balance showing NRW components; IWA water loss task force

<table>
<tr><td rowspan="9">System Input Volume for known errors)</td><td rowspan="4">Authorized consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
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<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer metering</td></tr>
</table>

2.2.1 Some Definitions of UFW

There is no universally applied or accepted definition of unaccounted-for water. In general, unaccounted-for water (UFW) is the difference between the water supplied to a distribution system and the water that leaves the system through its intended use (Richard G. et al., 2000) UFW may be defined as percentage of the water produced from the raw water source which is not accounted for (MWAC, 1999). UFW is defined as the difference between water delivered to the distribution system and water sold (Yepes, 1995). The term Unaccounted-for Water (UFW) refers to an accumulated range of losses that will be experienced by Water Utility when comparing the system demand of a hydraulic water network with the quantity of water that is acknowledged as consumed by the water consumers residing within the network (UNEDP 2000), If the term UFW ia used at all, it should be defined and calculated in the same way as non-revenue water (NRW) (Faerley and Trow 2003)

2.2.2 Non- Revenue Water (NRW)

Non-revenue water (NRW) is the total amount of water losses in the system from the water treatment plant outlet meter to the customers meter and it consists of real loss and apparent losses. Thus, it is described as the difference of total amount of water production and authorized

$$NRW = System\ Input\ Volume - Billed\ Authorized\ Consumption --(2.1)$$

consumption figure.

Unaccounted-for-water also expressed as a percentage and, has generally evaluated as the amount of water produced minus the metered customer use divided by the amount of water produced and multiplied by 100 (EPA, 2010).

$$\%\ unaccounted\ for\ water = \frac{water\ produced - meter\ water\ used * 100}{water\ produced} --(2.2)$$

2.2.3 Causes of water losses

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

Leakage from transmission and distribution mains

Leakages occurring from transmission and distribution mains are usually large in volume. Thus, considerable volume of water is lost through bursts, leaking pipes, joints, valves and fittings of distribution system components. These causes are usually as result of age of the installations, bad quality of materials used, and poor workmanship. Although this factors were lead to reduction of pressure in the distribution network and intermittent in water supply (Dighade, et al., 2014).

Leakages from reservoirs and storage tanks

Leakage and overflows from reservoirs and storage tanks are easily quantified. By observing overflows, utility experts can estimate the duration and flow rate of the events. While, most overflows occur at night when demands are low, therefore it is essential to undertake regularly night observations. Observations can be undertaken either physically or by installing a data logger, which record reservoir levels automatically at preset intervals. In addition, leakage from tanks is calculated using a drop test were the utility closes all inflow and outflow valves, measures the rate of water level drop, and then calculates the volume of water lost (Farley, et al., 2008).

Leakage on service connections up to the customer's meter

This leakage is more difficult to identify and it covers the greatest volume of physical losses. So that, utility experts can calculate the approximate volume of leakage in service connections by deducting the mains leakage and storage tank leakage from the total volume of physical losses (Farley, et al., 2008).

Commercial Loss and Real loss

Commercial loss is also refers to as apparent losses, and it consist of unauthorized consumption, all types of metering inaccuracies and data handling errors. It also includes water that is consumed but not paid by the users (Farley, et al., 2008). In the developing countries, metering inaccuracies (mainly under recorded problem) and illegal users of water within the distribution system is the common problem of water losses. Whereby, they contribute large coverage to apparent losses, so the levels of these losses were one of the significant concerns in developing country water distribution systems (Dighade, et al., 2014). Therefore, apparent losses can amount to a large volume of water than physical losses and often have a greater value, since reducing apparent losses increases revenue, whereas physical losses reduce production costs. For any profitable utility, the water tariff will be higher than the variable production cost and sometimes up to four times higher. Thus, even a small volume of apparent loss will have a large financial impact‟ (Farley, et al., 2008). Physical losses, on the other hand, sometimes called real losses, are the annual volumes lost through all types of leaks, bursts, and overflows on mains, service reservoirs and service connections up to the point of customer metering. Therefore, utility managers must verify the physical loss assessment of town's water distribution system (Farley, et al., 2008).

2.3 Hydraulic Modeling for Distribution Network Evaluation

Water utilities are facing the high level of water loss in their distribution networks. For many utilities, reducing loss should be the first option to pursue when addressing low service coverage levels and increased demand for piped water supply. However, expanding water distribution networks without addressing water losses will only lead to a cycle of waste and inefficiency (Frauendorfer & Liemberger, 2010). However, there is no simple solution to reduce water losses in the distribution system especially in the developing world, it should be involving improvements not only regard to the water system, but also required a change in attitudes. Also understanding how leakages are currently performing and collecting relevant data, and turning it into useful information for planning and good information systems‟ are essential to water loss reduction polices (Farley, et al., 2008). In general, using a computer model; assessing the hydraulic behaviors and evaluating the performance of existing towns‟ water distribution network are advantageous. Therefore, making hydraulic simulation software, especially from hydraulic point view using engineering approach is one of the method used for discussion and decision measure on the system, either is the system within level of service based on pressure consideration or not (Hussni & Zyoud, 2003).

2.3.1 Components of water distribution network

- **Transmission and distribution mains**

In the water distribution system, piping system is often categorized as transmission/trunk mains and distribution mains (Tomas, et al., 2003).

- **Transmission mains**

Transmission mains were consist of components that are convey large amounts of water over great distances, typically between major facilities within the distribution system. In most water supply system, transmission main are mainly used to transport water from treatment plant to service reservoirs/ storage tanks. Whereby, individual customers are usually not served from these mains.

- **Distribution mains**

Distribution mains are an intermediate pipeline used to delivering water from transmission main to customers. The mains are smaller in diameter than transmission mains, and typically follow the general topology and alignment of the town streets. Different fittings such as elbows, tees, reducers, crosses and numerous other accessories are used in the main to connect pipes. While other maintenance and operational appurtenances, such as fire hydrants and valves are connected directly to the distribution mains. Further, services also called service line were laid and transmit water from the distribution mains to end customers.

- **Reservoir and storage tanks**

In the water distribution system, reservoir and storage tanks are mainly provided to meet the fluctuations of water demand and to stabilize pressure within the distribution system. Similarly, these components were reserve water for emergency requirements. Accordingly, the common reservoirs established in the water supply system are circular and/or rectangular type, which builds either from concrete or steel materials. In addition, the recommended location of such facilities is mainly in elevated area beyond the center of service area (NRC, 2006).

- **Pump Stations**

Pumps are used for convey energy to the water to boost water at higher elevations. Most pumps used in the water supply systems are centrifugal, and are installed to improve the water distribution, if gravity is insufficient to supply water at an adequate pressure. So that, to control the operational condition of pumps switchboards was provided in the station. (NRC, 2006; Chambers, et al, 2004).

- **Accessory Equipment's**

The accessory equipment in the water distribution pipelines can be classified as fittings, valves (such as; control valves, air release valves, pressure reducing valves, etc.), hydrants, drainage facility, flow meters, etc. All these accessories have been installed at places were necessary for connecting the network, controlling and management of the system, and for maintenance purposes during failure is occur (Bhadbhade, 2009).

2.3.2 Factors causing loss of hydraulic integrity in water distribution network

In most of the developing regions, the design of water distribution systems is based on the assumption of direct supply, although most of these systems are intermittent systems which result in severe supply, insufficient pressure in the distribution system (pressure losses in several areas in the network), inequitable distribution of the available water and very short duration of supply (Hussni & Zyoud, 2003). However, the purpose of hydraulic integrity in the water distribution system is to supply water at adequate/acceptable pressure and flow. However, according to (Chambers, et al., 2004; NRC, 2006; Tomas, et al., 2003; Marta & Rudolf, 1987; Hickey, 2008; Dighade, et al., 2014) the most common factors for intermittent water supply and loss of hydraulic integrity in the distribution system are;

- **Low pressure**

However, there is pressure loss by the action of friction at the pipe wall and its magnitude also dependent on the water demand, properties of the fluid that is passing through the pipe, the speed at which it is moving, in addition, and the internal roughness of the pipe, pipe length, gradient and diameter of the pipe. Such situations may occur where there are: properties on high ground, remote properties at the end of long lengths of pipe, demands that are greater than the design demand, pipes of inadequate capacity (too small diameter), rough pipes (e.g. corroding iron pipes or pipes with a build-up of sediment) and equipment failures such as pumps and valves. In general, poor pressures tend to be caused by inadequate capacity in a pipe or pump, high elevations, or some combination of the two (Chambers, et al., 2004). Therefore, one of the hydraulic integrity is maintaining adequate water pressure inside the pipe. Hence, the water utilities should achieve a high degree of hydraulic integrity through a combination of proper system design, operation, and maintenance along with good monitoring.

- **High pressure during low demand conditions**

High pressure during low demand conditions can cause pipe bursting, leakage and large amount of water losses through the distribution networks. Therefore, when dealing with high pressures, PRVs should be used to reduce and regulate pressure in the system (Tomas, et al., 2003). Accordingly, pipes and pumps must be sized to overcome these problem and to provide acceptable pressure in the system. Although, sizing of control valves based on the desired flow conditions and pressure differential is vital (NRC, 2006).

- **Pump Capacity**

A pump is device in which mechanical energy is applied and transferred to the water as total head, and these head is a function of flow rate through the pump (Tomas, et al., 2003). While, the failures, location, size and capacity of pumps in water distribution are the major impacts for low flow or negative pressures arise in the system, and this can lead to intermittent water supply in the distribution system (Chambers, et al., 2004). There are many reasons and factors why a pump is not performing well in a certain situation of water distribution system. However, as per (Marta & Rudolf, 1987); the important and possible reasons to less performing of pumps were identified as below;

When the pump is of poor design and quality,

- If it is not suitable for the given situation and does not work in its optimal range,
- If the pump is not being used properly and maintained regularly (cleaning, greasing,
- If the pump is excessively exposed to sun, rain, dust, etc,
- If it is overused and was not repaired properly after a break-down and
- If supply of spare parts is difficult.

- **Demand Increase**

Rising water demand because of population growth and urbanization effects on the availability and reliability of existing water distribution system. Therefore, water demands need to be assessed based on considering the year and date supplying water through the distribution system. The primary objective is to make sure that the community is being serviced adequately. If there are deficiencies in meeting current or future goals because of population growth, this needs to be identified for the areas of the community where there may be inadequate flows to meet customers'‟ consumption during peak hour water demand of the day (Hickey, 2008).

1.1.1 Basic Principles of Hydraulic Modeling

In line with (Jalal, 2008); the main reason for modeling a system is to assist designers, managers and planners to explore the governing laws of such systems and to accurately analyze their behavior. Hence, models are employed to resolve problems in system's design and operation.

Model-based simulation is a method for mathematically approximating the behavior of real water distribution systems. To effectively utilize the capabilities of distribution system simulation software and interpret the results produced, the modeler must understand the mathematical principles involved (Tomas, et al., 2003). In networks of inter connected hydraulic elements, every element is influenced by each of its neighbors; the entire system is interrelated in such a way that the condition of one element must be consistent with the condition of all other elements. Two laws (Tomas, et al., 2003) mainly control these conditions.

- Law of Conservation of Mass

"The principle of conservation of mass dictates that the fluid mass entering any pipe will be equal to the mass leaving the pipe (since fluid is typically neither created nor destroyed in hydraulic systems). In network modeling, all outflows are lumped at the nodes or junctions." (Tomas, et al., 2003)

$$pipes = QI - U = 0 ------------ (2.3)$$

Where:-

Qi=water inflow to node in i th pipe (L^3/T)

U= water used at node (L^3/T)

During extended-period simulations; a term to the accumulation of water at certain nodes are considered, because water can be stored and withdrawn from storage tanks (Tomas, et al., 2003).

$$pipes = Qi - U - ds/(dt) = 0 ------------ (2.4)$$

Where:- Ds/dt=i s change in storage

Therefore, the concept to conservation of mass is applied to all junction nodes and tanks in a water distribution networks.

1. Law of Conservation of Energy

According to Bernoulli's equation, the principle of conservation of energy dictates that the difference in energy between two points must be the same regardless of the path that is taken (Tomas, et al., 2003). Within a hydraulic analysis, the equation is written in terms as follows:

$$Z1 + \Delta p = Z2 + hL + hm -------------- (2.5)$$

Where:-

Z = Elevation (L)

P = Pressure (M/L/T2)

γ = Fluid specific weight (M/L/T2) V = Velocity (L/T)

g= gravitational acceleration constant (L/T2)

P= head added at pump (L)

I = head loss in pipes (L)

M= head loss due to minor losses (L)

Therefore, in water distribution modeling the difference in energy at any two points connected in a network is equal to the energy gains from pumps and energy losses in pipes and fittings that occur in the path between them (Tomas, et al., 2003).

1.1.2 Water distribution network simulation

The term simulation generally refers to the process of imitating the behavior of one system through the functions of another. It can be used to predict system responses to events under a wide range of conditions without disrupting the actual system. Using simulations, problems can be anticipated in proposed or existing systems, and can be evaluated before time, money, and materials are invested in a real-world project (Tomas, et al., 2003). As per Tomas, et al., 2003, in water distribution networks the most basic type of model simulations are either

Steady state or extended-period simulation.

Steady-state simulations: represent a particular view of point in time and are used to determine the operating behavior of a system under static conditions. It compute the hydraulic parameters such as flows, pressures, pump operating characteristics, and others by assuming that demands and boundary conditions were not change concerning for time. In general, this type of analysis is used to determining the short-term effect of demand conditions on the system (Tomas, et al., 2003).

Extended- period simulations: - are determine the dynamic behavior of a system over a sometime, and it analyze the system on assumption that the hydraulic demands and boundary conditions were change concerning for time. Hence, extended period analysis used to evaluate system performance over time and allows the user to model pressures and flow rates changing, tanks filling and draining, and regulating valves opening and closing throughout the system in response to varying demand conditions and automatic control strategies formulated by the modeler. Therefore, regardless of project size, model-based simulation can provide valuable information to assist an engineer in making well-informed decisions (Tomas, et al., 2003).

1.1.3 Water CAD: Modeling Capabilities

Water CAD provides and allowing modeling practically for any distribution system aspect. Therefore, working with Water CAD used as for decision-support tool for water infrastructures and were help to assess and/or operate (Dawe, 2000; Water CAD: USER MANUAL, 2013); The hydraulic analysis at a steady-state or an extended-period simulation, pressure, flow and demands in the system and to see how behaves over time, the size of pipes, pump and computer system head curves, tank, pump and valve behavior in the system, leakage and water loss from the network, calibration the model either manually or use the Darwin Calibrator methods and, generate fully customizable in graphs, charts and reports form.

Input data for assembling the model

In practice, pipe networks consist not only of pipes, but composed of vary fittings, services, storage tanks and reservoirs, meters, regulating valves, pumps, and electronic and mechanical controls. For modeling purposes, these system elements were organized into the following categories (Water CAD: USER MANUAL, 2013).

Table 3.Input parameters and primary purposes of water CAD tools

Element	**Type**	**Primary modeling purpose**	**Input data**
Reservoir Tank	Node Node	Provides water to the system	Hydraulic grade line (water surface elevation) base elevation, max. elevation,
Junction Pipe	Node Link	Stores excess water within the system and releases that water at times of high usage	min elevation, diameter and elevation
		Discharge the demand required or recharge the inflow water	Elevation, diameter, material and roughness coefficient, elevation, pump definition (Characteristics of max. operation and design discharge and head efficiency)
		Transport water from one node to Another	
		Provide energy to the system and raise the water pressure to overcome elevation differences and friction losses	
Pump Valves	Node Node	Controls flow or pressure through a pipe and results in a loss of energy in the system	elevation, diameter and valve type

(**Source;** Water CAD: USER MANUAL, 2013)

1.1.4. Water demand modeling

The first question in the design and operation of WDN is: How much water is needed? The answer to this question is difficult because the required water is a function of various factors. While, some of the factors are completely independent and time varying. Therefore, water demand modeling is one of the most important challenges in the design of WDN, since it reflects the changes in population, climate, land use, the number of service connections and customer life style (Jalal, 2008).

Demand modeling approaches

In the water distribution system, there are two main approaches for water demand modeling (Jalal, 2008). Deterministic water demand estimation: In this approach, the actual water demand for all users is estimated based on predicted water consumption over the service time. One simple approach for deterministic water demand is estimating individual needs based on type of customers, their activities, and finally adding these lead to get total water demand. For example, the water demand can be estimated based on per capita demand in small urban areas (Jalal, 2008). Stochastic demand forecasting: this method mostly considers and adopts the uncertain fluctuations on demand over time and location spans. Risks and sensitivity of forecasts such as the consequence of total loss of supply and the effect of variations in rates income should be considered and included. Hence, Demand estimation based on historical consumption per user category (domestic, industrial/commercial) and expected changes (increasing or decreasing) in user category over the forecasting period is good example of stochastic demand forecasting (Jalal, 2008).

Variations in water demand

The per capita demand of a particular town is the average consumption of water for a year. In practice, it has been seen that this demand does not remain uniform throughout the year, but it various from season to season, even hour to hour (Venkateswara, 2005). Seasonal Variation: Water demand varies from season to season. In dry season, the water demand is maximum because the people will use more water for bathing, cooling, lawn watering and street sprinkling. While, demand will becomes minimum in rainy/wet season because less water is used in bathing and there is no lawn watering. Therefore, "maximum day water demand is considered to meet water consumption changes with seasons and it used to size source, treatment plant and rising mains. Hence, maximum day demands can be obtained by multiplying the average-day demands to the peaking factor applied to the node" (Venkateswara, 2005).

$$Q = PF * Qa \text{ ------------------------- } (2.6)$$

Where:- Q = Maximum day demand (m^3/s)

PF = Peaking factor between maximum day and average day demand

Q_a = Average day demand ($m^{3/}s$)

Daily Variation:-This variation mainly depends on the general behavior of people, climatic conditions and character of city as industrial, commercial or residential. More water demand is on Sundays and holidays due to bathing, that is more comfortable, washing etc. as compared to other working days. Accordingly, Average daily water demand is the sum of the domestic, non-domestic and NRW, which is used to estimate the maximum day & the peak hour demand. It expressed as economic calculations over the projects lifetime.

$$Q = Per\ capital\ water\ consumption * Total\ population\ of\ the\ town - -(2.7)$$

Where:-

Q = Average day demand (m^3/s)

Hourly Variation: In most developing countries the maximum hour water demand is happen during morning and evening time over 24 hour, because in these time most people use water for bathing, washing and cooking purpose. Therefore, peak hour demand is the highest demand of any one hour over the maximum day. In addition, it represents the hourly variations in water demand resulting from the behavioral patterns of the local population (Venkateswara, 2005).

$$Qp = PF * Qa -(2.8)$$

Where:-

Q^p = Peak hour demand (m^3/s)

PF = Peaking factor between maximum hour and average day demand

Q^a = Average day demand (m^3/s)

- **Baseline demands**

The most common method of allocating baseline demands is a simple unit loading method. This method involves counting the number of customers (hectares of a given land use, number of fixture units, or number of equivalent dwelling units) that contribute to the demand at a certain node, and then multiplying that number by the unit demand (for instance, number of gallons/ liters per capita per day) for the applicable load classification (Tomas, et al., 2003). Therefore, average day demand is used to estimate the baseline demand and other demand in the water distribution system including unaccounted-for water. Hence, most modelers determine the water demand analysis of a given town by applying baseline demand to a variety of peaking factors and demand multipliers (Bhadbhade, 2009).

- **Demand diurnal pattern and multipliers factors**

The variations in water usage for water supply systems typically follow a 24-hour cycle. However, in reality, water demand varies over time and for extended period simulation to reflect the dynamics of the real system, these demand fluctuations must be incorporated into the model and it requires both baseline demand data and information on how demands vary over time. These demands can be determined by applying a multiplication factors or a peaking factor. Multiplication/ Peaking factors from average day to maximum day tend to range from 1.2 to 3.0, and factors from average day to peak hour are typically between 3.0 and 6.0. Of course, these values are system-specific, so it must be determined based on the demand characteristics of the

$$Qi,t = Bi,j,pi,j,t ---------------------(2.9)$$

system at hand. Therefore, when more than one demand type is served by a particular junction, the total demand for a junction at any given time is equal to the sum of each baseline demand times with its respective pattern multiplier, and it is used in most software packages to assign a different pattern to the different components of the composite demand as per below:-

Where:-

$Q_{i,t}$ = Total demand at junction i at time t (cfs, m3/s)

$B_{i,j}$ = Baseline demand for demand type j at junction i (cfs, m3/s)

$P_{i,j,t}$ = Pattern multiplier for demand type j at junction i at time t.

- **Model calibration and validation**

Model calibration is the process of fine-tuning a model until it simulates field conditions for a specified time horizon to an established degree of accuracy. Fine-tuning includes making minor adjustments to the input data to achieve the desired output data (Gregory, 2011). Therefore, model will not be hundred percent correct and to be calibrating it must be accurately simulate the observed data. So that, calibration is a major portion of modeling process and proper calibration were achieved through accurate field data. Further, according to Tomas, et al. 2003; hydraulic model calibration is the necessary process of modeling and it is calibrated to have better confidence, understanding and identifying errors made during the model-building process.

- **Pressure calibration**

Collecting pressures data throughout the water distribution system used to indicate the level of service. Pressure readings are done using pressure gauge commonly taken at pump stations, storage tanks, reservoirs, fire hydrants, home faucets, air release and other types of valves. However, different factors can contribute to deviation between model simulation and actual field data. Therefore, calibration can be accomplished by adjusting only internal pipe roughness values or estimates of nodal demands until an agreement between observed and computed pressures and flows is obtained. The basis for this claim is that unlike pipe lengths, diameters, and tank levels, which are directly measured, pipe roughness values and nodal demands are typically estimated, and thus have room for adjustment (Tomas, et al., 2003).

1.2 Water Quality

Water quality is a term used to express the suitability of water to sustain various uses or processes (WHO, 1996). Anthropogenic activities and natural processes affect water quality. To prevent and reduce the problems associated with water, there are national and international standards or guidelines to be followed for water quality suitable for different purposes (drinking, personal hygiene, irrigation, etc.). Components of water quality include microbial or biological, chemical, and physical aspects.

1.2.1 Microbial Aspects

Drinking water should be free of all pathogenic micro- organisms. It should also not contain bacteria that would indicate excremental pollution, the primary indicator of which are coliform bacteria that are present in the feces of warm- blooded animals (Maher, et al. 1997). By using specified treatment techniques, the microbial quality of drinking water is controlled and the presence of coliform bacteria is monitored (Mark and Mark, 2005). Chlorine is the usual disinfectant, as it is readily available and inexpensive.

1.2.2 Chemical Aspects

Chemical contamination of water sources may be due to certain industries and agricultural practices, municipal solid waste, urban runoff or from natural sources. When toxic chemicals are present in drinking water, there is the potential that they may cause either acute or chronic health effects. After exposure of chemicals in drinking water for extended years rather than months, they become of health concern (WHO, 2006). Chronic health effects are more common than acute effects because the levels of chemicals in drinking water are seldom high enough to cause acute health effects. There are many evidences that chemical contaminants created adverse human health problems in urban watersheds (EPA, 2005).

1.2.3 Physical Aspects

Water for drinking should be free of objectionable taste, odor, color and suspended materials. These are often called aesthetic parameters. Aesthetic parameters are those detectable by the senses, namely turbidity, color, taste, and odor. They are important in monitoring community water supplies because they may cause the water supply to be rejected and alternative (possibly poorer-quality) sources to be adopted, and they are simple and inexpensive to monitor qualitatively in the field. Physical Parameter of water includes also such parameters as pH, TDS, salinity and hardness. The chemical quality influences also the physical quality. The appearance, taste, odor, and feel of water determine what people experience when they drink or use water and how they rate its quality; other physical characteristics can suggest whether corrosion and encrustation are likely to be significant problems in pipes or fittings. The measurable characteristics that determine these largely subjective qualities are true color (i.e. the color that remains after any suspended particles have been removed), turbidity (the cloudiness caused by fine suspended matter in the water), hardness (the reduced ability to get a lather using soap), total dissolved solids (TDS), pH, temperature, taste, odor and dissolved oxygen (ADWG, 2006).

1.1.1 Biological aspects

Water naturally contains a diverse population of living organisms, such as aquatic plants, animals, algae, bacteria, parasites and viruses. Some of these organisms are harmless and others can be harmful to humans. Those of greatest concern to us are pathogens, or disease causing organisms. We sometimes refer to these pathogens as microorganisms, microbes or bugs, depending on the local language and country. In the 21st century, contaminated water is the world's second biggest killer of children. Every year some 1.5 million people die because of diarrhea and other diseases caused by unclean water and poor sanitation. Close to, half of all people in developing countries suffer at any given time from a health problem caused by water and sanitation deficits (UNDP, 2006). The WHO Guidelines for Drinking Water Quality highlight that infectious diseases caused by pathogenic bacteria, viruses, protozoa and helminthes are common in drinking water and inflict widespread health effects. Although there are several contaminants in water that may be harmful to humans, the priority is to ensure that drinking water is free of microorganisms that cause disease (WHO, 2006).

1.2 Operation and maintenance

As per manual on operation and maintenance of water supply systems, World health organization, January 2005, in an engineering sense, operation refers to hourly and daily operations of the components of a system such as plant, machinery and equipment (valves etc.) which is done by an operator or his assistant. This is a routine work. The term maintenance is defined as the art of keeping the plant, equipment, structures and other related facilities in optimum working order. Maintenance includes preventive maintenance or corrective maintenance, mechanical adjustments, repairs and corrective action and planned maintenance. Often repairs, replacements and corrections of defects (of material or workmanship) are considered as actions excluded from preventive maintenance. In some organizations, the normal actions taken by operation staff are considered as maintenance activities whereas a separate unit or cell does repairs and replacements. Often both corrective and preventive maintenance are included in the job functions of operators and limits to which operators are expected to do normal maintenance are set forth for various equipment. Budgetary provisions of operation and maintenance organizations also incorporate heads of expenditure under maintenance for cost of spare parts and cost of labor or contract amount for repairs and replacements and the objective of an efficient operation and maintenance of a Water Supply System is to provide safe and clean drinking water in adequate quantity and desired quality, at adequate pressure at convenient location and time and as economically as possible on a sustainable basis. In engineering parlance, operation refers to timely and daily operation of the components of a Water Supply system such as headwork, treatment plant, machinery and equipment, conveying mains, service reservoirs and distribution system etc. effectively by various technical personnel, which is a routine function. The term maintenance is defined as the art of keeping the structures, plants, machinery and equipment and other facilities in an optimum working order. Maintenance includes preventive maintenance or corrective maintenance, mechanical adjustments, repairs, corrective action and planned maintenance. However, replacements, correction of defects etc. are considered as actions excluded from preventive maintenance. In this study, the existing operation and maintenance practice of Assosa Town water supply system is assessed and recommendations are given to improve the operation and maintenance practice. Besides as stated before there is very high water loss in water supply system and this can also be reduced by improving the operation and maintenance system.

1.1 Customer satisfaction

It is the very nature of this commodity that makes the customer satisfaction so important. Water is a lifeline whose importance is felt only when people cannot get enough of it. It is keeping this in mind that urban water distribution networks are designed to supply water for household customers as well as industrial concerns twenty-four hours a day, sixty-five days of the year. Any disruption or inconsistency in this service even though for a short while has an unpleasant effect on all sorts of customers. There is a great pressure on the water delivering agencies to ensure customer satisfaction. One of the most relevant aspects of water services therefore is the important role of customers. Water supply agencies as well as their regulators are becoming increasingly sensitive to customer protection issues and customers opinions about the service quality and performance. (Customers satisfaction with clean drinking water provided by Lahore Cantonment Board (LCB), Omar Saeed, September, 2011). The research made by Omar Saeed to check whether the residents are satisfied or not with clean drinking water provided by Lahore (Pakistan) Cantonment Board (LCB) used main research questions that summarize the main aspects of clean drinking water. The research questions were overall satisfaction of people with the clean drinking water, aspects of the water that the customers have complaints against such as quality, quantity and price and on the satisfaction of the customers with the responsiveness of LCB to their complaints. The process and the results of the research are explained below. The research was exploratory as it seeks to find out whether the customers are satisfied or not with the clean drinking water provided by LCB. To carry out the research, survey strategy has been used with households as units of analysis. This survey served as a basic investigative tool to prove or disprove the hypothesis. The research was carried out in Lahore Cantonment (population 268,166) where two levels of household's concerning for income were taken into consideration i.e. high and low income. The data was divided into primary and secondary data. The research instruments were a combination of a survey with questionnaires, in-depth and semi-closed interviews. Questionnaires were used to collect primary data from customers concerning for their response regarding the quality, quantity, continuity of water, monthly tariff, and disposal of complaints by the LCB authorities. Semi structured and in-depth interviews were used to collect primary data from the officials of the LCB, and others. The secondary data was collected through visits to the Record Room of LCB and the information consisted of readily available compendia and reports of LCB. Frequency distributions and percentages were the main analytical methods. The display methods used were tables and graphs. It was found out during the fieldwork that LCB‟s water supply systems were characterized by contamination of the clean drinking water through sewerage water entering the old and rusty water pipelines, no proper treatment other than chlorination, intermittent water supply (8-10 hrs a day), and low per capita water supplied per day, and low responsiveness to customer complaints. The results of the research show that although a majority of customers belonging to both the high and low income areas are overall satisfied with the clean drinking water provided by LCB but a deeper analysis of questionnaires survey and interviews (corresponding to the second and third research question) revealed that owing to various reasons more than a quarter of them were not satisfied with various aspects of clean drinking water. It is startling to know that LCB has no mechanism in place to ascertain the customers‟ satisfaction and neither is it using any form of benchmarking and key performance indicators to measure, monitor and improve its performance. This is the major reason why more than a quarter of the customers of both the income groups have serious reservations about the various aspects of clean drinking water such as quality, quantity and continuity, and the responsiveness of the staff to customer complaints. The situation is expected to get worse if immediate corrective actions are not taken by the LCB soon. (Customers' satisfaction with clean drinking water provided by the Lahore Cantonment Board (LCB), Omar Saeed, September,2011). In this study of Assosa Town, existing water supply System performance assessment Sample Household interviews using prepared questionnaires for the 280- metered customers located in town Keble's is carried out to collect information about customer's satisfaction towards the water supply service.

1.1.1 Measuring Satisfaction

Consumer satisfaction is closely related to acceptance and preferences of the customers. Satisfaction is the fulfillment of the desire for a stated good or service. The extent to which a consumer is satisfied with a good or service is therefore determined by the perceived performance of the utility which is an evaluation of that good or service in the light of consumer's needs. If the utilities know what customers regard as important and if the utilities can gauge to what extent their customers are satisfied, they can devise strategies aimed at improving the aspects of services vital to the customers. One method that seeks to acknowledge the linkage between customers‟ expectations and utilities performance and seeks to measure satisfaction by taking into account the gap between the expectations and performance is the SERVQUAL method. The greater the positive gap between the performance and the expectations the better the service and vice versa. This model identifies empirical factors that determine the quality of provided service as perceived by the customers: External Characteristics or Tangibles e.g. the taste of drinking water, Reliability of the service Responsiveness to complaints and assurance that is knowledge and politeness of the personnel.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the Study Area

Benishangul-Gumuz National Regional State (BGNRS) is one of the nine regional states established in 1994 by the new constitute of Ethiopia that created a federal system of governance. Hence, the study area is Assosa Town in western Ethiopia and which is the capital city of the Benishangul-Gumuz Region that located at a distance of 667 km of asphalted road west of Addis Ababa. (Capital city of Ethiopia) with a latitude and longitude of 10°04′N 34°31′E, with an average elevation of 1570 meters and have Asosa Town have its master plan.

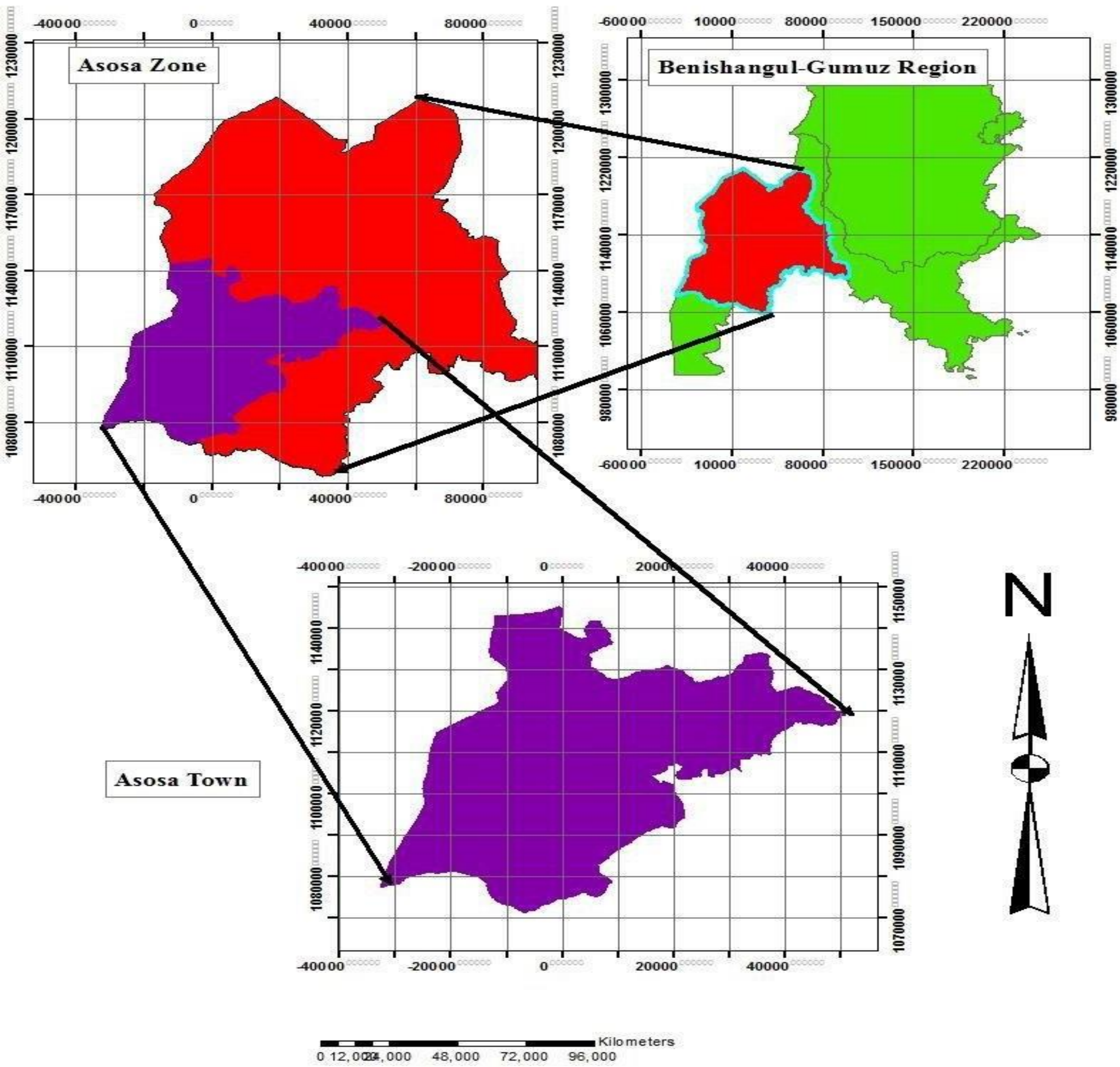

Figure 1.Location Map of the Study Area in Benishangul-Gumuz Region.

3.2. Socio Economic Structure

3.2.1. Demography

Assosa Town is one of the dynamic areas of Benishangul Gumuz regional State that is Increasing population from time to time has created a serious burden on the environment particularly manifested in increasing demand of water supply households, high population density, low per capita income, increasing demands for water resources and environmental degradation. Relatively low access to basic services (health, education, sanitation and water supply) and food security further compounded the problem of population growth.

The study and design of water for any city or town is depend on its population number and other water demands. Assosa Town is the center of 4 administrations these are Assosa Town administration offices, Assosa Woreda, Assosa zone and Benishangul Gumuz regional offices are found in the town. Population may include those who live in the town, civil servants since they use water in the office compound in addition to home institution water users and even in prisons. According to the town administration health office, the population of the town is about 55,583.

In addition to the available social institutions, the number of employers‟ worked in Assosa Town, Assosa Woreda Assosa zone and Benishangul Gumuz region are 7335(regional human resource commission) people military service employees are 3351and Assosa zone prisoners are 1400, around 30 churches and 23 mosques are found in the town and the expected visitors are 3000 and 69000 people daily respectively (respective institutions 2011). As shown above, the employers worked in these institutions had a demand for water in the respective institutions daily.

Guests and tourists visit the town are important factors in determining water demand of the project area. So the data of these are collected from town tourism development office 1388 visitors visit the town in 2011 Ec. This figure is decrease in the mentioned years because of political instability problem and fewer activities in the grand Ethiopian renaissance dam .In the year 2010 around 4433 visitors visit the town monthly.

The household survey conducted in each kebele as depicted in the table below of 431 valid respondents 233(54.1%) is from kebele 04 by the former name followed by kebele 03 with 104 respondents. Around 20% of the respondents are females. The detail is depicted below.

3.1.1 Household Information

According to the MS consulting plc design report, the number of families per household is between four and six as shown in the table below. Average family size per household is found to be 4.92.

Table 4.Family sizes per household

Family Size	Percentage of the total Population
Less than Four	0
Four	7.9
Greater than Five	91.1

(**Source** MS consultancy Report)

The average family size recognized in the survey study is somewhat higher than the size scrutinized by the 2007 population poll of CSA, 4.8 members per family head for Benishangul Gumuz region. In this study the CSA value approximated to 5 is used.

3.1.2 Growth potential of the study area

The project town is being highly developed through the establishment of large number of small to medium houses, condominium houses, real estates, commercial centers and different scale industries resulting in high degree of population growth. Thus the town has dramatically in few years has turned from mere rural locality into prominent town. This speedy growth, has a great negative impact on the quality of the abstracted water supply source such as a spring which supplies only a small portion of the town and a few boreholes which yield too little water to meet the enormous water demands of the ever increasing population. In addition to the legitimate settlements within the town, some illegal settlements within the existing well field and beyond the location of existing service reservoirs are constructed and are still under constructions which are out of reach of the existing distribution system. Privately owned business centers, schools and government owned organizations are under construction and operation within the town further aggravating the water supply shortage and coverage.

3.2 Existing water Supply System Description

The existing Water Supply System was examined in close co-operation with the representatives of Assosa Town Water Supply and Sewerage Enterprise and regional water, irrigation and Energy Bureau professionals regarding the existing town water supply conditions of water production and consumption, treatment, transmission, storage and water distribution network.

Assosa water supply scheme was constructed in different years starting from 1977 to 2007. The source for the existing water supply system source of Assosa Town is borehole (ground water). There are eleven existing bore holes and one new drilled around and within the town from this borehole only eight of them are giving service for the town. The water from the wells are connected and pumped to the Amba 1 booster pump station and further pumped to the Collection chamber constructed around Amba 5. Then water flows through gravity system to Medhanialem booster station. Finally, water pumps to Enzi service reservoir. There are two service reservoirs constructed on Enzi which have a capacity of 800m^3 and 300m^3. The water is distributed to the consumers via private (yard/house) connections and public fountains.

3.2.1 Water Sources

The water for Assosa water supply system is extracted from eleven boreholes which are drilled in different years out of which only eights are working for a total yield of 63.3l/s. The others are not functioning because of low yield and drain. Description and available data on the boreholes are presented in the Table 3.3.

Table 5. Description of existing boreholes in Assosa

Borehole	Year E.C	Well Depth (m)	Q (l/s)	Raiser pipe (inch)	Raising Main pipe (inch)	GPS Location (m)			Status
						E	N	Ele	
Amba 1 No-1	1996	50	7.5	2 ½	2 ½	678220	1122286	1435	NF
Amba 1 No-2	1996	50	7.5	2 ½	4	678290	1122109	1435	NF
Amba 1 new	2010	75	3	2	4	678549	1122060	1431	F
Amba 1 new	2010	83	7.5	2 ½	4	678959	1122171	1430	F
No 10	2009	110	6.7	2	2	670848	1114265	1527	F
No 9	2003	110	19	4	6	670646	1114397	1529	F
No 8	2003	70	7.5	2	4	670259	1114393	1532	F
No 7	1999	70	7.5	2	3	669943	1114400	1528	F
No 6	1999	70	6.5	2	4	669723	1114346	1533	F
No 5	1988	70	5.6	2	3	669262	1113750	1533	F
No 1	1977	50	3.5	2	2	668904	1113164	1542	NF

NB: F - Functional, NF - Non-functional

Figure 2. Existing boreholes at Assosa Town

3.2.2 Existing Transmission Mains and Collector

According to site visit wells which are located in Amba 1 Well number 3 and 4 during construction had a junction to a common DCI pipe of diameter 150 mm that lead to Amba 1 Booster station. Water pumped from this booster station to Amba 5 Collection chamber

Figure 3.Source: Assosa Town administration office

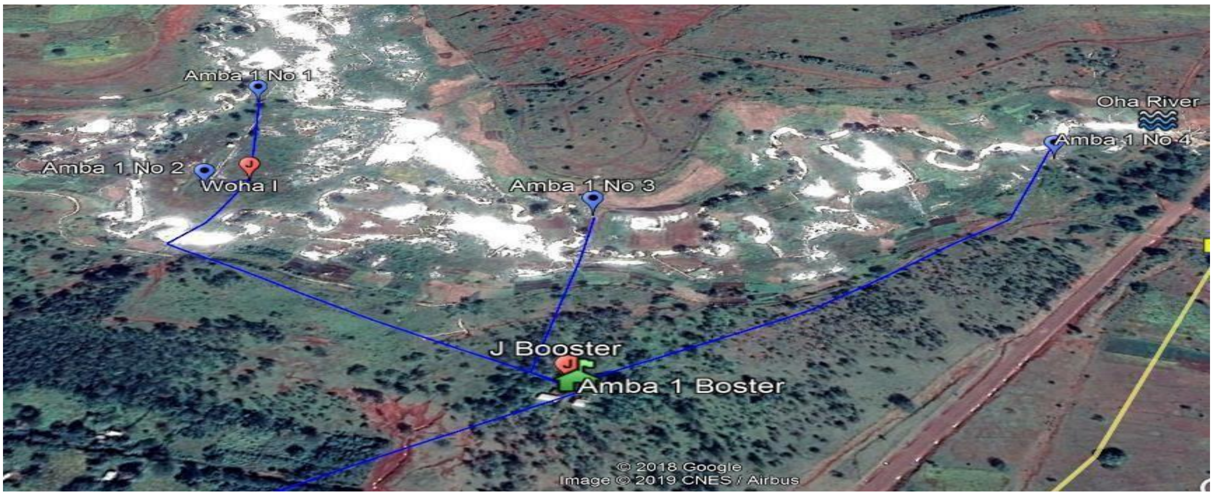

Figure 4.Assosa Town booster station

Figure 5.Arrangement of the wells and Conveyance system

3.2.3 Existing Reservoirs

There are a total number of seven concrete, steel, fiber made reservoirs, and storage tankers in the distribution system located at different at Inzi reinforced concrete reservoirs are located on the Inzi hill at an elevation of 1633 masl. They are two circular concrete reservoirs each having a capacity 1500 m^3 & 1000m^3 which are constructed at 1996 & 2007 EC respectively. These two reservoirs had a leakage in the walls around the valve rooms. However, the aged and recently expanded resident areas of the town do not get sufficient water quantity with pressure due to location and capacity limitation of the existing reservoirs. Mainly the problem of the existing town's water supply system arises from the insufficient capacity of water sources and smaller sizes of scheme components (reservoirs, pipes etc.). Accordingly, this design report incorporates design of an additional service reservoir to be constructing to maintain sufficient water pressure at the end user houses of the whole town and fringe areas. The existing Enzi 1500 m^3 and 1000 m^3 service reservoirs are incorporate to the additional new reservoirs & the proposed service reservoir are shown on Annex A.

Figure 6.Enzi 800 m3 & 300 m3 Reservoirs captured during site visit

3.2.4 Existing Distribution Network

The existing water supply distribution system of Asosa Town comprises pipeline works including primary, secondary and tertiary pipes. According to the information obtained from the town water supply and sewerage service office, the distribution network is a composition of uPVC, GI, DCI and HDPE pipes with sizes ranging from the diameter of 25mm to 350mm. The system is constructed on 1977, 1988, 1996 and 2007 E.C. However, there are newly established residential areas where the water pressure from the existing service reservoir couldn't reach. Currently the total length of distribution pipelines installed is 65.7 km. All the pipes are DCI, GI, uPVC & HDPE. With diameters ranging from DN 25 to DN 350 and pressure capacity from PN 10. Most of the distribution system is looped system and some are branched ones.

Table 6.The details of the installed existing pipelines diameter, length and material are given

Pipe Diameter (mm)	Length (m)	Pipe Diameter (mm)	Length (m)
350	982	65	5183
200	2476	50	14310
150	4266	40	8756
100	16276	25	1934
80	11523	Total length	65706

The existing distribution network of the town has been studied in line with the town development plan and the projected water demands. The distribution network is simulated using Bently water Cad software, Version 8. The simulation was carried out for steady state by taking into consideration the actual yield and the future demand. The water Cad uses the Hazen Williams Equation for calculations. Thus, the Hazen Williams Coefficients (HWC) has been chosen for the pipes according to the material and age For Hazen-Williams (C-value):

Type of Pipe	uPVC	Steel	DCI/GI
New	130	110	120
Existing	100-110 *	90-110 *	100-110*

The design lifetime of system components mostly adopted for financial/economic comparison of alternative projects are summarized in table 8 below.

Table 7.Design life of water supply components

Items	Civil (years)	Mechanical
River Water Intakes	50	15
Boreholes	25	15
Impounding Dams	50	
Treatment Plant		
I. Clarifiers	50	15
II. Filtration	50	15

III. Chemical Dosing	50	10
Pumping Stations	50	15
Service Reservoirs		
I. Concrete	50	15
II. Pressed Steel	20	15
Pipelines		
I. Ductile iron pipes	40	
II. Steel pipes	40	
III. UPVC pipes	25	
Pipeline Fittings		25
Building	50	

After performing the hydraulic calculations, the final results for each scenario are presented under pipe result and node result along with the inputs and out puts in Annex-C. Results have shown that most of the existing pipelines, laid are found to be in good condition and are proposed to be used in parallel with the new lines. 48 Km existing pipe are incorporate to the new system based on the age and the appearance of the pipes.

3.3. WATER DEMAND

The present and future water demand of the town is presented in this chapter.

Water demand depends on the size of the population to be served, their standard of living and activities, the cost of water supplied and the availability of wastewater service. It varies according to the requirements of the population, industry, livestock farming, institutional and social establishments, municipal water supplies for the watering of public green area and street cleaning. In addition to these demands allowances need to be included for leakage, wastage, and operational requirements such as flushing of mains.

The standard approach to forecasting would normally involve a detailed analysis of past consumption trends by consumer groups to which alternative economic development scenarios would be applied to produce future consumption levels. This approach requires detailed information on the present consumption patterns and future economic development scenarios.

3.2. Population Projection

Based on the National Population and Housing Census Statistical report, the projected population figure from the 1994 CSA of Assosa in 2019 is 55,583.

For the projection of the population, the medium variant growth rate given in the 1994 population and housing census of Ethiopia result for Benishangul Gumuz Region Volume II Analytical Report Dated December 1998 have been considered. Moreover, the geometric growth rate model has been used.

Pt = Po (1+r)t

Where:

Pt -----is projected population at time t

Po-----is initial population at time o

r ------is annual growth rate

t-------number of years

Table 8.Population Growth rates

Region	**Settlement Type**	**2000 - 2005**	**2006 - 2010**	**2011 - 2015**	**2016 - 2020**	**2021 - 2025**	**2026 - 2030**
Benishangul	Urban	4.4%	4.2%	4.0%	3.8%	3.6%	4.4%
	Rural	1.7%	1.5%	1.3%	1.1%	0.9%	1.7%

Applying the above growth rate in the geometric model, the urban population of Assosa is projected up to year 2041 and is presented in Table 2-3

Table 9.Population Projection (2022-2041)

	2022	**2026**	**2031**	**2036**	**2041**
Annual growth rate (urban)	4.4%	4.2%	4.0%	3.8%	3.6%
Population (urban)	62,283	72,234	86,540	103,180	122,427
Annual growth rate (urban)	1.7%	1.5%	1.3%	1.1%	0.9%
Population (urban)	12,798	13,664	14,691	15,640	16,487

Note: - The 1994: CSA National census figures are used as a base

3.3. Domestic Water Demand

The quantity of water required in the houses for drinking, bathing, cooking, washing, flushing toilet, etc. is included under domestic water demand and mainly depends upon the habits, social status, climatic conditions, customs of the people, mode of service & above all on the price of the water & affordability of the users.

Water supply for population is served by the mode of service which is prevalent to most Ethiopian towns used to be classified in to three major categories as follows

- House tap users (HTU)
- Yard tap users (YTU)
- Public tap users (PTU)

3.3.1 Per-capita demand and growth rate of Domestic Water Demand

The per capita water demand for various demand categories varies depending on the size of the town, the level of development, the type of water supply schemes, the socioeconomic conditions of the town, cost of water, system of sanitation and climatic condition of the area. The basic human water requirement for different use could vary based on the mode of service to be used and the closeness to water supply facilities. The following table shows the composition of the basic human per capital water demand based on needs for different use adopted for the estimation of water demand for Assosa Town. In projecting the domestic water demand of the study area the following main steps are followed.

- Population distrubtion by mode of service,
- Establishment of continuous water demand of each mode of service,
- Projection of consumption by mode of service,
- Adjustment of socio-economic standard & climate,

Table 10. Per capita water demand by GTP-2 plan (l/c/d)

	Town categories					
	Rural	C-1	C-2	C-3	C-4	C-5
Consumption, l/c/d	25	100	80	60	50	40

The project town is under category 3.

It is so much tedious to estimate how exactly the per capita water demand will grow in between the design horizons. The values given in table below is develop based on minster of water resources guide line for the annual grouse rate of the connection types as presented below

- Public tap users (PTU) = -2.0% to 0 % per annum
- Neighbourhood tap users (NTU) = -3 % to 0 % per annum
- Yard tap users (YTU) = 1% to 6% per annum
- House tap users (HTU) = 1% to 3% per annum

Therefore, in our assumption each category to grow by 3% for HCU, 1% for YTU and 1% for YTU. Per capita demands from 2022 to 2041 is presented in table below. It should be noted at this stage that the reality of the situation will only be able to be determined with constant monitoring of consumptions and tracking of data over the years between implementation and the final year of the design horizon.

Table 11.Projected per capita water demand by mode of service (l/c/d)

Category	**Mode of Service**				
	2022	2026	2031	2036	2041
HCU	80	90	104.4	121	140.3
YTU	65	70.4	77.7	85.8	94.7
PTU	40	41.62	43.75	45.98	48.32

Source: GTP-2 guideline

3.3.2 Population distribution by Mode of services

The percentage of population to be served by each mode of service will vary with time. The variation is caused by changes in living standards, improvement of the service level, changes in building standards and capacity of the water supply service to expand. Therefore, the present and projected percentage of population served by each demand category is estimated by taking the above stated conditions and by assuming that the percentage for the house and yard tap users will increase gradually during the project service period while the percentage of tap users will dramatically reduce as more and more people will have private connections as the living standard of people and the socio-economic development stage increase.

The standard approach of projecting would normally involves a detail analysis of past consumption trends by consumers group to which alternative economic development scenarios would be applied to produce future consumption levels, this approach requires detail information on the present consumption pattern and future economic development scenarios, which is not possible to get for target area with limited water supply source and water supply system having so many problems listed above in the past. However, the information obtained from household sample interviews of the population is used to estimate the percentages of each demand category.

As per the information obtained Assosa water supply and sewerage Enterprise, 34.8% of the population was using traditional water source users, 24.5% of the population was public tap users and 41.42% of the population was yard tap users and house connected user in year 2018. But when the project implemented, which is estimated at the end of 2041 we assume the connection pattern of the town based on the actual facts and the future expectation of the town development to be 1.2% of the population will be user of public tap, 72.5% of thepopulation will be yard tap users, 26.3% of the population will be hose connection users and there will no traditional water source user in the town.

Table 12.Population Percentage Distributions by Mode of Service

Distribution(%)	2022	**2026**	**2031**	**2036**	**2041**
HTU	15	16.9	19.6	22.7	26.3
YTU	60	62.4	65.6	69.0	72.5
PTU	25	20.7	14.8	8.3	1.2
Sum (%)	100	100	100	100	100

Table 13.Population Percentage Distributions by Mode of Service

User Population	**2022**	**2026**	**2031**	**2036**	**2041**
HTU	9342	12195	16937	23410	32201
YTU	37370	45100	56788	71162	88743
PTU	15571	14939	12814	8608	1482
Total	62283	72234	86540	103180	122427

3.3.3 Average Domestic Water Demand Computation

The average water domestic demand of Assosa town is computed based on Per-capita demand, growth rate of domestic water demand and Population distribution by Mode of services as described in the above paragraphs. Summarized average day demand at each year starting from 2022 to the end of the design period is computed and presented in the table below.

Table 14.Projected domestic water demand

Projected Av. DWD (m3/day)	**2022**	**2026**	**2031**	**2036**	**2041**
HTU	747.4	1098.0	1767.9	2832.8	4517.2
YTU	2429.0	3173.2	4411.4	6103.3	8403.3
PTU	622.8	621.8	560.6	395.8	71.6
PA DWD	3799.3	4893.0	6739.9	9331.9	12992.
AS GTP II for category 3	61.0	67.7	77.9	90.4	106.1

3.3.4 Adjusted Domestic Water Demand

In order to account for changes in climate and socioeconomic condition of the town which affect water consumption of the community, the values of the average per capita domestic water demand established above should be factored for climate and socioeconomic changes using the climate and socioeconomic factors suggested in ministry of water resource guide line values.

3.3.5 Adjustment due to socio-economic factor

In order to apply socio-economic adjustment factor, the design criteria of ministry of water resources provided a categories of socioeconomic condition for various degrees of development is used.

Table 15.Adjustment factor due to socio-economic conditions

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

(Source: MoWR Water Supply Guideline, 2006)

Considering the above point of view and the improving development of the study area. Assosa town is classified into group B; towns having a very high potential for development but lower living standard at present and the appropriate Socio-economic adjustment factor of 1.05 is adopted.

3.3.6 Adjustment due to climatic effect

Consumption of water is directly influenced by climate of the study area. In order to account for changes in climate which affect the water demand, the values of the average per capita domestic water demand established above should be factored for climate changes using the climate factors suggested in table below. The climatic condition of the area can be classifying base on average altitude of the area. The table below suggest climatic adjustment factors that are going to be used for different altitude.

Table 16.Adjustment Due to Climate Effect by Mean annual precipitation

Group	Mean Annual Precipitation – mm	Factor
A	600 or less	1.10

B	601-900	1.05
C	901 or more	1.00

Table 17.Adjustment Due to Climate Effect by altitude of the study area

Altitude	**Factor**
>3300	0.8
2300-3300	0.9
1500-2300	1
500-1500	1.3
<500	1.5

The mean annual precipitation is more than 1000mm and average altitude of Assosa is 1580 masl so the climatic adjustment factor from table 1-8 shows 1.

3.4. Non-domestic water demand

Depending on the relative importance, size, economic conditions of a city, the rate of water demand will always be associated with non-domestic need also. The various aspects of non-domestic need will be discussed below.

3.4.1 Institutional water demand

This includes the quantity of water required to supply offices, hospitals, Schools, Universities, etc. This quantity will vary considerably with the nature of the city and with the number and type of institutions establishments present in it.

3.4.2 Commercial water demands

Commercial water demand consumption includes water used for commercial buildings & commercial centres including stores, hotels, shopping centres, cinema houses, restaurants, bars, airports and bus stations etc.

3.4.3 Industrial Water Demand

The industrial water demand is the water required by factories, paper mills, cloth mills, cotton mills, breweries, sugar Refineries etc. The water required in the industries mainly depends on the type of Industries, which exist in the city.

3.4.4 Water Demand for Livestock

In the town and the surrounding area there are livestock found which includes cattle, sheep, goats, donkey, etc. Currently the main sources of water for animals are from rivers, and springs. They require too much water for their drinking purposes. Livestock water demand analysis is included in this study.

Studies in other similar study areas, having measured water consumption show that public consumption amounts to about 10-20% of domestic consumption depending on the size of the study area and the type and extent of commercial and institutional activities in the project area. But this project area the no of public institutions, commercial institutions, small industries that are supplied by the water supply office and the current population of livestock of the study area are collected. Therefor based on the collected information the average non domestic demand of Assosa town is calculated and it accounts which is 52% of the average domestic demand. The table below present the computation of non-domestic demand of Assosa town.

Table 18.Non domestic demand analysis

Description	**Demand/ Unit**	**Quantity**	**Unit**	**Demand**
Public Demand				
Restaurants	10 l/seat	7450	seats	74500
Boarding schools	100 l/pupil	11390	pupil	1139000
Day schools	5 l/pupil	10789	pupil	53945
Public offices	5 l/employee	4634	employee	23170
Military Camps	60 l/person	8429	Person	505740
Workshop/shops	5 l/employee	35	employee	175
Abattoir	150 l/cow	35	cow	5250
Mosques & Church	5 l/worshiper	6000	worshiper	30000
Hospitals & health center	50 - 75 l/bed	134	bed	8375
Bus station	5 l/user	2000	user	10000
Public bath	30 l/visitor	1000	visitor	30000
Hotels and Pensions	25 -50 l/bed	3000	bed	112500
Prison	30 l/person	1400	Person	42000
Total public demand (lit/day)				2034655
Domestic animals water demand				
Cattle	50 l/head/d	680	Head	34000
Sheep and goats	10 l/head/d	1393	Head	13930
Pack animals (equines)	50 l/head/d	149	Head	7450
Pigs	10 l/head/d	35	Head	350
Hens	0.2 l/head/d	13028	Head	2605.6
Total domestic water demand (liter/day)				58335.6
Total non-domestic water demand (l/day)				2,092,990.60

Total public demand in (m3/d)	2,092.99
Total average day demand (m3/d)	3989.23
Public (non-domestic) water demand (%)	52%

3.4.5 Fire Fighting Water Demand

The quantity of water needed to extinguish fire depends upon population, contents of buildings, density of buildings and their resistance to fire.

Additional reserve in reservoir volume is not considered, rather the system is assumed to accommodate the requirement by stopping the supply to the consumers and directing it to the firefighting purpose. Therefore, for firefighting purpose a chosen location for fire hydrants will be made available and the fire brigade trucks can fill in by the available head.

3.4.6 Water Demand for Unaccounted Water Loss

All the water that goes in the distribution pipe does not reach the consumer. Some portion of this is wasted in the pipelines due to defective pipe joints, cracked and broken pipes, faulty valve and fittings, wastage at public taps, and bad plumbing or damaged meters. Some consumer keeps open their taps or public taps even when they are not using the water and allow continuous wastage of water which also includes illegal connection, unmetered usages such as flushing, firefighting, cleaning the system and overflow from components of the water supply system and etc. These losses should be taken into account while estimating the total requirements.

3.5. Variation of Water Use

The rate of water use varies from season to season, from day to day and from 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 pipes in distribution networks.

3.5.1 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.

The ratio of the maximum daily consumption to the mean annual daily consumption is the maximum day factor. This demand is used to design source capacity, riser mains, and service reservoir.

3.5.2 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 behavioural 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.

Previous studies and experiences clearly demonstrate that peak hour factor is greater for a smaller population. According to water supply design criteria prepared by ministry of water resource and World Bank design guide line the proposed maximum day and peak hour factor are summarized below

Table 19.Recommended water demand peak factors

Total population	**Maximum day Factor**	**Peak Hour Factor**
0 to 20000	1.3	2.0
20001 to 50000	1.25	1.9
50001 and above	1.2	1.8

(*Source: MoWR Water Supply Guideline, 2006)*

3.5.3 Summary of Water Demands

The total water demand is obtained by adding all domestic and non-domestic demands, and unaccounted water and applying all demand factors mentioned in the previous sections.

Table 20.Total Water Demand

YEAR	**2022**	**2026**	**2031**	**2036**	**2041**
POPULATION					
Growth Rates(%)	3.8	3.7	3.6	3.5	3.4
Population Urban	62283	72234	86540	103180	122427
Total	**62283**	**72234**	**86540**	**103180**	**122427**
Mode of Service					
Distribution(%)					
HTU	15	16.9	19.6	22.7	26.3
YTU	60	62.4	65.6	69.0	72.5
PTU	25	20.7	14.8	8.3	1.2
NTU	0	0	0	0	0
Sum (%)	**100**	**100**	**100**	**100**	**100**

Population					
HTU	9342	12195	16937	23410	32201
YTU	37370	45100	56788	71162	88743
PTU	15571	14939	12814	8608	1482
NTU	0	0	0	0	0
Total Beneficiaries	**62283**	**72234**	**86540**	**103180**	**122427**
WATER DEMAND					
Domestic Water Demand(DWD)					
Percapita Demand (lit/day)					
HTU	80.0	90.0	104.4	121.0	140.3
YTU	65.0	70.4	77.7	85.8	94.7
PTU	40.0	41.6	43.7	46.0	48.3
NTU	0.0	0.0	0.0	0.0	0.0
Projected Av. DWD (m3/day)					
HTU	747.4	1098.0	1767.9	2832.8	4517.2
YTU	2429.0	3173.2	4411.4	6103.3	8403.3
PTU	622.8	621.8	560.6	395.8	71.6
NTU	0.0	0.0	0.0	0.0	0.0
PA DWD	3799.3	4893.0	6739.9	9331.9	12992.2
AS GTP II for category 3	**61.0**	**67.7**	**77.9**	**90.4**	**106.1**
Adjusted Average DWD (m3/day)					
Climatic factor	1	1	1	1	1
Socio-economic factor	1.05	1.05	1.05	1.05	1.05
AA DWD	**3989.23**	**5137.67**	**7076.90**	**9798.45**	**13641.80**
Public Demand (m3/day)					

Rate per AA DWD(%)	52%	52%	52%	52%	52%
PD	2092.99	2695.53	3712.97	5140.86	7157.31
Unaccounted for Water (m3/day)					
Rate(%)	39	20	20	20	20
UL	2372.1	1566.6	2158.0	2987.9	4159.8
Average Daily Demand					
m3/day	8454.3	9399.8	12947.8	17927.2	24958.9
lit/sec	97.9	108.8	149.9	207.5	288.9
Maximum Day Demand (MDD)					
Max day Factor	1.2	1.2	1.2	1.2	1.2
m3/day	10990.6	12219.8	16832.2	23305.3	32446.6
lit/sec	127.2	141.4	194.8	269.7	375.5
Peak Hour Demand (PHD)					
Peak hour Factor	1.8	1.8	1.8	1.8	1.8
m3/day	19783.0	21995.6	30297.9	41949.6	58403.9
lit/sec	229.0	254.6	350.7	485.5	676.0
	Rural Villages around Assosa town				
Maximum Day Demand (MDD)					
lit/sec	6.60	7.93	9.88	12.20	14.91
Peak Hour Demand (PHD					
lit/sec	13.20	15.86	19.77	24.40	29.81

3.6. Water supply coverage

3.6.1. Mode of services

According to the town water service office reports, there are four major modes of services for domestic water consumers of Assosa Town. These are; house connections, yard connections private, yard connections shared and public fountains.

3.6.2. Population distribution by mode of services

The percentage of population served by each mode of service is varying with time. This variation is caused because of the changes in living standards, improvement of the service level, changes in building standards and capacity of the water supply service to expand. The greater number of the populations was served from their house connection and the others obtain from both shared yard taps and public fountains found in the town. Domestic demand is usually distributed by considering the socio-economic conditions of the community, population density and degree of services extended to the population. Based on these factors, the supply connection pattern to be divided into three namely:

(i). House connection

(ii). Yard connection, and

(iii). Public fountains.

These demand categories have been practiced by BGWSSE for several years. The division is made based on the level of consumption and socioeconomic condition of the community living in different kebeles. According to the table below, the per-capita demands are in the order of 110, 60 and 30 l/cap/day for house, yard and public fountain user levels of consumptions at the end of 2019. Though the logic behind categorizing the level of consumptions per connection pattern is acceptable, the per-capita demand indicated for each category hardly show the current consumption pattern of the area.

Table 21.Summarized Assosa Town domestic water demand pattern by level of Consumption

Mode of service	Demand L/C-day
HC	110
YC	60
PF	30

(**Source:** Assosa Town Water Supply & Sewerage Enterprise 2016 report)

3.6.3. Source of data

The source of data was taken both primary and secondary data. For the study, the primary data were obtained from pressure reading, elevation surveying and from discussion with water utility staff members to obtain additional relevant information on the subject matter. While, secondary data were collected from different literature reviews, design report, the town water supply service office existing documents and annual reported papers.

3.6.4. Equipment's and Software Used

GPS instrument was used to collect the required elevation data during pressure reading. Pressure readings were done using pressure gauge, which is commonly taken in the selected points of distribution system.

- **Hydraulic Model: Water CAD**

Model is something that represents things in the real world. Computer model uses mathematical equations to explain and predict physical events. Modeling of water distribution systems can allow determining system pressure and flowing rate under a variety of different conditions without having to go out and physically monitor the system (Dawe, 2000). Water CAD is a software tool and, primarily uses in the modeling and analysis of hydraulic and water quality-modeling application of water distribution systems.

- **Additional software**

ArcGIS was used to display the overlapped shape file of the distribution network on the topographic map of the town. While, Microsoft Excel sheet were used to organize elevation data, to calculate a repeated work of nodal base water demand requirement of distribution network simulation and for manual pressure validation work.

3.7. Methods

3.7.1.Selection of Sample Study Area

Although the area to be studied is a subsystem, the whole area is considered in this research and the random sampling is used in the selection of samples.

3.7.2. Data Collection

3.7.2.1. Preliminary data collection

Data collection is the most significant part in research work. To accomplish this work, the data were gathered about the necessary input parameters of model simulation, water losses and leakage management trend in the system. The data collection techniques were done by conducted a field visit and collecting data to Assosa Town on November 12- 16, 2020.

3.7.2.2. Secondary data collection

Data of water production, water consumption were obtained from town water supply office, design reports from the previous consulting offices were used as the secondary data in this research. The summarized collected data were presented as below;

3.8. Summary of Collected Data

3.8.1. Borehole Characteristics and submersible pump

In general, there are twelve bore holes with submersible pumps in the subsystem and only six of them are currently operational. The other previously working was currently totally not operational. The summarized borehole and submersible pump detail obtained is shown on Annexes B and C

3.8.2. Power supply units

There is power supply service in the town. The water utility were served power from Assosa substation and used with its transformer which is provided by Ethiopian Electric Power (EEP). The water distribution system was operated for 24 hours of its design period. But, there is no standby generator for distribution system during power failure is occurring.

3.8.3. Base water demand data

To estimate the current water demand of each node in the distribution network, it was necessary following the steps below.

Step one:**-Assigning the total population of the town**

Population is the important data to assess water demand in the distribution network. Facts show that there are different population forecasting methods which are used for estimating the current or future population of a given town, but the results of the methods are vary from one to the other due to considering parameters of each method. To predict the population of a town, it is necessary knowing factors affecting the population distribution, size and growth rate. In Ethiopia, the major factors that influences on the changes in population figure are births, death and migration. All these factors are influenced by family planning practice, war, natural disasters, development of the towns and the socio-economic activities in and around the towns. According to CSA data (2007) obtained from Assosa Statistics sub office, the total population of Assosa Town 55,583. The number of males is slightly higher than females. The following table 3.1.shows the population in a sex group.

The project area will cover the population of Assosa Town, Amba 4,6,8,12,14, Gamibela, Komeshiga 28 Kebeles of Assosa Wereda and Amba 16, Garabiche Metema, Menider 49, 48,47, 46 and 44, Dabusi, Mutsa Mado Kebeles of Bambasi Wereda; if the intake site is in Dabusi Kebele or Assosa Nekemet road. Similarly, the population of Assosa Town and Amba 4,6,8,12,2,5, Basha Buda, Tsenitsahalu, Baro, Siliga 22, 23, 24 and Belimili Kebeles of Assosa Wereda will included if the intake site is in Aba Dabusi Kebele

To conclude that according to CSA data if the intake site is in Dabusi Kebele 98,092 people will be accessed. And if the intake site is at Ada Dabus Kebele 74,741 people will be accessed.

Table 22.Total Population

Geographical Area	Population 2019		
	Both Sexes	Male	Female
Assosa Town	55,583	28,517	27,065
Assosa-Wereda			
Basha Buda	1,296	615	680
Tsenitsahalu	852	415	436
Baro	2,621	1,279	1,340
Amba 5	1,726	971	753
Amba 2	2,051	1,043	1,006
Amba 8	1,609	843	765
Amba 12	1,363	684	677
Amba 4	1,602	832	769
Amba 6	1,217	612	604
Siliga 23	1,369	680	688
Siliga 24	1,244	626	617
Siliga 22	1,322	653	668
Belimili	886	400	485
Komeshiga 28	1,675	824	850
Amba 14	1,563	819	743
Gamibela	2,023	1,039	983
Bambasi-Wereda			
Bambasi 01-Town	5,603	2,870	2,727
Bambasi 02-Town	8,018	4,080	3,931
Amba 16	2,365	1,186	1,177
Garabiche Metema	1,384	658	724
Menider 49	2,115	1,077	1,036
Menider 48	2,402	1,180	1,221
Menider 47	2,667	1,330	1,335
Menider 46	3,291	1,695	1,593
Menider 44	1,985	988	996
Dabusi	1,205	585	618
Mutsa Mado	6,213	3,170	3,037

Step two:- **Identification of number of houses around each supply node**

For this study, Assosa Town topographic map was obtained and bought from Ethiopian Mapping Authority, with the scale of 1:50,000 and twenty meter contour interval. In ArcGIS this topographic map was displayed and the town distribution network map which was drawn in Water CAD was exported in to ArcGIS shape file and overlapped it in the topographic map of the town. Therefore, the number of houses nearby each node was physically counted from the overlapped map and assigned to every node in the network by considering the actual condition of the residents in the town.

Step three:-**Assigning number of peoples in each supply node**

The current average number of person in each house (person per housing unit) was obtained from the revised design report of the town population projection and taken. The total number of houses in the town was identified by dividing the total population to the average number of person in the town. Therefore, in the opened Microsoft Excel sheet, all the nodal junctions in the system and the number of houses assigned for each node were entered respectively.

$$No\ of\ people\ for\ a\ supply\ nod = No\ of\ housees\ assigned\ by\ that\ node\ * average\ no\ of\ people\ in\ each\ house - (3.2)$$

Step four**:-Assigning average day water demand of Assosa Town**

For assessing the average water demand of the town, deterministic water demand estimation method was used. Hence, the per capital water consumption of the town was calculated using the annual water consumption recorded data and projected total population figure during (2016). Therefore using equation below it was assessed.

$$\text{Per capital consumption} = Annual\ consumption\,(m3 * 1000/m3)/Total\ popon * 360 --(3.3)$$

Therefore, the average water demand of the town was calculated by multiplying the per capital demand with the estimated number of population as follow.

$$Qave = Per\ capital\ water\ consumption * total\ population --- (3.4)$$

Step five:-**Assigning base water demand in each supply node**

Once the average day water demand of the system was determined, to calculate base water demand for the particular supply node the following equation was used (Bhadbhade, 2009).

$$Base\ water\ demand\ for\ a\ supply\ node = (Popn\ served\ by\ that\ node/total\ popn\ of\ the\ town) * average\ day\ water\ consumption --(3.5)$$

3.8.4. Demand multiplier factors

For modeling, peak hour demand scenario was adopted. Demand for each supply node was performed by taken demand multiplier factors of 24 hour flow duration and computed with assessed base demand. Therefore, for this study by considering the peak flow time, minimum flow condition and the actual condition of population served from the system; the demand multiplier factors were adopted data obtained from the regional water, energy and mineral bureau. Therefore, the proposed peak factor and patterns for demand multiplier factors were listed in table below.

Table 23.Hourly peak factor

Population	Peak Hours
0 – 50,000	2
50,001 – 100,000	1.8
101,000 & above	1.6

(**Source:** FDRE, MoWR)

3.8.5. Roughness coefficients for pipeline

The Hazen-Williams equation was developed for the action of friction at the pipe wall, because its formula uses a pipe carrying capacity factor. Higher C-factors represent smoother pipes (with higher carrying capacities) and lower C-factors describe rougher pipes (Tomas, et al, 2003). The value of roughness coefficient, C-factor is depending on pipe materials and its age; this effect can be shown in table 3.6 and 3.7 below (Tomas, et al., 2003). According to Assosa Town water service office, PVC pipe laid in the water distribution network was served without replacement work for the last 13 years. Roughness coefficient, C- factor for different pipe material is attached to as Annex-L.

3.8.6. Network Simulation

To build and simulate the hydraulic model, water CAD stand-alone, graphical editor water distribution modeling software was used. The water distribution network map was obtained from the town water service office. The network simulation was taken extended periods by consideration of hourly demand variation pattern over 24 hour flow duration analysis work. For this study, the network operational set-up was done by system international; SI unit and the project liquid were taken water at 20°c.

The other model input were taken and carried out as mentioned below;

- Coordinate................................X-Y
- Setting...................................... Pressure
- Tank level… ....Elevation
- Drawing Scale............................Scaled
- Annotation Multiplier… .... Adjusted for report visibility

3.8.7. Model calibration and validation

The computed parameters of a model and actual field observation are not always has the same value. Therefore, before discussion about the simulated model results, the entire model data quality must be analyzed by calibration and validation technique. Calibration is a process of adjusting the model input data until its results become closely approximate to the measured field data. Whereby, it used to obtain approach, realistic and acceptable results. Therefore, in this study the model data quality analysis was done by comparing and calibrating the computed pressure data with the observed one. All sampling points were selected after the computed model was simulated and knowing the pressure variation area (pressure zone) in the town water distribution network ±0. 5% of the maximum head loss across the system, whichever is greater) and then finally it was validated manually using the correlation coefficient (R^2) method using Microsoft Excel sheet. The calibration process was performed by adjusting sensitive parameters related with flow; like pipe roughness coefficient and water demand until it was become within the acceptable limit of 85% of field test measurements (it should be within ±5% of the maximum head loss across the system, whichever is greater) and then finally it was validated manually using the correlation coefficient (R^2) method using Microsoft Excel sheet.

3.9. Water Loss Assessment

Unlike the water consumption, the water production of Assosa Town was only recorded at the town level. Hence, the water loss analysis in Assosa was assessed at the town level based on the percentage of Non-Revenue Water which was obtained from the total production and actual consumption figure. As per data obtained from the town water service office, the past four year (January, 2013 to January, 2016) water production and consumption (billed water volume) in the system was identified. Using this data and equation below; the total Non-Revenue Water (NRW) in the system was calculated for each recorded year.

$$NRW = SIV - BAC - - - - - - - - - - - - - - - - (3.6)$$

Where,

NRW= Non-Revenue Water SIV= System Input Volume

BAC= Billed Authorized Consumption

During field visit, it was also observed that the utility do not have any recorded data related with average leak flow, number of reported bursts and average leak duration; due to these physical loss in the main was assessed base on the available data, and it was adopted by considering the minimum achievable annual physical losses (unavoidable annual real loss) in the system (Farley, et al., 2008).

$$UARL(liters/day) = 18 * Lm + 0.8 * Nc + 25 + L * P - - - - - - - - - - -(3.7)$$

Where,

Lm = mains length (km);

Nc = number of service connections;

Lp = total length of private pipe, property boundary to customer meter (km); P = average pressure (m)

As per data collected from town water service office, and during the year 2016 the town water system covers;

Total mains length of the system = 6.76 Km,

Number of service connections (registered) = 5,584 in number,

The water utility was laid an average length of 0.018 Km private pipe from distribution line to customer boundary. Therefore, for this work total length of private pipe was taken by multiplying number of service connections and average length of private pipe, and it was used 100.51 Km. Average pressure was taken from the actual observed pressure value of 24 hour duration, and the average value of 52.8 m was adopted. While, the total water loss was identified as per number of connection and pipe length at the town level.

3.9.1. Water loss as per number of service connection

One of the appropriate indicators of water loss in the distribution system is describing it as per number of service connection (liters per service connection per day, l/c/d), and it gives more precise figure than NRW as a percentage of inputs volume. Based on the obtained data; the total number of service connections in Assosa Town in 2016 was 5,584 and taken this, the volume of water loss as per connection were analyzed from the total unbilled volume.

$$Loss\ per\ connection = (Unbiled\ V * 1000lt/m3)/total\ No\ of\ connection * 360day)/loss\ per\ connection - -(3.8)$$

3.9.2. Water loss as per pipe length

The other good indicator of water loss in the distribution network is determining loss as per pipe length (liters per kilometer of pipeline per day, l/km/d). Water loss as per pipe length was calculated as

$$Loss\ per\ pipe\ length\ = (Unbilled\ V * 1000lt/m3)/(total\ pipe\ length\ in\ the\ town * 365day - -(3.9)$$

3.10. Assessment of Maintenance Practice

The water distribution leakage management practices of the town water service office were assessed based on the management, technical and financial; plan, policy and strategies. Hence, field visits were made to identify the leakage in the system and its managing processes. During field observation, discussions were conducted with town water supply service personnel to obtain information on the common failure of system, financing mechanisms, and the maintenance culture and cost drivers of maintenance. While, cost related data was collected by reviewing the annual reports and financial statements of the utility. Finally, the collected data were analyzed and presented in the next chapter.

3.10.1. Assessment of Water Quality

Samples collected from House connection, Public fountains were taken to Addis Ababa Environment protection authority laboratory and the physical, chemical and Biological characteristics of the Assosa water analyzed. The parameters taken to the laboratory are summarized.

Table 24.Water quality parameters

S.No	Type	Parameter
1	Physio Chemical and Biological parameters	PH
2		TDS
3		TSS
4		Turbidity

5		Hardness
6		Total Coli form
7		Chloride ion
8		Fluoride ion
9		BOD(Biological Oxygen demand)

3.10.2. Sampling

Water samples were collected from different sources of water used by the communities in the town sources. A total of nine water samples were collected for laboratory analysis from which five samples were from house connection, three samples from yard connection and two from public fountain and a total of nine samples were taken for sample. Also, samples were collected both from improved water sources. The sample distance between each sample is at average of one km to two km. Each sample is coded as Assosa S1, to Assosa S9. The standard test method is adopted. The Sample and description is described below. The test method is as ES ISO Ethiopian Standards Agency guidelines.

Table 25.Sample sources

Sample code	Source	Kebele
Assosa S1	HH	02
Assosa S2	HH	02
Assosa S3	HH	08
Assosa S4	PF	02
Assosa S5	PF	08
Assosa S6	PF	02
Assosa S7	YC	08
Assosa S8	YC	02
Assosa S9	YC	02

3.11. Assessment of Customer Satisfaction

- The primary assessment for the customer satisfaction evaluation will be done from the output from the water CAD analysis, the water quality outputs and the operation and maintenance by comparing with the national and international standards.
- In addition to this the questionnaires are prepared and distributed to 5% of the population in the town and the output is analyzed.

- The random sampling is used to distribute the questionnaires but the total subsystem area is considered.
- Excel chart is used to analyze the questionnaires.

3.11.1. Sampling Technique and Sample Size

Assosa Town has four adminstraive Kebeles. In order to have the representative samples four Kebeles will be selected for this study. In this study, both probability and non-probability sampling techniques will be employed to draw the sample households, focus group discussants and key informants. Accordingly, the sample size of **295** households will be selected using systematic randam sampling technques from the total of **1136** households in the town.

3.12. Sample Size Calculation

A two stage stratified sampling design was used for the study. The frist stage is selection of Kebeles in the town and the second stage is drawing of water points constracted by the two implementers. A level of significance of 5% and margin of error of 10% were used for the computation of the sample size.

$$n = \frac{N}{1 + N(e2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (1)$$

$$n = \frac{1136}{1 + 1136(0.052)} = 295 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (2)$$

Where: n= Sample size

N= Total number of households in the selected Kebeles;

e=Precision level or sampling of error 5% (0.05);

Based on the above sample size determination calculation 295 sample households were obtained. Totally, 295 households were selected accordingly; the sample size of 295 households will be selected using systematic random sampling techniques from the 1136 households in the town.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Estimated water demand

Estimating the expected water demand of the town were used for assessing and sizing system components such as pumping station, reservoirs, and transmission and distribution pipe line.

4.1.1 Population forecasting

Population figures are available from the 2007 population and housing census of Ethiopia, published by the Central Statistical Authority (CSA), Office of Population and Housing Census Commission. The CSA makes population projections for towns (urban) and rural areas by region. Population growth rates will vary from town to town, depending on numerous factors. The basic growth rates for domestic water demand calculation will be those available or implied from the above-mentioned CSA publications for the corresponding population. For the future population prediction, the above mentioned method (S curve) will be used if found suitable otherwise the geometric growth method with CSA growth rates established at national level for every 5 years' interval will be used.

4.1.2 Per capital water consumption

The per-capita water consumption for various demand categories varies depending on the size of the town and the level of development. In Assosa, because of the growth of the socio economic activity in both governmental and private sectors, there was the high water demand in the town. A per-capital demand of a particular group depends on the life style and awareness of the group. Once the water is available in the locality and with the awareness that is expected to be created after the implementation of the project the per-capital consumption of a user in each mode of service is expected to grow.

4.1.3 Average water demand

There are several mathematical methods of estimating the water demands of a given town; including extrapolating historical trends and correlating demand with the socio- economic variables of the town. But, the most common means of forecasting future water demand is estimating current per-capital water consumption, and multiply this by the projected population figure. Therefore, during 2019 the average water demand for Assosa Town was calculated to be 3,331,065 l/d or 33.31 l/s, which mean 3331.06m3/d.

4.2 Water distribution network analysis

In the modern water supply system, clear water shall be delivered to the service reservoirs directly through the transmission main and which is completely isolated from the distribution system. However, existing Assosa Town water supply system, which was constructed before 13 years ago and as it, was the old system; water is pumped simultaneously into the distribution network and service reservoir. So, the impact of this network configuration and the capacity of distribution system components were described as below.

4.2.1 Reservoirs capacity

The capacities of reservoirs in the water supply system were determined using different methods. The most appropriate and economical approach of determining storage volume of reservoir is the 24 hours supply demand simulation mass curves. To develop such type of curves, it requires reliable recorded historical data of hourly water demand figures of the town. But, in the absence of such type of data, to determine the size of reservoirs, it was adopted the commonly practiced in many water supply systems and based on the urban water supply design criteria of the ministry of water resources; it was used for sizing the reservoir volume as one third of the maximum daily demand. Therefore, as per the design criteria of the FDRE; MoWIE, the maximum day factor usually varies between 1.0 and 1.3. Hence, a maximum day factor of 1.15 was adopted for assessing the maximum day water demand and reservoirs capacity for Assosa Town and applied it corresponding to the total average day demand of a particular year (2019). The maximum day demand will be 1.15 times the average day demand. This is calculated to be 3,830.72 m^3/d. Accordingly, the current (2019) required reservoirs volume capacity for water demand of Assosa Town should accommodate 1, 2 76.90 m^3 one third of the maximum day demand. Hence, from the above finding to satisfy the current water demands of Assosa Town; the clear water reservoir was sized as a 1500 m^3 volume capacity of standard reservoir. But, in the existing water supply system of Assosa, both storage tanks which serve as clear water tank and service reservoir had a capacity of 2500 m^3. This indicate, the existing reservoirs capacities were very well enough in size comparing with the current water demand of the town, and however one of the major factors of the day to day intermittent water distribution in the town was this reservoir never became full in history due to the absence of enough water wells.

4.2.2 Pump and pump capacity

One of the main components of water distribution systems is the pump stations. Pumps deliver energy to the hydraulic system to overcome elevation difference and head losses due to pipe friction and fittings. Pump head curve is one of the necessary input parameters for water distribution modeling and according to Tomas, et al., 2003, is an energy equation which used for solving pipe network problems. For this study, pump efficiency were conducted to determine the pumps capacity in the town water distribution system.

According to field observed data and model simulated result .the pump brake horse power and maximum water power were collected as 75 kW and 34.14 kW, respectively. Therefore, the maximum pump efficiency is calculated to be 45.2% According to the pump characteristic comply with (ISO 9906:2012); most pumps, which present and perform in a good condition, have an efficiency of 60-80%. While, in Assosa a frequent failure and damaged of pumps due to long service time, the challenges of supplying spare parts and improper repaired after failure; made the pumps perform below the required efficiency. As per the computed water CAD model outputs and information obtained from Assosa Town water service office; those pumps performing in the system were operating an average of effective 16 hours in a day. With this the pumps maximum capacity of delivering water to the distribution system was discussed as:4320,000 l/d or 4320 m^3/d of maximum water were deliver to the system. But from the above finding the current maximum water demand of the town is 3,830.72 m^3/d and this indicates that the pumps capacity can meet the current water demands of Assosa Town if the operation system was good.

4.2.3 Transmission main line

It is discussed that the transmission main was not isolated from the distribution network and it gives water to distribution line before entering to service reservoir. The service reservoir is found at the highest point in the town and the supply is done by gravity force from reservoir to the lower points. However, the system is also interconnected that water directly enters the distribution system when necessary. As per model analysis, maximum water pressure in the transmission main was 242m head at pumping station, and this water head was delivered using small pipe diameter (DN 150mm). Accordingly, the minimum water pressure was recorded as 14m head at junction Al_j20 when all water sources are operating. Small sizes of pipe in the main at a high pressure were lead for a frequent pipe bursting and leakage and the minimum pressure indicates that there is a less supply of water in the system.

4.2.4 Distribution main line

Regards the topography of Assosa Town, the locations of nodes in the water distribution line is near each other. According to the design report of MS Consultancy, the maximum and minimum water pressure in the distribution system was 78m and 20m head around treatment plant and service reservoir, respectively and as model developed for this research the average head for maximum and minimum is close to this head. According to the design criteria of the FDRE; MoWIE, the maximum and minimum water pressure in the distribution system is 70m and 15m, respectively. Beside these comparisons; the current Assosa Town existing water distribution network was operating out of the recommended limitation for the minimum pressure. However it is acceptable for this evaluation purpose.

4.2.5 Pressure variation in the distribution system

Variation of water pressure in the distribution system is mainly because of hourly fluctuation of water demand. As shown in Figure 8 and Figure 9 below; the water pressures in Assosa water distribution system were a function of this factor. Variation of elevation difference in most of the town has also an impact for the rising and reduction of water pressure in the network. Therefore, during peak demand time most of the network was disconnected from the system and wide residential area of the town were not getting water. While, most of the residences were get and collect water at night flow during low demand time. However, residences found at the higher altitude usually faced in getting water and subjected to get water during the night time, where there is interruption of some sources and only five or twice times a week.

4.2.6 Negative pressure

Situations that give rise to negative pressures should always be avoided. Hence, pressure in the distribution system is one of the factors for intermittent water supply. For this study, all negative pressure presented in Annex indicated; the some borehole in the system was disconnected during peak demand time with scenario two and water was not reaching to customers. Whereby, these was mainly as a result of; there is demand concentration (greater demand than the design demand), inadequate pipe capacity (small diameter), and availability of residences on higher ground of the town.

4.2.7. Hydraulic model calibration and validation

In the modern time, water utilities have been analyzed for the status of their existing water supply system using hydraulic models. But, for assuring the entered water distribution model inputs data accuracy; the computed model results have been compared with the actual observed field conditions of study area. As shown in Figures 8 and 9; during the comparison of measured pressure value with the simulated one, gaps were recorded up to 14m head and it was out of the pressure standard and limitations suggested by Tomas, et al, (2003). Therefore, the computed pressure value of both scenarios, during peak demand time and low demand time (night flow) were calibrated until the result was approach to the observed pressure value.

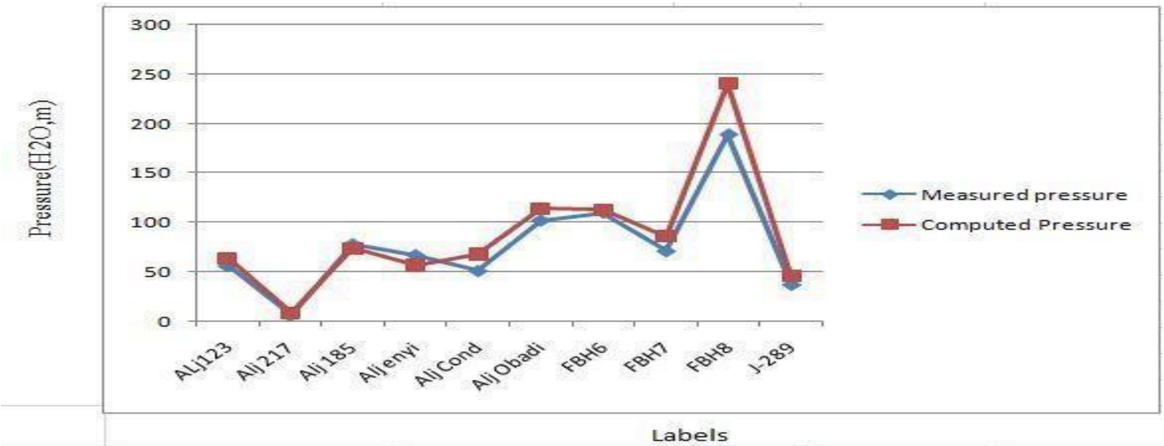

Figure 7.Graphical representation of observed pressure value during peak demand time

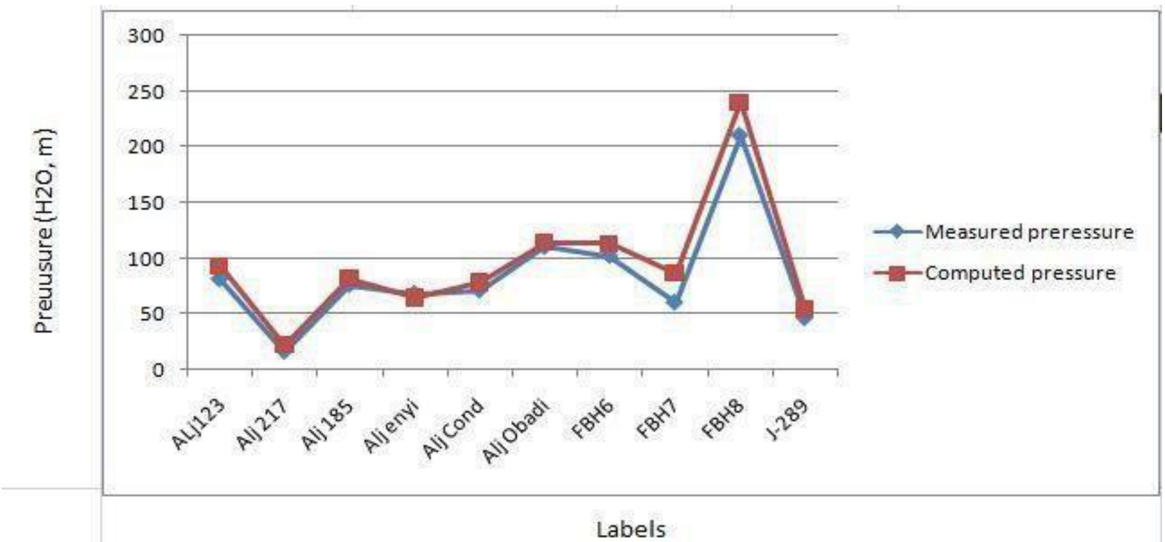

Figure 8.Graphical representation of observed pressure value during night flow

As per pressure criteria 85% of the computed model results should become within ±0.5m head of the observed field conditions. Hence, to assure the acceptable level of calibration, the two most commonly used model inputs parameters; pipe roughness coefficients and junction demand data were adjusted. Therefore, during model calibration; C-factor was used 150 for PVC and average value of 109 for DCI pipe. In Assosa the maximum hour water demand is happen during morning and evening time, when most people use water for bathing, washing and cooking purpose. Accordingly, demand adjustment was undertaken by adopting multiplier factors in reasonable way (a maximum and minimum of 2 and 0.3, respectively) and demand concentration also adjusted based on actual condition of the town.

4.2.7 Model validation

The model validation work was taken by comparing the measured pressure and computed values. The correlation is used to check that the model is validated. The correlation coefficient equation (R^2) method and it were described and represent graphically in Figures shown below. As shown in figure 10 and 11; it explain the results of correlation value (R^2) for both peak and low demand time was represent as 98.03% and 98.92%, respectively. Thereby, the calibrated pressure value was validated within the recommended standard.

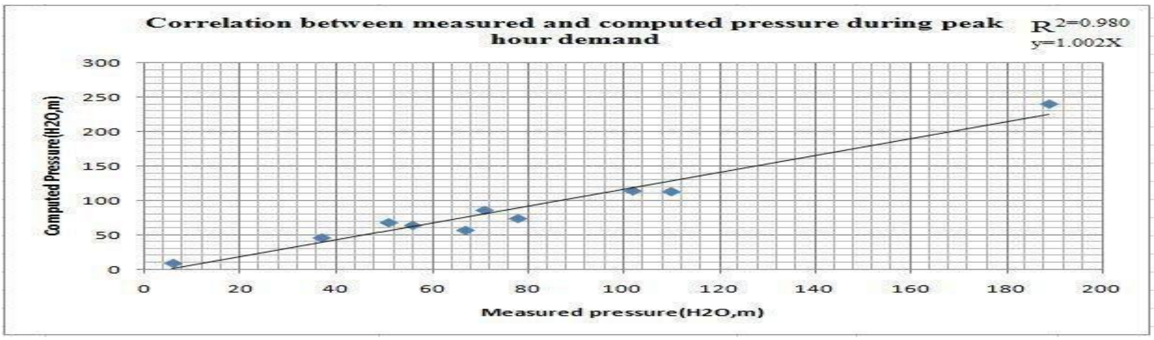

Figure 9. Correlated plot during pressure calibration for peak demand time

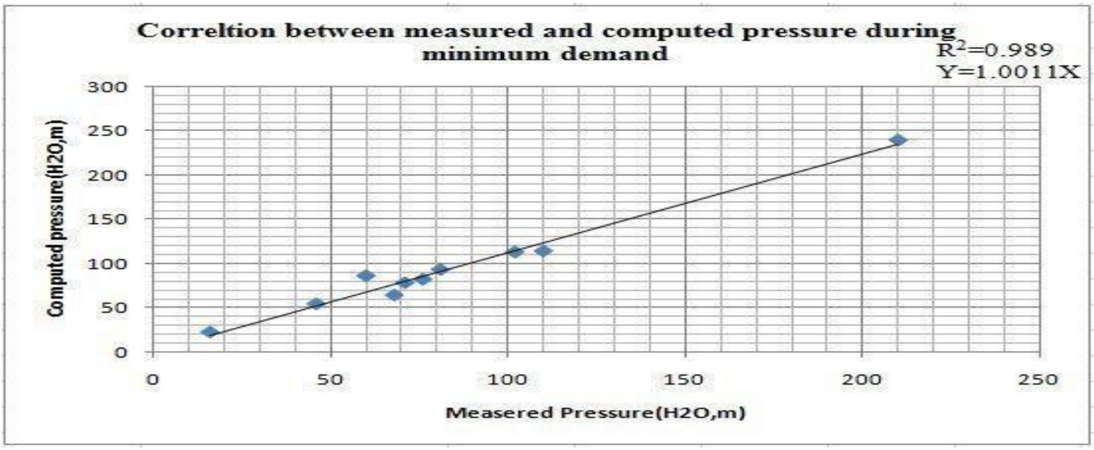

Figure 10.Correlated plot during pressure calibration for min demand time

4.3 Water loss Analysis and Findings

One of the major challenges of water utilities is high volume of water loss in their distribution networks. If a large quantity of supplied water is lost; it is difficult to meet the required quantity demands, and correspondingly made challenges to keep the water tariffs in the system at a reasonable level. Whereby, water loss for Assosa Town was assessed and discussed as below;

4.3.1 Percentage of water loss

Unaccounted for water include water losses due to leakage in the water supply system, illegal connections, legitimate unmetered for flushing, overflow from reservoirs, improper metering and others for which bills are not paid. It is very crucial to estimate this quantity as it usually varies from 15 % to 50% depending on the age of pipelines in the system and the size and complexity of the distribution system. Non-consult's study proposed the value of unaccounted for water to be from 30 to 35% of the domestic and non-domestic water demands and assumed a constant value of 30% during the design period. Howe ever based on the water produced and consumed data obtained from the Assosa water office, the percentage of water loss is 37.38%. Therefore, water authority should plan to work on identification of causes for unaccounted for water and hence appropriate mitigation measures to minimize the problem and thereby save water for the domestic and other municipality purposes. According to the town water service office; during 2016, total Non-Revenue Water in Assosa Town was estimated as 37.38%.

Table 26.Percentage of Non-Revenue Water

Year in G.C	Annual water with in the sub-system production in m^3	Annual incoming to the sub-system m^3	Annual outgoing from the sub-system m^3	Total production for Assosa sub-system m^3	Annual water consumption in m^3	NRW m^3	Perce
2013	374988	-	-	374,988	252,275	122713	32.72
2014	368938	-	-	368,938	270,707	98231	26.63
2015	671593	100739	67159	705,173	448,159	257014	38.27
2016	698522	104778	83823	719,478	458,372	261106	37.38

(**Source:** Assosa Town water supply service office, existing document)

The percentage of NRW in 2019 in the town is 37.38, which is greater than the permissible water loss percentage, which is 25%. The possible reasons may arises from overflow from tankers due to absence or malfunction of automatic flow control valve or float valves, leakage from transmission and distribution pipes, leakage due to high pressure at transmission and distribution pipes, leakage due poor workmanship and using of non- standard pipes and fittings and lack of sudden maintenance during burst of pipes.

4.3.2 Category of water loss

From the bellow table 17, the total Non-Revenue Water during 2019 was recorded as 261,106m^3. These amounts of water loss were categorized as physical/real and apparent loss. Unavoidable annual real loss (UARL) or the minimum achievable annual physical losses was adopted as the total physical loss in the system, and it was analyzed and calculated to be 136,508.25 m3/yr. Total apparent losses in the system were determined from the town water balance as:

Apparent loss= Total NRW–UARL= (153,187–136,508.25) m3/year= 16,678.75m^3/year. From the above descriptions, apparent loss was large in volume, and it covers 21.12% of total volume of water losses in Assosa Town water distribution system. While, physical losses were also contribute a considerable volume of loss in the system and it covers 10.88% of total NRW. The total water loss can be summarized as follows.

Table 27.Category of water loss

	NRW	Apparent loss	Real Loss
Year (2019)	261,106.00	136,506.25	16,678.75
Percentage	63.02	32.95	4.03

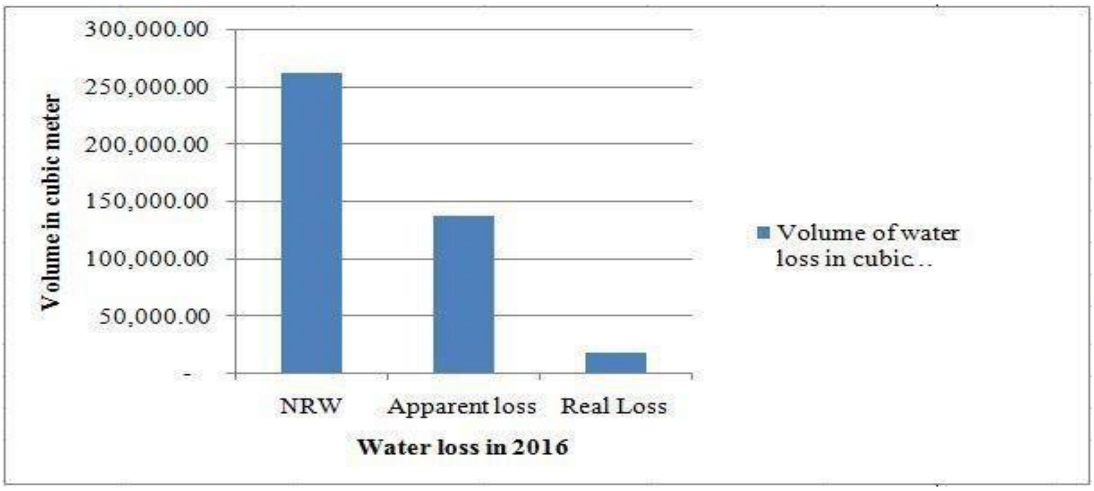

Figure 11. Category of water loss, 2019

4.3.3 Water loss as per number of service connection

One of the appropriate indicators of water loss in the distribution system is describing it as per number of service connection (liters per service connection per day, l/c/d), and it gives more precise figure than NRW as a percentage of inputs volume. Based on the obtained data; the total number of service connections in Assosa Town in 2019 was 5,584 and taken this, the volume of water loss as per connection were analyzed from the total unbilled volume and it was calculated to be 128.11 liters/c/day. Performance indicator of physical loss target matrix; Assosa Town water loss per connection were found in good condition, which is < 150 l/c/day of when the system is pressured in distribution system with average pressure of 52.5m. However, leakage related with connection contributed as the sources of physical loss in Assosa Town water distribution system.

4.3.4 Water loss as per pipe length

The other good indicator of water loss in the distribution network is determining loss as per pipe length (liters per kilometer of pipeline per day, l/km/d). According to the town water utility, the total length of water distribution line including both main and privet pipeline (from property boundary to customer's meter) were estimated about km. Therefore using this, the estimated amount of water loss; as per kilometer of the pipe, length of the town was calculated as 10,822.25 liters/km/day or 10.82 m^3/km/day. As per revised literature, the average condition of water loss as per pipe length is 10,000-18,000 liter/km/day, and bad condition of system is >18,000 liter/km/day. Therefore, this figure shown that if distribution line is expanded, water loss also increases in the pipe network.

4.3.5 Other Reasons of water loss

- **Data handling errors**

Data handling error in the meter reading and billing process were contributed for apparent losses. Customer meter reading practice; especially unbilled metered trends were the common problem of Assosa Town water service office. Whereby, recording of under/overestimated figure lead the water utility to improper collection of revenue, and at the end of the month the authority were lost money. Accordingly, as per the authority 2019 annual report, the town water authority has lost 3,497m^3/year of water due to poor data handling process.

- **Illegal connections**

As a developing town; there are a significant number of illegal users of water within Assosa Town water distribution network, and were contribute to the reduction in service level to authorized consumers. The town water utility were not known the actual figure of residences that do not pay water tariffs but received water from the distribution system. However, as per the feedback from the water utility; construction sectors, different enterprises and hotels in the town are mainly contributing in large number. Due to limitation of data, water losses as result of illegal connections cannot be figured clearly in Assosa Town.

4.4 Operation and maintenance Analysis

As per the collected information and field observation, the operation and maintenance culture of Assosa Town water Sources and office operation can be summarized below.

Table 28.Practices of Operation and Maintenance

S. No	Basic Standards Detail Activity Best Practice	Daily	Month
1	Preparation of water supply network map of -Water sources supply Map village/town starting including water source, -Water Lines (transmission and distribution If update head works, treatment and distribution network. Available		X
2	Preparation of a plan involves list of routine -checking the whole system tasks, specific tasks at regular intervals including -Pump operation timings (start and end time daily). Inspection of system and taking action. -Current drawn by each pump unit and total Units.		X

3	Institutional arrangements and hiring adequate Team & human resource and capacity building. Experts		X
4	Overall system follow up:- Readings of vacuum and pressure gauges. Bearing temperature for pump and motor. Water level in intake/sump. Flow meter reading Any specific problem or event in the pumping installation or pumping system Clean the pump, motor and other accessories... Records of pressure, voltage and current. Check free movement of the gland of the stuffing box. Verify and rectify alignment of pump and drive. Clean oil lubricated bearings and replenish with fresh oil. Check vibration level with instruments if available; otherwise by observation. Clean flow indicator, other instruments and appurtenances in the Pump house.	X	
5	Store Management for availability of tools, -Full system spare parts with equipment’s Available parts/spares, equipment’s, basic materials etc. daily	X	
6	Maintenance of records and details of Inspect the mechanical seal for wear and replacement, if necessary. When materials/tool/equipment is purchased like date of Check condition of bearing oil and replace or top up, if necessary. updated purchase, manufacturer details, cost of Detail of the replaced part purchase, warranty, dates for part replacement		X
7	Financial Arrangements out average annual O&M expenditures and work out financial arrangement		X

Table 29.Observed sources

Sources	**Day 1 (15 June, 2017)**	**Day 2 (23 July 2017)**	**Day 3(3rd Oct 2017)**	**Reason**	**Person On Site**
ABH-1	Not Operation	Operating	Operating	Damage of Pump	Operator
ABH-2	Not Operating	Not Operating	Operating	Pump Problem	Guard
ABH-3	Operation	Operation	Not Operating	No power	Guard
ABH-4	Operating	Not Operation	Operation	Not known	Guard
FBH3	Operating	Operating	Operating	Pump Problem	Operating
FBH4	Not Operation	Operating	Operating	Not known	Guard
FBH5	Operating	Operating	Not Operating	No power	Guard
FBH6	Operating	Operating	Operating		Guard
FBH7	Operating	Operating	Operating		Operating
FBH8	Operating	Operating	Operating		Operating

Table 30.Water Quality Analysis, Result and Discussion

S.No.	Parameter	Test Result S1	Test Result S2	Test Result S3	Test Result S4	Test Result S5	Test Result S6	Test Result S7	Test Result S8
1	PH	7.20	7.24	7.26	7.5	7.25	7.05	7.34	6.82
2	TDS	461ppM	481ppM	411ppm	334 ppm	326 Ppm	353 Ppm	323 Ppm	357 Ppm
3	TSS mg/l	<0.0001 mg/l	<0.0001	<0.0001mg/	<0.0001m g/l	<0.0001m	<0.0001mg/l	<0.0001	<0.000 mg/l
4	Total Hardness	228.6ml/l	214.4 mg/l	275mg/l	125mg/l	121 mg/l	129.4 mg/l	121.4 mg/l	120mg.l
5	Turbidity NTU	<0.0001	<0.0001	<0.0001 NTU	<0.0001 NTU	<0.0001 NTU	<0.0001 NTU	<0.0001mg/l	<0.0001mg/l
6	Chloride 1	10.6mg/l	13.2mg/l	10.6mg/l	9mg/l	10mg/l	8.8mg/L	8.4mg/L	9.6mg/L
7	Fluoride	-	-	-	0.32mg/l	0.50mg/l	0.35mg/l	0.46mg/l	0.53mg/l
8	Total Coliform	2041/100m1	1872/100ml	1467/100m1	840/100m/l	6701/100ml	564/100m1	1034/100mg/l	306mg/l
9	BOD	7mg/l	7mg/l	6mg/l	6mg/l	7mg/l	-	-	-

(**Table: 20** Sample taken from (Assosa) selected household Result)

The results of the water samples taken from all existing sources, selected households, and Public fountains in comparison with the international (WHO) and national (Ethiopian) standards are indicated on table below. Water quality result for water samples are taken during the dry season.

4.5. Summary of Water quality findings

The PH value of all taken water samples is within the range of the national and international standard. TDS value for all samples is within the national and international standards. However, this does not mean that the water utility is working well on the quality of the pipe water supply because the observed TDS value in samples S1, S2, S3 are high. Total hardness for all samples is within the limit of both national and international standards. The chloride content for the samples is within the relevant range. Turbidity the samples taken from all sources are less than both national and international standards. From this, it is possible to conclude that the possibility of the system to be contaminated by the soil particles or other surface particles is very low or null. The total coliform for all samples is much departed from both the national and international standards. This shows that the drinking water sources can be contaminated by storm water run-off from roadways, farms and livestock operations, and discharges from sewage treatment or septic systems. The presence of coli form bacteria in water does not guarantee that drinking the water will cause an illness. Rather, their presence indicates that a contamination pathway exists between a source of bacteria (surface water, septic system, animal waste, etc.) and the water supply. Disease-causing bacteria may use this pathway to enter the water supply. Since coliform bacteria usually persist in water longer than most disease-causing organisms, the absence of coliform bacteria leads to the assumption that the water supply is microbiologically safe to drink. BOD (Biological Oxygen demand) standard is also within the limit of both standards. A studies shows that BOD level of 1-2 ppm is considered very good. There will not be much organic waste present in the water supply. A water supply with a BOD level of 3-5 ppm is considered moderately clean. In water with a BOD level of 6-9 ppm, the water is considered somewhat polluted because there is usually organic matter present and bacteria are decomposing this waste. At BOD levels of 100 ppm or greater, the water supply is considered very polluted with organic waste. As it is indicated on table above the total hardness of water samples taken from different water sources, reservoirs and households is below the national and international standards and the water in existing water supply system is soft. This may leads to corrosion of pipes which can shorten the life span of the pipes in the water supply system and corrosion can result in the contamination of drinking-water and adverse effects on its taste and appearance. At levels above 250 mg/l Cl water will begin to taste salty and will become increasingly objectionable as the concentration rises further .The Chloride content in all samples taken is all less than both international and national standards as shown on the table. From this, we can conclude that the Chlorination in the system is very low with results in high contents of Coliform in water.

4.6 Customer Satisfaction Analysis

Introduction and purpose of the survey as per the information obtained from Assosa Town water utility customers service department; there are 5584 private houses, institutional, commercial and industrial customers. The number of private house customers estimated up to 65% of the total customers.

Table 31.Category of customers Responded to questionnaires

Customer type	Frequency	Percentage (%)
Private	196	70
Commercial	34	12
Industries	28	10
Public	16	6
Bono	6	2

4.6.1 Results of house hold Survey

Table 32.Customer response on effective water usage

Do You use pipe water effectively.

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Yes	275	98.21	100	100
	No	0	0.00	0	100
	Total	275	98.21	100	-
Missing	Missing	5	-	-	-
Total		280			

Out of 280 customers, asked for effective usage of water, 275 answered that they use water effectively, and no one responded that they does not use water effectively. This clearly shows that everyone is responsible for effective usage of water.

Table 33.Customer response on accessibility of other water source

Can You Get Water Other than Pipe Water for all Purpose?

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Yes	55	19.64	20.22	20.22
	No	217	77.5	79.78	100
	Total	272	97.14	100	-
Missing	Missing	8	-	-	-
Total		280			

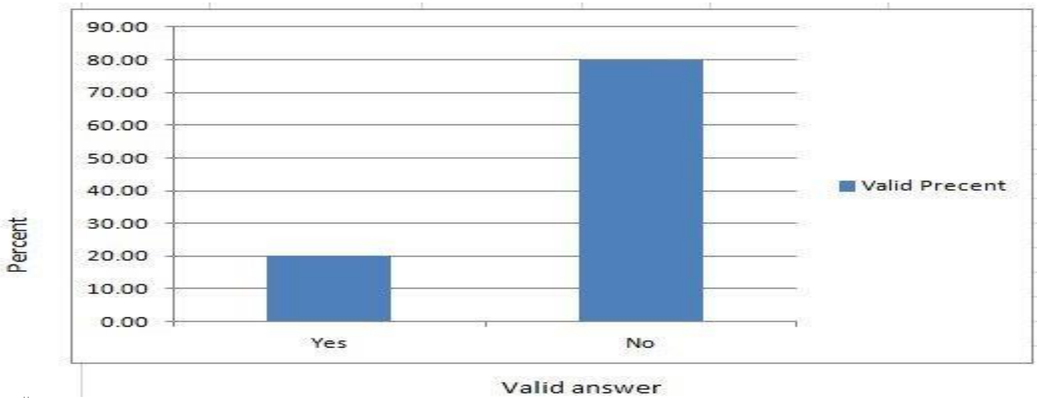

Figure 12. Customer responses on accessibility of other water source

Out of 272 valid respondents for the question water source other than pipe water, 55 customers can get water other than pipe water from their source, 217 cannot get water other than pipe water. Those who responded that they can access water from other sources have their bore holes. The pipe water customers also uses from neighbor people who have their water sources bore holes. Due to frequent pipe water interruption in the town, most of industrial, commercial and public institutions uses their sources for different purposes.

Table 34.Customer responses on if they are using pipe water for drinking purpose

Do You use pipe water for drinking purpose?

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Yes	262	93.57	94.57	94.57
	No	15	536	542	100
	Total	277	98.93	100	-
Missing	Missing	3	-	-	-
Total		280			

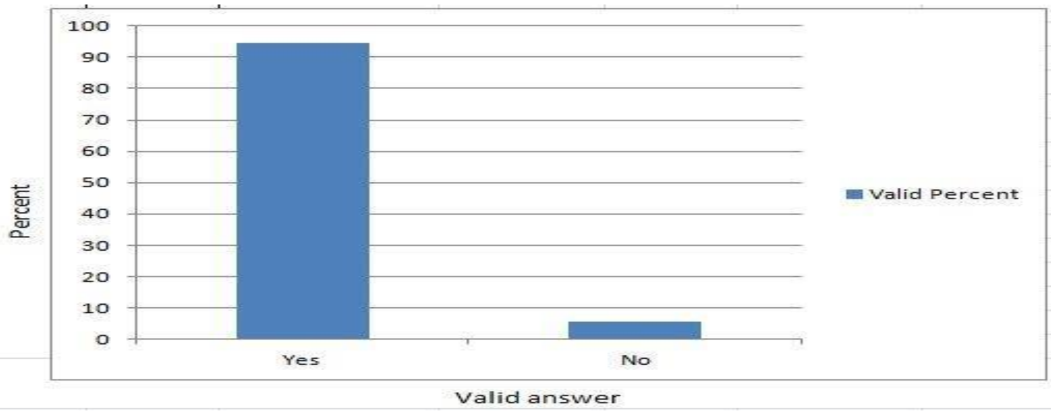

Figure 13.Customer responses on if they are using pipe water for drinking purpose

Out of 277 valid respondents asked for the question, “Do use pipe water for drinking purpose?” 262-use pipe water for drinking purpose, 15 do not use pipe water for drinking purpose. The water utility must care about how to control the quality of the pipe water as contaminated water cause several diseases.

Table 35.Customer responses on pressure of water pipe

Does the water you get from the pipe have enough pressure?

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Yes	102	36.43	36.82	36.82
	No	175	62.50	63.18	100
	Total	277	98.93	100	-
Missing	Missing	3	-	-	-
Total		280	-	-	-

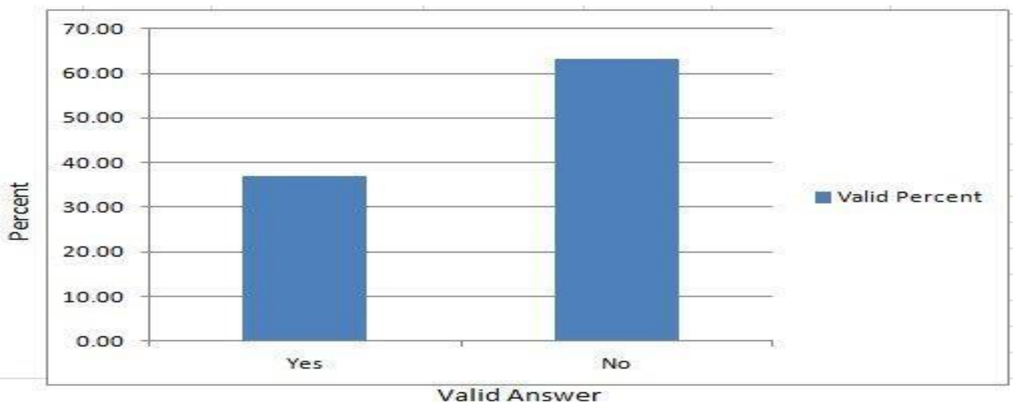

Figure 14. Customer responses on pressure of water pipe

Out of 277 valid respondents asked for the pressure of pipe water, 102 responded the pipe water reach to them with enough pressure, 175 responded that the pipe water have no enough pressure at their tab. Water pressure during peak hour demand may become minimum because of the imbalanced water availability and topography of the town. Among the respondents, the customers who live in high elevation of town responded that water reaching to their tap has no pressure. This can happen due the water sources do not frequently provide water due to the damage the part either of it or due to power problem.

Table 36.Customer responses on is pipe water clean?

Do you think that the water get from the pipe is clean?

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Yes	227	81.07	93.80	93.80
	No	15	5.36	6.20	100
	Total	242	86.43	100	-
Missing	Missing	38	-	-	-
Total		280			

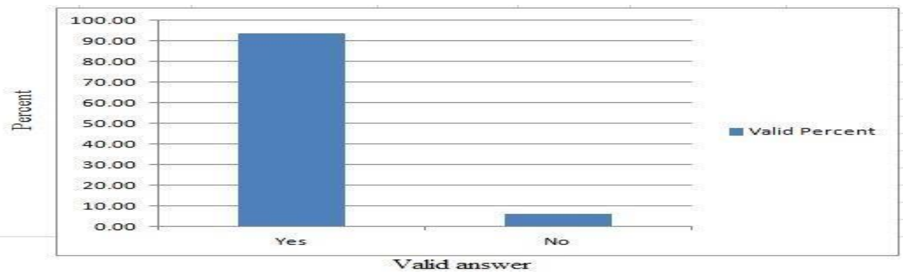

Figure 15.Customer responses on is pipe water clean?

Out of 242 valid respondents about what they think about the quality of pipe water they use, 227 think that the pipe water is clean, 15 customers responded that the pipe water is not clean.

Table 37.Customer responses on other mechanism of water cleaning at home

Do you have any water cleaning mechanism at your home?

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Yes	53	18.92857	20	20
	No	212	75.71429	80	100
	Total	265	94.64286	100	-
Missing	Missing	15	-	-	-
Total		280	-	-	-

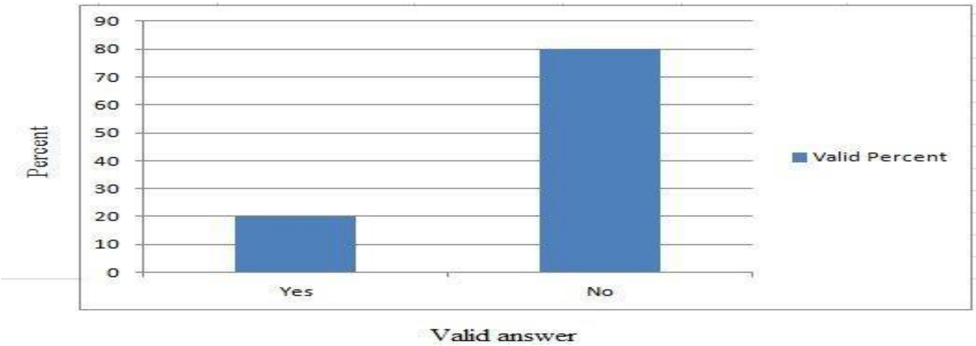

Figure 16.Customer responses on other mechanism of water cleaning at home

Out of 265 valid respondents for the question “Do you have water cleaning mechanism at your home?” 53 customers have water cleaning mechanism at their home, 212 do not have water cleaning mechanism at their home. The water Assosa Town water utility office must works on the quality of the water they are providing as more than eighty percent of the customers directly use the pipe water without cleaning it. The laboratory output from sample taken shows that there is a high amount of coli bacteria which is more than both national and international standard.

Table 38.Customer responses on maintenance

respond earlier for your question on maintenance

	Valid	**Frequency**	**Percent**	**Valid Percent**	**Cumulative %**
Valid	Yes	175	62.50	65.30	65.30
	No	93	33.21	34.70	100.00
	Total	268	95.71	100	-
Missing	Missing	12	-	-	-
Total		280	-	-	-

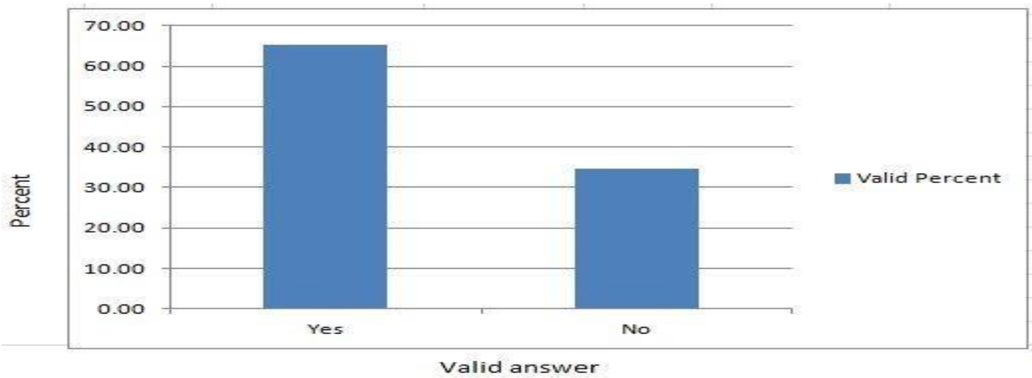

Figure 17.Customer responses on maintenance

Out of 268 valid respondents about water utility office respond quickly on maintenance 175 answered yes and 93 responded no.

Table 39.Customer responses on water meter

How many months you wait to get water meter after applying for it?

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	One	26	9.29	29.55	29.55
	Two	45	16.07	51.14	80.68
	< a month	17	6.07	19.32	100
	Total	88	31.43	48.86	-
Missing	Missing	192	-	-	-
Total		280	-	-	-

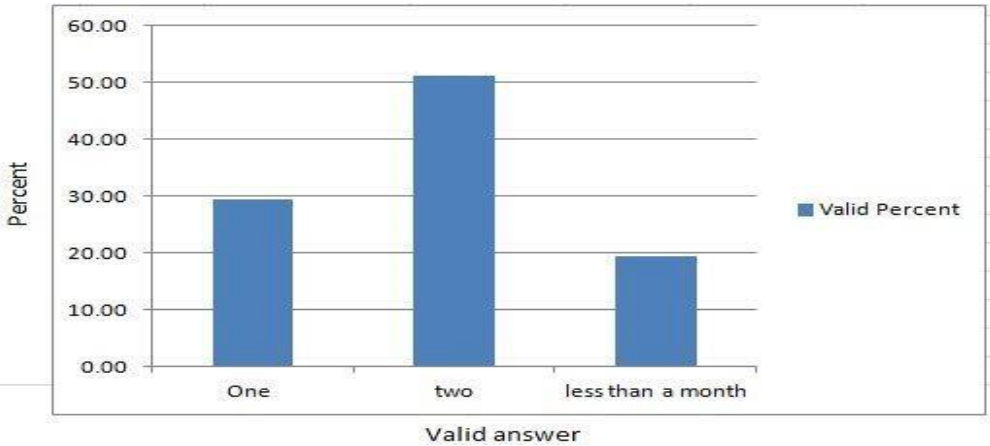

Figure 18. Customer responses on maintenance

Out of 88 valid respondents for the question “how many months you wait after applying for water meter?”, 17 responder less than a month, 26 responded one month, 45 responded two months .Although the best practice on water supply operation and maintenance is providing adequate water supply and following up the system day to day, more than twenty nine percent of the customers in Assosa Town must wait at least a month to get water meter at their home. So I can conclude that the service is poor.

Table 40.Customer responses on water meter Does your water meter works properly.

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Yes	268	95.71429	100	100
	No	0	0	0	100.00
	Total	268	95.71429	100	100
Missing	Missing	12	-	-	-
Total		280	-	-	-

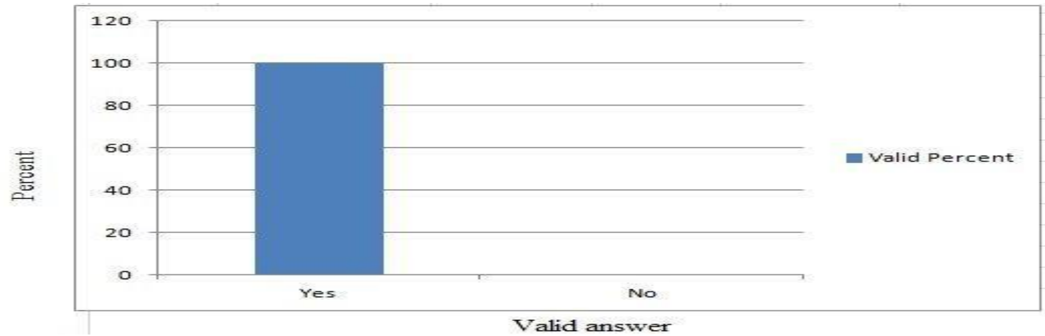

Figure 19.Customer responses on water meter

Out of 268 valid respondents for the question “does the water meter works properly?” 268 responded yes. The customer is not familiar with how water meter works and they cannot think that the water meter may read error. So all respondent answered that the water meter works properly. Due to lack of data, the water loss because of meter error is not studied in this research. However it is recognized that water meters sometimes read error

Table 41.Customer responses on how long the water available?

How many days you get water per week?

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Seven days	0	0	0	0
	Five days	89	31.79	34.90	34.90
	Three days	56	20	21.96	56.86
	Twice	110	39.29	43.14	100
	Total	255	91.07	34.90	-
Missing	Missing	25	-	-	-
Total		280	-	-	-

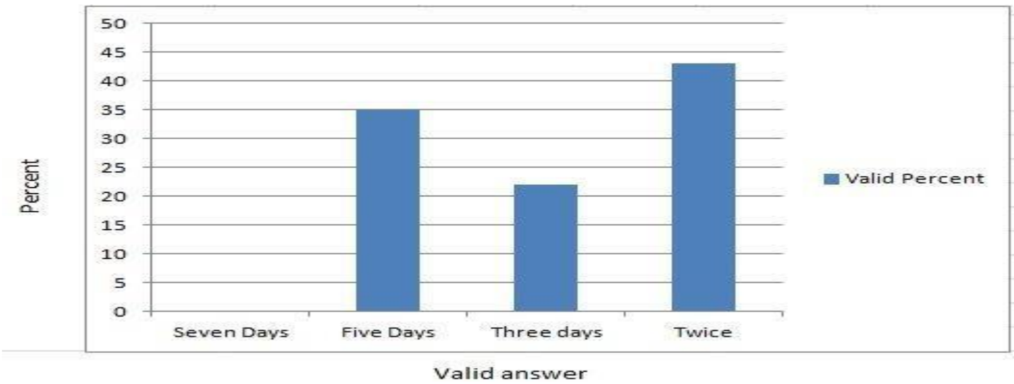

Figure 20.Customer responses on how long the water available?

Out of 255 valid respondents about “How many days you get water per week?” 89 responded five days a week, 56 responded three days a week, 110 responded twice a week. According to the respondents, no one can get water seven days per week. Although Assosa Town is served from twelve bore holes found in the town, there is no continuous access of water in the town. As discussed in chapter four of this thesis under the operation and maintenance topic, there is a frequent of interruption due to damage of parts of the system or due to power interruption

Table 42.Customer responses on level of satisfaction

What is the level of your satisfaction on the water supply service?

	Valid	Frequency	Percent	Valid Percent	Cumulative %
Valid	Very Satisfied	0	0	0	0
	Satisfied	50	17.86	17.99	17.99
	Fairly satisfied	62	22.14	22.30	40.29
	Not satisfied	166	59.29	59.71	100
	Total	278	99.29	17.99	-
Missing	Missing	2	-	-	-
Total		280	-	-	-

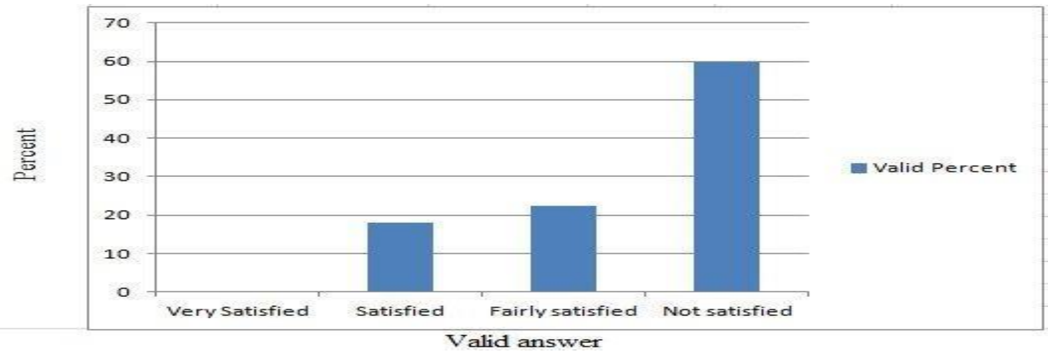

Figure 21.Customer responses on level of satisfaction

Out of 278 valid respondents about how much the customers are satisfied with the water utilities service, 50 responded satisfied, 62 responded fairly satisfied, 166 responded not satisfied. The town's water utility is not providing adequate water with standardized quality. There is no water source problem however the problem is the operation. Therefore, the water utility office must reorganize how to operate to satisfy the customers need to access safe water. Summary of Customer Satisfaction Findings Out of 280 customers, asked for effective usage of water, 275 answered that they use water effectively which shows everyone know the value of water. From 272 valid respondents for the question water source other than pipe water, 55 customers can get water other than pipe water from their source, 217 cannot get water other than pipe water. This mean about 79.78% of people are dependent on pipe water. Two hundred seventy seven valid respondents asked for the question "do use pipe water for drinking purpose?" 262 –use pipe water for drinking purpose, 15 do not use pipe water for drinking purpose. In percentage, nearly 94.6% of the population use pipe water for drinking purpose. The water utility should greatly care about the water quality. From 277 valid respondents asked for the pressure of pipe water, 102 responded the pipe water reach to them with enough pressure, 175 responded that the pipe water have no enough pressure at their tab. Out of 242 valid respondents about what they think about the quality of pipe water they use, 227 think that the pipe water is clean, 15 customers responded that the pipe water is not clean. Out of 265 valid respondents for the question, "Do you have water cleaning mechanism at your home?" 53 customers have water-cleaning mechanism at their home, 212 do not have water-cleaning mechanism at their home. More than 80% of the population has no pipe water cleaning mechanism at home. Out of 268 valid respondents about water, utility office respond quickly on maintenance 175-answered yes and 93 responded no. Out of 88 valid respondents for the question, "how many months you wait after applying for water meter?" 17 responder less than a month, 26-responded one month, 45 responded two months. Only 19.3 % of the total population can get water supply less than a month after applying to it. Out of 268 valid respondents for the question, "does the water meter works properly?" 268 responded yes. Out of 255 valid respondents about "How many days you get water per week?" 89 responded five days a week, 56 responded three days a week, 110 responded twice a week. In percentage, only 34.9% of population can get water five times a week. Out of 278 valid respondents about how much the customers are satisfied with the water utilities service, 50 responded satisfied, 62 responded fairly satisfied, 166-responded not satisfied. In summary, about 60% of the population in Assosa Town is not satisfied in the water utility service.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The existing water distribution system of Assosa Town was established for small population, but upgraded with population of 55,583 projected to 2020 with twelve sources, two reservoir and with appropriate pump capacity and pump stations and now; the design life span is within the projection period. However, as per this research the biggest problem observed is there is a poor operation practice in the water utility. Most of the boreholes are currently not operational and this makes the town to face the pipe water problem. Due to the lack of proper maintenance practice, there are also a lot of pipes and valves that are closed and not working at this time. Accordingly, the water distribution network were faced a frequent pipe bursts and failures during low demand time and exposed to large volume of water loss especially in high pressure zone areas, while during high demand time mostly residences found in dense population and higher level of the town were not received and/served continuous water from the system. Thereby, water pressure in the distribution network observed that were not perfectly Performing within the proposed maximum and minimum design criteria set by FDRE, MoWIE. Due to lack of operation and maintenance practice the water loss in the town goes up which makes the water demand and supply unbalance. The water quality management is also as not as guide line of the national and international standards as some parameters depart from these guidelines. This also clearly shows that there is lack of operation and management. In general, the main problem in the town can be generalized as the problem of operation.

5.2 Recommendations

The following recommendations about water loss, water quality, customer's satisfaction and operation and maintenance have been proposed respectively to improve the performance of existing Assosa Town water supply system.

- There should be structured operation and maintenance practice to improve the whole pipe water system in the town.
- There should be planned and routine inspection for leakage from water supply system components such as transmission and distribution pipes, reservoirs, collection chambers and pump houses. In addition, there should be immediate rehabilitation and maintenance when leaks are observed.
- Inspection should also be done for transmission pipes and for main distribution pipes for assessing damage of the transmission system following a heavy storm, unauthorized construction activity near or on the utility pipeline.
- Water meters should be installed at all sources, reservoirs and collection chambers inlet and out let pipes and proper water production recording should be in place. Faulty water meters should be maintained or replaced.
- Stand by generators shall be installed in pumping stations in case the power interruption.
- It is recommended that Bacteriological and chemical water quality test be conducted periodically (at least four times a year). In addition, as it is indicated on the Ethiopian guideline for drinking water quality the bacteriological test should be accompanied with turbidity and free residual chlorine and pH where chlorination is applied.
- The water utility should respond immediately to maintenance requests of customers to avoid water loss and complaints from customers and need to regular discussions with the customers. The water utility should also conduct a regular survey to know customers satisfaction level and the service deficiencies and should make improvements on its service to increase the customer's satisfaction.
- There must be updated water supply system map, which provide an overall view of the water supply system components like distribution, and transmission pipes layout, sizes and length, location of valves, flow meters, fire hydrants, reservoirs, pumping stations, and sources should be prepared and be available in the water utility office for proper operation and maintenance of the system.
- The water production and water consumption recording system should also updated to have a clear water balance and water loss.

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ANNEXES

Annex-A

Pipe Detail and Summary

Label	Length (Scaled (m)	Start Node	Stop Node	Diameter (mm)	Material	Length (User Defined) (m)
P-2	74	Al_J178	Al_J158	400	PVC	74
P-3	48	Al_J158	Al_J159	400	PVC	49
P-4	89	Al_J159	Al_J160	400	PVC	90
P-5	200	Al_J160	Al_J161	400	PVC	200
P-6	63	Al_J161	Al_J162	400	PVC	63
P-7	137	Al_J162	Al_04_Enyi	400	PVC	137
P-8	200	Al_04_Enyi	Al_J164	350	PVC	200
P-9	200	Al_J164	Al_03_Obad	350	PVC	200
P-10	183	Al_03_Obad i	Al_J166	350	PVC	184
P-11	217	Al_J166	Al_J225	300	PVC	217
P-12	200	Al_J225	Al_J226	300	PVC	200
P-13	200	Al_J226	Al_J227	300	PVC	200
P-14	116	Al_J227	Al_J260	300	PVC	116
P-15	200	Al_J260	Al_J259	100	PVC	200
P-16	200	Al_J259	Al_J258	100	PVC	200
P-17	55	Al_J258	Al_J257	100	PVC	56
P-18	145	Al_J257	Al_J256	100	PVC	145
P-19	134	Al_J256	Al_J255	100	PVC	134
P-20	121	Al_J255	Al_03_1	100	PVC	121
P-32	22	Al_J242	Al_03_2	100	PVC	22
P-33	141	Al_J241	Al_J242	100	PVC	141
P-34	33	Al_J241	Al_J236	100	PVC	33
P-35	66	Al_J236	Al_J237	200	PVC	66
P-36	69	Al_J237	Al_J238	200	PVC	70

P-37	26	Al_J238	Al_J216	200	PVC	26
P-38	85	Al_J216	Al_J217	100	PVC	85
P-39	119	Al_J217	Al_J218	100	PVC	120
P-40	163	Al_J218	Al_J219	100	PVC	164
P-41	70	Al_J219	Al_J220	100	PVC	70
P-42	132	Al_J220	Al_J221	100	PVC	133
P-43	151	Al_J221	Al_J222	100	PVC	151
P-44	144	Al_J222	Al_03_3	100	PVC	242
P-45	49	Al_J216	Al_J215	150	PVC	49
P-46	78	Al_J215	Al_J214	150	PVC	78
P-47	76	Al_J214	Al_04_3	150	PVC	76
P-48	63	Al_04_3	Al_J213	100	PVC	63
P-49	200	Al_J213	Al_J212	100	PVC	200
P-50	90	Al_J212	Al_J211	100	PVC	91
P-51	20	Al_J211	Al_J210	100	PVC	20
P-52	29	Al_J210	Al_J209	100	PVC	30
P-53	64	Al_J209	Al_J208	100	PVC	65
P-54	25	Al_J208	Al_J207	100	PVC	26
P-55	28	Al_J207	Al_J206	100	PVC	28
P-56	89	Al_J206	Al_J205	100	PVC	89
P-57	30	Al_J205	Al_04_4	100	PVC	31
P-65	283	Al_04_5	Al_J197	100	PVC	284
P-66	277	Al_J197	Al_J196	100	PVC	277
P-67	197	Al_J196	Al_J195	100	PVC	198
P-68	177	Al_J195	Al_J194	100	PVC	178
P-69	75	Al_J194	Al_J193	100	PVC	75
P-70	241	Al_J193	Al_J189	80	PVC	241
P-71	137	Al_J189	Al_J190	80	PVC	138
P-72	200	Al_J190	Al_J191	80	PVC	200
P-73	112	Al_J191	Al_J127	80	PVC	113
P-74	83	Al_J127	Al_J126	200	PVC	83
P-75	117	Al_J126	Al_J125	200	PVC	117
P-76	22	Al_J125	Al_J124	200	PVC	22
P-77	200	Al_J124	Al_J102	150	PVC	200

P-78	200	Al_J102	Al_J101	150	PVC	200
P-79	127	Al_J101	Al_J100	150	PVC	127
P-80	73	Al_J100	Al_J99	150	PVC	74
P-81	38	Al_J99	Al_04_9	150	PVC	38
P-82	351	Al_J93	Al_04_9	80	PVC	351
P-83	200	Al_J94	Al_J93	80	PVC	200
P-84	200	Al_J95	Al_J94	80	PVC	200
P-85	200	Al_J95	Al_J96	80	PVC	200
P-86	72	Al_J72	Al_J96	80	PVC	72
P-87	128	Al_J72	Al_J73	100	PVC	128
P-88	200	Al_J73	Al_J74	100	PVC	200
P-89	286	Al_J74	Al_04_8	100	PVC	287
P-90	108	Al_04_8	Al_J76	50	PVC	108
P-91	200	Al_J77	Al_J76	50	PVC	200
P-92	231	Al_J77	Al_J78	50	PVC	231
P-93	224	Al_J78	Al_J79	50	PVC	224
P-94	181	Al_J79	Al_J80	50	PVC	181
P-95	180	Al_J80	Al_J81	50	PVC	180
P-96	184	Al_J81	Al_J82	50	PVC	185
P-97	200	Al_J82	Al_J83	50	PVC	200
P-98	194	Al_J83	Al_J84	50	PVC	194
P-99	210	Al_J84	Al_J85	50	PVC	210
P-100	367	Al_J85	Al_04_10	50	PVC	367
P-101	110	Al_J87	Al_04_10	80	PVC	110
P-102	82	Al_J88	Al_J87	80	PVC	82
P-103	200	Al_J89	Al_J88	80	PVC	200
P-104	200	Al_J90	Al_J89	80	PVC	200
P-105	200	Al_J91	Al_J90	80	PVC	200
P-106	249	Al_04_9	Al_J91	80	PVC	249
P-107	204	Al_04_10	Al_J114	100	PVC	205
P-108	89	Al_J114	Al_J113	100	PVC	89
P-109	22	Al_J113	Al_J112	100	PVC	22
P-110	89	Al_J112	Al_J111	100	PVC	90
P-111	107	Al_J111	Al_J110	100	PVC	108

P-112	49	Al_J110	Al_J109	100	PVC	49
P-113	44	Al_J109	Al_J108	100	PVC	44
P-114	200	Al_J108	Al_J107	100	PVC	200
P-115	200	Al_J107	Al_J106	100	PVC	200
P-116	200	Al_J106	Al_J105	100	PVC	200
P-117	200	Al_J105	Al_J104	100	PVC	200
P-118	178	Al_J104	Al_J124	100	PVC	179
P-121	84	Al_J260	Al_J229	250	PVC	85
P-122	251	Al_J229	Al_J230	250	PVC	251
P-123	103	Al_J230	Al_J231	250	PVC	104
P-125	200	Al_J232	Al_J233	250	PVC	200
P-126	143	Al_J233	Al_J234	250	PVC	143
P-127	71	Al_J234	Al_J235	250	PVC	71
P-128	22	Al_J235	Al_J236	250	PVC	22
P-129	46	Al_J166	Al_J167	200	PVC	46
P-130	150	Al_J167	Al_J168	200	PVC	150
P-131	200	Al_J168	Al_J169	200	PVC	200
P-132	28	Al_J169	Al_04_2	200	PVC	28
P-133	172	Al_04_2	Al_J170	150	PVC	172
P-134	200	Al_J170	Al_J171	150	PVC	200
P-136	200	Al_J171	Al_J172	150	PVC	200
P-137	124	Al_J172	Al_J182	150	PVC	125
P-138	76	Al_J182	Al_J183	150	PVC	76
P-139	156	Al_J183	Al_J184	150	PVC	157
P-140	244	Al_J184	Al_J185	150	PVC	244
P-141	233	Al_J185	Al_J186	150	PVC	233
P-142	167	Al_J186	Al_J187	150	PVC	167
P-143	125	Al_J187	Al_J193	150	PVC	125
P-144	199	Al_J182	Al_J174	80	PVC	200
P-145	203	Al_J174	Al_J175	80	PVC	204
P-146	197	Al_J175	Al_J176	80	PVC	197
P-147	176	Al_J176	Al_04_6	80	PVC	176
P-148	223	Al_04_6	Al_J132	150	PVC	223
P-149	200	Al_J132	Al_J131	150	PVC	200

P-150	200	Al_J131	Al_J130	150	PVC	200
P-151	200	Al_J130	Al_J129	150	PVC	200
P-152	200	Al_J129	Al_J128	150	PVC	200
P-153	88	Al_J128	Al_J127	150	PVC	88
P-154	173	Al_J124	Al_J118	50	PVC	173
P-155	174	Al_J118	Al_J119	50	PVC	174
P-156	226	Al_J119	Al_J120	50	PVC	226
P-157	200	Al_J120	Al_J121	50	PVC	200
P-158	200	Al_J121	Al_J122	50	PVC	200
P-159	101	Al_J122	Al_J123	50	PVC	102
P-160	20	Al_J123	Al_J68	100	PVC	20
P-161	79	Al_J68	Al_J67	100	PVC	79
P-162	200	Al_J67	Al_J66	100	PVC	200
P-163	213	Al_J66	Al_J65	100	PVC	214
P-164	187	Al_J65	Al_J64	100	PVC	187
P-165	82	Al_J64	Al_04_7	100	PVC	82
P-166	150	Al_04_7	Al_J62	150	PVC	150
P-167	116	Al_J62	Al_J61	150	PVC	116
P-168	280	Al_J123	Al_J70	100	PVC	280
P-169	200	Al_J70	Al_J71	100	PVC	200
P-170	200	Al_J71	Al_J72	100	PVC	200
P-171	200	Al_J178	Al_J179	200	PVC	200
P-172	200	Al_J179	Al_02_Cond	200	PVC	200
P-173	141	Al_02_Cond	Al_J181	200	PVC	141
P-174	59	Al_J141	Al_J181	80	PVC	59
P-175	200	Al_J142	Al_J141	80	PVC	200
P-176	148	Al_02_7	Al_J142	80	PVC	149
P-177	252	Al_02_7	Al_J53	150	PVC	252
P-178	200	Al_J53	Al_J54	150	PVC	200
P-179	200	Al_J54	Al_J55	150	PVC	200
P-180	234	Al_J55	Al_J56	150	PVC	234
P-181	166	Al_J56	Al_J57	150	PVC	167
P-182	231	Al_J57	Al_J58	150	PVC	232
P-183	169	Al_J58	Al_J59	150	PVC	169

P-184	231	Al_J59	Al_J60	150	PVC	232
P-185	418	Al_J60	Al_J61	150	PVC	418
P-186	189	Al_J156	Al_J178	400	PVC	189
P-187	200	Al_J155	Al_J156	400	PVC	200
P-188	200	Al_J154	Al_J155	400	PVC	200
P-189	87	Al_02_5	Al_J154	400	PVC	87
P-190	108	Al_02_5	Al_J148	150	PVC	108
P-191	200	Al_J148	Al_J147	150	PVC	200
P-192	200	Al_J147	Al_J146	150	PVC	200
P-193	200	Al_J146	Al_J145	150	PVC	200
P-194	200	Al_J145	Al_J47	150	PVC	200
P-195	59	Al_J47	Al_J48	200	PVC	59
P-196	92	Al_J48	Al_J49	200	PVC	92
P-197	200	Al_J49	Al_J50	200	PVC	200
P-198	200	Al_J50	Al_J51	200	PVC	200
P-199	117	Al_J51	Al_02_7	200	PVC	117
P-200	67	Al_J46	Al_J47	80	PVC	68
P-201	181	Al_J45	Al_J46	80	PVC	181
P-202	200	Al_J44	Al_J45	80	PVC	200
P-203	88	Al_02_4	Al_J44	80	PVC	88
P-204	112	Al_02_4	Al_J43	150	PVC	112
P-205	162	Al_J43	Al_J42	150	PVC	162
P-206	238	Al_J42	Al_J41	150	PVC	238
P-207	200	Al_J41	Al_J40	150	PVC	200
P-208	200	Al_J40	Al_J39	150	PVC	200
P-209	191	Al_J39	Al_02_3	150	PVC	192
P-210	113	Al_J150	Al_02_5	450	PVC	113
P-211	200	Al_J151	Al_J150	450	PVC	200
P-212	39	Al_J32	Al_J151	450	PVC	40
P-213	200	Al_J32	Al_J33	200	PVC	201
P-214	200	Al_J33	Al_J34	200	PVC	200
P-215	200	Al_J34	Al_J35	200	PVC	200
P-216	200	Al_J35	Al_J36	200	PVC	200
P-217	200	Al_J36	Al_J37	200	PVC	200

P-218	209	Al_J37	Al_02_3	200	PVC	209
P-219	161	Al_J31	Al_J32	500	PVC	161
P-220	200	Al_J30	Al_J31	500	PVC	200
P-221	242	Al_J29	Al_J30	500	PVC	242
P-222	158	Al_J28	Al_J29	500	PVC	158
P-223	266	Al_02_2	Al_J28	500	PVC	266
P-224	132	Al_J26	Al_02_2	500	PVC	133
P-225	200	Al_J25	Al_J26	500	PVC	200
P-226	200	Al_J24	Al_J25	500	PVC	200
P-227	201	Al_J21	Al_J24	500	PVC	202
P-228	166	Al_J21	Al_J20	200	PVC	166
P-229	200	Al_J20	Al_J19	200	PVC	200
P-230	200	Al_J19	Al_J18	200	PVC	200
P-231	206	Al_J18	Al_02_1	200	PVC	206
P-232	196	Al_02_1	Al_J16	150	PVC	196
P-233	178	Al_J16	Al_J15	150	PVC	178
P-234	91	Al_J15	Al_J14	150	PVC	91
P-235	202	Al_J14	Al_J13	150	PVC	202
P-236	130	Al_J13	Al_J12	150	PVC	130
P-237	200	Al_J12	Al_J11	150	PVC	200
P-238	35	Al_J11	Al_01_2	150	PVC	35
P-239	240	Al_01_2	Al_J10	100	PVC	241
P-240	251	Al_J10	Al_J9	100	PVC	252
P-241	273	Al_J9	Al_J8	100	PVC	274
P-242	200	Al_J8	Al_J7	100	PVC	200
P-243	150	Al_J7	Al_J6	100	PVC	150
P-244	250	Al_J6	Al_J5	100	PVC	250
P-245	200	Al_J5	Al_J4	100	PVC	200
P-246	161	Al_J4	Al_J3	100	PVC	161
P-247	285	Al_J3	Al_J2	100	PVC	285
P-248	201	Al_J2	Al_01_1	100	PVC	144
P-249	343	Al_J181	Al_04_1	250	PVC	343
P-250	58	Al_04_1	Al_J139	200	PVC	58
P-251	200	Al_J139	Al_J138	200	PVC	200

P-252	86	Al_J138	Al_J137	200	PVC	87
P-253	314	Al_J137	Al_J136	200	PVC	314
P-254	200	Al_J136	Al_J135	200	PVC	200
P-255	178	Al_J135	Al_04_6	200	PVC	178
P-256	593	Al_J178	Al_02_6	100	PVC	593
P-257	104	AR	Al_J21	500	PVC	105
P-1	229	Al_J231	Al_J261	250	PVC	230
P-21	72	Al_J261	Al_J232	250	PVC	72
P-22	96	Al_J261	Al_J262	150	Ductile Iron	97
P-23	20	Al_J262	Al_J263	150	Ductile Iron	21
P-24	147	Al_J263	Al_04_Cond	150	Ductile Iron	147
P-25	89	Al_04_Cond	Al_J264	80	Ductile Iron	89
P-26	110	Al_J264	Al_J265	80	Ductile Iron	110
P-27	86	Al_J265	Al_J207	80	Ductile Iron	86
P-28	77	FBH1	AL_TRJ37	150	Ductile Iron	77
P-29	43	AL_TRJ37	AL_TRJ38	150	Ductile Iron	44
P-30	157	AL_TRJ38	AL_TRJ39	150	Ductile Iron	157
P-31	108	AL_TRJ39	AL_TRJ40	150	Ductile Iron	108
P-119	92	AL_TRJ40	AL_TR1	200	Ductile Iron	92
P-120	155	AL_TR1	AL_TRJ2	200	Ductile Iron	155
P-124	200	AL_TRJ2	AL_TRJ3	200	Ductile Iron	200
P-135	181	AL_TRJ3	AL_TRJ4	200	Ductile Iron	157
P-258	65	AL_TRJ4	AL_TRJ5	250	Ductile Iron	73
P-259	146	AL_TRJ5	AL_TRJ6	250	Ductile Iron	171
P-260	200	AL_TRJ6	AL_TRJ7	250	Ductile Iron	200
P-261	200	AL_TRJ7	AL_TRJ8	250	Ductile Iron	200
P-262	200	AL_TRJ8	AL_TRJ9	250	Ductile Iron	200
P-264	200	AL_TRJ10	AL_TRJ11	300	Ductile Iron	200
P-265	219	AL_TRJ11	AL_TRJ12	300	Ductile Iron	219
P-266	66	AL_TRJ12	AL_TRJ13	300	Ductile Iron	66
P-267	63	AL_TRJ13	AL_TRJ14	300	Ductile Iron	63
P-268	252	AL_TRJ14	AL_TRJ15	300	Ductile Iron	253

P-269	97	AL_TRJ15	AL_TRJ16	300	Ductile Iron	97
P-270	64	AL_TRJ16	AL_TRJ17	300	Ductile Iron	64
P-271	28	AL_TRJ17	AL_TRJ18	300	Ductile Iron	28
P-272	60	AL_TRJ18	AL_TRJ19	300	Ductile Iron	60
P-273	118	AL_TRJ19	AL_TRJ20	300	Ductile Iron	118
P-274	69	AL_TRJ20	AL_TRJ21	300	Ductile Iron	69
P-275	165	AL_TRJ21	AL_TRJ22	300	Ductile Iron	165
P-276	200	AL_TRJ22	AL_TRJ23	300	Ductile Iron	200
P-277	200	AL_TRJ23	AL_TRJ24	300	Ductile Iron	200
P-278	184	AL_TRJ24	AL_TRJ25	300	Ductile Iron	184
P-279	216	AL_TRJ25	AL_TRJ26	350	Ductile Iron	216
P-280	200	AL_TRJ26	AL_TRJ27	350	Ductile Iron	200
P-281	200	AL_TRJ27	AL_TRJ28	350	Ductile Iron	200
P-282	200	AL_TRJ28	AL_TRJ29	350	Ductile Iron	200
P-283	134	AL_TRJ29	AL_TRJ30	350	Ductile Iron	134
P-284	266	AL_TRJ30	AL_TRJ31	350	Ductile Iron	266
P-285	155	AL_TRJ31	AL_TRJ32	350	Ductile Iron	155
P-286	254	AL_TRJ32	AL_TRJ33	350	Ductile Iron	255
P-287	203	AL_TRJ33	AL_TRJ34	350	Ductile Iron	203
P-288	205	AL_TRJ34	AL_TRJ35	350	Ductile Iron	205
P-289	178	AL_TRJ35	AR	350	Ductile Iron	179
P-290	64	FBH2	AL_TR1	150	Ductile Iron	65
P-291	54	PMP-1	FBH2	100	Ductile Iron	54
P-292	31	R-1	PMP-1	100	Ductile Iron	31
P-293	41	FBH1	PMP-2	100	Ductile Iron	42
P-294	45	PMP-2	R-2	100	Ductile Iron	46
P-295	54	AL_TRJ9	J-278	250	Ductile Iron	55
P-296	146	J-278	AL_TRJ10	300	Ductile Iron	146
P-297	21	FBH6	J-278	150	Ductile Iron	54
P-298	74	FBH5	J-279	150	Ductile Iron	125
P-299	162	J-279	J-280	150	Ductile Iron	162
P-300	159	J-280	J-281	200	Ductile Iron	159
P-301	241	J-281	AL_TRJ4	200	Ductile Iron	241
P-302	198	FBH4	J-280	150	Ductile Iron	198

P-303	103	FBH3	J-282	150	Ductile Iron	103
P-305	52	FBH7	J-283	150	Ductile Iron	52
P-306	372	J-283	J-284	150	Ductile Iron	372
P-307	99	J-284	J-285	150	Ductile Iron	99
P-309	135	FBH8	J-286	150	Ductile Iron	113
P-310	130	J-286	J-287	150	Ductile Iron	162
P-311	199	J-287	J-288	150	Ductile Iron	197
P-312	108	J-288	AL_TRJ25	150	Ductile Iron	64
P-313	64	FBH3	PMP-3	100	Ductile Iron	64
P-314	82	PMP-3	R-3	100	Ductile Iron	82
P-315	83	FBH4	PMP-4	100	Ductile Iron	84
P-316	87	PMP-4	R-4	100	Ductile Iron	87
P-317	63	FBH5	PMP-5	100	Ductile Iron	63
P-318	71	PMP-5	R-5	100	Ductile Iron	63
P-319	67	FBH7	PMP-6	100	Ductile Iron	54
P-320	70	PMP-6	R-6	100	Ductile Iron	75
P-321	39	FBH6	PMP-7	100	Ductile Iron	43
P-322	75	PMP-7	R-7	100	Ductile Iron	65
P-323	41	FBH8	PMP-8	100	Ductile Iron	42
P-324	72	PMP-8	R-8	100	Ductile Iron	72
P-325	58	ABH-4	J-289	150	Ductile Iron	58
P-326	383	J-289	J-290	150	Ductile Iron	385
P-327	396	J-290	J-291	150	Ductile Iron	396
P-328	261	J-291	J-292	150	Ductile Iron	282
P-329	256	J-292	J-293	200	Ductile Iron	236
P-330	262	J-293	J-294	200	Ductile Iron	258
P-331	274	J-294	J-295	250	Ductile Iron	287
P-332	287	J-295	J-296	250	Ductile Iron	301
P-333	165	J-296	J-297	250	Ductile Iron	144
P-334	258	J-297	J-298	250	Ductile Iron	285
P-335	230	J-298	J-299	250	Ductile Iron	247
P-336	159	J-299	J-300	250	Ductile Iron	193
P-337	333	J-300	J-301	250	Ductile Iron	288
P-338	236	J-301	J-302	250	Ductile Iron	264

P-339	304	J-302	J-303	250	Ductile Iron	301
P-340	178	J-303	J-304	250	Ductile Iron	188
P-342	278	J-305	J-306	250	Ductile Iron	262
P-343	98	J-306	J-307	250	Ductile Iron	103
P-344	171	J-307	J-308	250	Ductile Iron	151
P-345	350	J-308	J-309	250	Ductile Iron	347
P-346	348	J-309	J-310	250	Ductile Iron	308
P-347	138	J-310	J-311	250	Ductile Iron	131
P-348	118	J-311	J-312	250	Ductile Iron	212
P-349	204	J-312	J-313	250	Ductile Iron	124
P-350	203	J-313	J-314	250	Ductile Iron	200
P-351	177	J-314	AR	250	Ductile Iron	174
P-352	50	J-304	J-315	250	Ductile Iron	82
P-353	130	J-315	J-305	250	Ductile Iron	75
P-354	48	ABH-4	PMP-9	100	Ductile Iron	48
P-355	64	PMP-9	R-10	100	Ductile Iron	64
P-356	24	ABH-2	J-294	150	Ductile Iron	24
P-357	39	ABH-2	PMP-10	100	Ductile Iron	39
P-358	32	PMP-10	R-11	100	Ductile Iron	37
P-359	54	ABH-1	J-316	150	Ductile Iron	54
P-360	112	J-316	J-296	150	Ductile Iron	112
P-361	49	ABH-1	PMP-11	100	Ductile Iron	49
P-362	64	PMP-11	R-12	100	Ductile Iron	64
P-363	99	ABH-3	J-317	150	Ductile Iron	99
P-364	173	J-317	J-292	150	Ductile Iron	173
P-365	51	ABH-3	PMP-12	100	Ductile Iron	52
P-366	73	PMP-12	R-13	100	Ductile Iron	73
P-367	220	J-282	J-318	150	Ductile Iron	220
P-368	217	J-318	AL_TRJ40	150	Ductile Iron	218
P-369	264	J-285	J-319	150	Ductile Iron	265
P-370	96	J-319	AL_TRJ13	150	Ductile Iron	96

Annex-B

Water point and water quality datas

	Zone36p,UTM, meter			Major Cations						Major anions					Ph	TDS	SiO2	HBO2	EC	T(oc)
Id	Easting	Northing	Elev	depth	Na	K	Ca	Mg	Fe	HCO3	Cl	So4	F	NO3						
SBH_5	669015	1113469	1550	96	6	1.1	19	13	0.1	148		1	0.08	0.03	7.41	238.41	50	0.1	218	25
AH _3	665605	1104440	1524	27.2	2.2	1	8	4.4	0.1	46	1	1	0.07	0.31	6.78	88.26	25	0.18	71	23.9
TBH_8	655805	1126991	1336	26	12	6	35	9	0.1	178	2	7	0.25	3.71	7.45	310.54	57	0.48	298	24.3
HBH_9	676530	1130822	1550	23	6	2	10	2.2	0.1	57	1	1	0.47	0.17	6.73	122.04	42	0.1	89	23.2
HBH_10	684520	1121768	1408	21	2.4	1.3	11	6	0.1	74		1	0.07	0.07	6.98	135.42	39	0.48	121	24.9
HBH_12	680597	1121041	1465	20	3.34	1.1	18	6.2	0.1	96		1	0.07	0.41	7.12	169.42	43	0.14	145	24.3
DH_1	667534	1108688	1500	20	3	1.3	4	1	0.1	29		1	0.06	0.17	6.65	57.81	18	0.8	44	20.3
DW_10	668491	1118893	1480	20	0.6	0.3	1.3	0.4	0.1	11		1	0.02	0.29	6.2	22.19	7	0.18	14	21.9
DW_11	669726	1121611	1470	20	1.8	0.8	1.6	0.5	0.1	22		1	0.05	0.03	6.22	51.06	23	0.18	22	24.2
DW_12	668939	1123872	1500	20	0.8	0.1	1.9	0.6	0.1	12		1	0.03	1.01	6.21	24.72	7	0.18	19	24
DW_13	681321	1116252	1495	20	4	9	26	11	0.1	129		1	0.07	0.8	7.13	221.05	48	0.18	192	22.9
DW_14	690372	1109017	1370	20	1.8	1.1	8.4	1.5	0.1	34		1	0.05	1.57	6.68	68.7	19	0.18	54	24.3
DW_17	679818	1124478	1470	20	1.5	0.4	5.4	1.2	0.1	28		1	0.03	0.07	6.58	46.88	9	0.18	44	26.8
DW_18	677831	1126180	1475	20	4.6	2.5	10.4	3.4	0.1	67		1	0.15	0.17	7.01	121.5	32	0.18	94	25.3
DH_2	667385	1107919	1510	20	4.3	1.3	5.2	1.4	0.1	44		1	0.1	1.28	6.82	87.86	29	0.18	62	22.5
DW_3	666729	1104875	1490	20	1.4	1	2	1	0.2	16		3	0.05	0.03	6.37	39.86	15	0.18	22	22.4
DW_35	684707	1129226	1545	20	2	2	26	3	0.1	102		2	0.08	1.95	6.8	156.31	17	0.18	164	23.9
DW_36	693760	1130067	1420	20	5	0.8	27	13	0.1	167		2	0.08	3.34	6.97	277.86	59	0.54	251	24.7
DW_37	700223	1116549	1060	20	15	1	32	6	0.1	124	6	2	0.21	12.72	7.08	257.21	58	0.18	276	27.2

DW_38	699885	1117658	1140	20	14	2	64	19	0.1	345		2	0.13	0.04	7.04	514.81	68	0.54	491	26.8
DW_39	669230	1113170	1480	20	2	0.7	3.4	1.1	0.1	21		1	0.07	0.44	5.92	44.99	15	0.18	36	0
DW_40	707160	1118995	1024	20	25	0.9	24	8	0	137	11	4	0.83	23.04	7.26	314.5	80	0.73	296	0
DW_41	702889	1125884	1100	20	24	2	46	14	0	285	9	1	0.21	0.89	7.52	14.39	62	0.29	400	0
DW_42	669476	1113004	1555	20	1	0.6	1.1	0.1	0	12	3	1	0.08	0.44	6.01	34.47	15	0.15	17	0
DW_5	673555	1110499	1550	20	0.8	1.1	25	1.2	0.1	70		1	0.06	0.14	7.02	114.85	15	0.18	92	22.2
DW_6	673484	1111279	1540	20	0.7	0.4	6	0.1	0.1	29		1	0.02	0.03	6.8	49.67	12	0.32	41	22.8
DW_7	682065	1105926	1490	20	1.2	0.1	3	2	0.1	20		1	0.03	8.16	6.49	47.75	12	0.16	40	22.6
DW_8	679039	1109942	1530	20	0.8	0.7	9	0.9	0.1	44		1	0.04	0.21	6.7	71.91	15	0.16	55	22.7
DW_9	669469	1118068	1490	20	1	0.6	5	2	0.1	26		1	0.02	0.94	7.25	48.82	12	0.16	37	22.7
DW_16	686151	1112559	1480	12.7	3.8	1.5	8.6	3.8	0.1	60		1	0.05	0.03	6.96	118.06	39	0.18	91	25
CS_1	671688	110597	1500	0.1	2	1.2	5.3	0.7	0.1	21		2	0.07	0.04	6.24	57.18	24	0.77	28	22.7
RW_1	669230	1113170	1000	0.1	0.1	0.3	0.5	0.1	0	6	4	1	0.02	0.89	6.44	14.06	1	0.15	15	0
SW_1	700733	1114330	970	0.1	5.2	2.4	12	5	3.4	66		1	0.17	0.04	7.36	116.67	21	0.46	124	30.9
SW_2	679200	1122300	1460	0.1	2	1	9	4.4	0.8	56		1	0.1	0.8	7.34	96.03	18	2.93	89	0

Annex-C

Vertical Electrical Sounding Raw data for Assosa Town water supply project

Region:	Benshangul	Easting:	673607	676601	675477	673395	669296	677865	675798
Zone:	Asosa	Northing:	1108595	1109504	1109818	1110136	1107879	1110132	1102491
Woreda:	Asosa	Altitude:	1521	1486	1490	1510	1473	1475	1382
VES NO:			APV-1	APV-2	APV-3	APV-4	APV-5	APV-6	APV-7
Locality:			Ateto	Ateto		Amba-12	mengele-30		
AB/2			app. Ress	app. Ress	app. Ress	app. Ress	app. Ress	app. Ress	app. Ress
1.5			76.67	16.66	131.8	748.57	74.16	192.48	87.48
2.1			78.66	14.78	75.84	779.45	69.77	156.15	42.54
3			98.91	13.22	42.59	802.45	57.61	122.92	18.2
4.2			126.13	13.4	24.94	912.94	46.93	100.64	12.19
6			159.78	14.01	16.49	1100.16	35.06	77.29	12.48
9			199.39	14.47	14.98	1091.94	26.16	44.45	13.45
13.5			237.95	14.87	14.3	1142.28	26.31	30.88	15.72
20			251.9	16.14	15.34	974.9	31.16	34.11	19.14
30			322.72	20.79	20.66	487.9	42.48	39.58	18.62
45			472.68	32.48	27.56	326.04	58.99	41.08	17.16
66			567.68	45.17	37.96	296.47	82.49	42.02	14.11
100			712.24	64.43	50.81	302.4	126.25	45.8	18.34
150			723.24	78.72	68.78	328.95	177.54	56.61	32.92
200			941.41	104.5	77.39	350.23	230.12	66.93	39.74
250			1053.3	85.6		308.2	295.9	65.85	57.2
300			1179.3	89.05		373.35	372.9	69.06	65.71
400			1334.38	89.3		429.49	441.17	74.4	
500			1563.8	95.19		405.01	380.78	64.04	

Annex-D

Boreholes and Submersible pump detail

Description	ABH1	ABH2	ABH3	ABH4	FBH1	FBH2	FBH3	FBH4	FBH5
	1	1	1	1	1	1	1	1	
Q - Single Pump Discharge at Duty Point, Itr/sec	14	14	14	14	12	12	12	12	
Qm - Maximum Single Pump Discharge over Operating Range, Itr/sec	14	14	14	14	12	12	12	12	
Altitude of water pump station, Masl	2213	2193	2171	2148	2254	2255	2250	2252	
Habs - Absolute Pressure at pump station altitude, Mtr	7.89	7.91	7.94	7.96	7.85	7.85	7.86	7.86	
Storm Factor	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	
Habsm - Modified Absolute Pressure at 485 Masl, Mtr	6.71	6.73	6.74	6.76	6.68	6.68	6.68	6.68	
Hvp - Vapour Pressure of Water at 25 degree Celsius, Mtr	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	
Common Suction Pipe Dia, Mtr	0	0	0	0	0	0	0	0	
Independent Suction Pipe Dia, Mtr	1.78	1.78	1.78	1.78	1.53	1.53	1.53	1.53	
Velocity of water, Common Suction Pipe, Mtr/sec	0	0	0	0	0	0	0	0	
Velocity of water, independent Suction Pipe/submersible pump inlet	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	
Common Suction Pipe Length, Mtr	0	0	0	0	0	0	0	0	
Independent Suction Pipe Length, Mtr	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
loss factor for inlet	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
loss factor for valve pump independent suction	0	0	0	0	0	0	0	0	
loss factor for 1 bend pump independent suction	0	0	0	0	0	0	0	0	
loss factor fori reducer pump independent suction	0	0	0	0	0	0	0	0	
loss factor for valve pump common suction	0	0	0	0	0	0	0	0	
Hfs - friction loss, Mtr	0	0	0	0	0	0	0	0	
Hs = maslpump inlet center - masLwetwell water level = kv-/2g	0.11	0.11	0.11	0.11	0.08	0.08	0.08	0.08	
NPSHa, net postive suction head available= Habs - Hs - Hfs – Hvp									
assuming Hs = 0, NPSHa, net positive suction head available	6.28	6.29	6.31	6.33	6.27	6.27	6.28	6.27	

Annex-E

Water production and Consumption in a subsystem

Year in G.C	Annual water with in the sub-system production in m^3	Annual incoming to the sub-system m^3	Annual outgoing from the sub-system m^3	Total production for Assosa sub-system m^3	Annual water consumption in m^3	NRW	
						m^3	Perce
2013	374988	-	-	374,988	252,275	122713	32.72
2014	368938	-	-	368,938	270,707	98231	26.63
2015	671593	100739	67159	705,173	448,159	257014	38.27
2016	698522	104778	83823	719,478	458,372	261106	37.38

Annex-F

Existing Water storage tanks and Reservoirs

	Type	**Capacity m^3**	**Year E.C**	**Source**	**GPS Location**			**Status**
					E	N	ELV	
Shah Hojele	CircularB rick reservoir	50	1977	-	66845	1112565	1570	NF
Stadium	Elevated Steel tanker	25	1977	-	667967	1112199	1578	NF
Selam Ber tanker	Elevated Circular concrete	50	1988	BH#5	670105	1112849	1587	F
Water supply office tanker	Elevated Steel tanker	25	1988	BH#5	669834	1113127	1579	F
Around University Temporary reservoir	Elevated Super fiber	10	2010	BH#10	671426	1115022	1576	F
Enzi #1	Circular Concrete Reserv	300	1996	Medha nialem Booster	670142	1111386	1633	F
Enzi #2	Circular Concret reservoir	800	2007	Medha nialem Booster	670142	1111386	1633	F

Annex-G

Existing Water storage tanks and Reservoirs

	Type	Capacity m^3	Year E.C	Source	GPS Location			Status
					E	N	ELV	
Shah Hojele	CircularB rick reservoir	50	1977	-	66845	1112565	1570	NF
Stadium	Elevated Steel tanker	25	1977	-	667967	1112199	1578	NF
Selam Ber tanker	Elevated Circular concrete	50	1988	BH#5	670105	1112849	1587	F
Water supply office tanker	Elevated Steel tanker	25	1988	BH#5	669834	1113127	1579	F
Around University Temporary Reservoir	Elevated Super fiber	10	2010	BH#10	671426	1115022	1576	F
Enzi #1	Circular Concrete Reservoir	300	1996	Medha nialem Booster	670142	1111386	1633	F
Enzi #2	Circular Concrete reservoir	800	2007	Medha nialem Booster	670142	1111386	1633	F

Annex-H
'Questionaries'

Hawassa University Institute of Technology

Survey questionnaire on the **"Urban water supply System Performance Assessment: the Case of Assosa Town"**

Dear respondents several questions are presented here below in two sections. The researcher kindly request you to read each question very carefully and pout a tick "√" mark to the choice that you think represent activities going on in Benishangul-Gumuz Regional State Water And Irrigation Energy Resource Development Bureau and Assosa Town Water Supply and Sewerage Service Enterprise in relation to Urban water supply System Performance Assessment, and for the open-ended questions write down your answer on the space provided. As your response is valuable for the success of this research; please feel free to share your comments and experiences frankly. The information obtained from the questionnaire will be only used for the purpose of this research and shall be kept strictly confidential.

Thank you in advance for your kindly cooperation!

Part I: Questions on "Assosa Town water supply system and Background information Thank you for responding forward."

1. Sex? ☐ Male ☐ Female ☐
2. Age? below 25 ☐ between 25-45 ☐ above 45 ☐ ☐
3. Level of education?
   Literate ☐ Primary level complete (1-8) ☐
   Secondary level complete (9-10) ☐ preparatory complete ☐
   Degree and above ☐
4. What is your occupation
   Self-employed ☐
   Government employees ☐
   Non-Governmental Organization (NGO) employees ☐
   Unemployed ☐

5. Marital Status: ☐ Single ☐ Married ☐ Divorced ☐

6. Level of income

   1000-2000 ☐ 2001-3000 ☐ 3001 and above ☐ No income

7. If your birth place is out of Assosa Town, why did you come here?

   In search of better life ☐ Seeking employment ☐

   Because of job transfer ☐ previous resident ☐

8. How long have you stayed in Assosa Town? _____Years _________months.

Part II: <u>Questionnaires on customer satisfaction of water supply as one indicator of urban water supply system performance, a case of Assosa Town.</u>

1. Do you use pipe water effectively? Yes ☐ No ☐

   Other____

2. Can you get water other than pipe water for all purpose? Yes ☐ No ☐

   Other____

3. Does the water you get from the pipe have enough pressure? Yes ☐ No ☐

   Other____

4. Do you use the pipe water for drinking purpose? Yes ☐ No ☐

5. Do you think that the water get from the pipe is clean? Yes ☐ No ☐

   Other____

6. Do you have any water cleaning mechanism at your home? Yes ☐ No ☐
   Other____

7. Does the water supply office respond earlier for your question on maintenance?

   Yes ☐ No ☐

   After week ☐ after month ☐ after three ☐ months ☐ after five

   Months Other____

8.Is the water tariff you paid balance the water you used?

Yes ☐ No ☐

Other____

9. How many Months you wait to get water meter after applying for it?

One week ☐ one month ☐ two months ☐ five months ☐

specify _________

10. Does your water meter works properly? Yes ☐ No ☐

Other____

11. How many days you get water per week?

And hours per day respectively?

2days/week ☐ 4days/week ☐ 6days/week ☐ all days ☐

Other____

12. What is your level of satisfaction on water supply service? Very satisfied

Satisfied ☐ fairly satisfied ☐ not satisfied ☐

Other_

____

13. Do you have any idea how to upgrade water supply system?Yes ☐ No ☐

Other____