Evaluation of the Performance of the Water Supply Distribution System, the Case of Bishoftu Town, Ethiopia

Getahun Hailu Gebrie

A Thesis Submitted to

The Department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Supply and Environmental Engineering

Office of Graduate Studies

Adama Science and Technology University

September, 2023

Adama, Ethiopia

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Declaration

I hereby declare that this Master thesis entitled "Evaluation of the Performance of Water Supply Distribution System, the Case of Bishoftu Town, Ethiopia", is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Recommendation

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Evaluation of the Performance of Water Supply Distribution System, the Case of Bishoftu town, Ethiopia"** prepared under my guidance by Getahun Hailu submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Water Supply and Environmental Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Andinet Kebede (PhD)	______________________	_______________
Major Advisor	Signature	Date

APPROVAL PAGE

I, the advisor of the thesis entitled "**Evaluation of the Performance of Water Supply Distribution System, the Case of Bishoftu town, Ethiopia"** and developed by **Getahun Hailu,** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Getahun Hailu have read and evaluated the thesis entitled "**Evaluation of the Performance of Water Supply Distribution System, the Case of Bishoftu town, Ethiopia"** and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Water Supply and Environmental Engineering.

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List of Abbreviations

CAD	Computer Aided Design
CSA	Central Statistical Agency
E.C.	Ethiopian Calendar
EPA	Environmental Protection Agency
EPS	Extended Period Simulation
GIS	Geographic Information System
GPS	Global Positioning System
HC	House Connection
MoWR	Ministry of Water Resources
mwc	meter water column
NRW	Non-Revenue Water
O&M	Operation and Maintenance
UfW	Unaccounted for water
WDS	Water Distribution System
WHO	World Health Organization
Wp	Water points
YC	Yard Connection

ABSTRACT

*In developing countries, urban water supply infrastructures are often under a lot of burden, mainly due to rapid population growth and industrialization. System underperformance, operation and management problems, and limited technical capacity of the utilities are some of the serious issues in the water supply sector that demand close follow-up and action. Thus, the objective of this study was to assess the overall water supply performance of Bishoftu Town of Ethiopia, by evaluating the water supply coverage, the hydraulic performance of the distribution system and the level of customer satisfaction. The methodology used to evaluate the hydraulic parameters pressure and velocity was Bentley Water GEMS v8i software that used topo data of infrastructures, pipe size, water demand, and population size of the research area and digitalized to undertake the analysis. General satisfaction of the population was done through collecting data by use of prepared questionnaires and analyzing using stata/SE 14.2 software, which the data collected from all kebeles and the random sampling methods was implemented for analysis. The research result shows that the average daily per capita water consumption and water supply coverage of the town found to be **44.85l/c/d** and **84.9%,** respectively. On the other hand, the results of the extended period simulation at peak hour consumption indicated that the performance of the distribution system connected to pressure found to be **3.16%** of the nodes acquired pressure of **15m** head, **40.91%** nodes have **15m - 70m, 31.62%** have **70m - 100m**, and **24.31%** have **>100 m**. On the other hand, the system's performance during peak hour consumption showed that **51.7%** of the pipes had flow velocities below **0.2 m/sec**, **24.5%** had velocities between **0.2m/s** and **0.6 m/s**, **19.50%** had velocities between **0.7** and **2 m/sec**, and **4.83%** had velocities above 2 m/sec. With regard to customer satisfaction, the study found that only **28.57%** were generally satisfied with the current water delivery system, **41.88%** were neutral, and **29.55%** were dissatisfied. From the result, the performance of Bishoftu town water supply system has found to be low velocity, high pressure and low level of overall satisfaction in quantity, quality and continuity for main pipelines. The high pressure resulted due to looping system of main pipelines and two methods of water distribution system pumping and gravity system; this might result in water wastage in the secondary and water collection point. On the other hand, low velocity in the main pipeline system is due to looping system which similar research also revealed that looping system of main pipelines in the town result in low velocity which is the source of water quality deterioration. Bishoftu town enterprise can undertake the* *improvement of the water supply system considering the detail finding of this thesis, under taking assessment on nonfunctional water sources which was not consider during the system analysis, assessment on new connected service area, and evaluation of water quality issues to ensure the a sustainable water supply system for future development. From the research, it is recommended that the enterprise could undertake improvement of the system through connecting pressure reducing valve, Gate valve, and use of appropriate pumps specifications and changing old pipes with new ones at recommended areas.*

Key Words*:* *hydraulic performance, WDN, WaterJEMSV8i, EPS, steady state simulation, user satisfaction, EPS, Network Analysis, modelling*

1 INTRODUCTION

1.1 Background of the Study

Water distribution systems are among the most important public utilities since a consistent supply of drinking water is a basic human necessity in every town (Swamee, 2008).

About 85% of the world's population, or 6.74 billion people, had access to pipe water supply in 2010. Communities, counties, and municipalities all include water supply networks in their master planning. To achieve the demand of the population the planning and design must take into account a variety of considerations, including location, present demand, projected expansion, leakage, pressure, pipe size, pressure loss, firefighting flows, etc… (Anisha, 2016).

Different researches showed that, the main purpose of water distribution systems is to provide an appropriate supply of water for demands like firefighting, commercial, industrial, and domestic. These purposes were considered under these research for the analysis of the research. The effectiveness of a distribution system can be calculated based on the pressure that exists in the system at a particular flow rate. To efficiently use the water distribution system and connect customers to water sources, hydraulic components like pipelines, valves, and reservoirs are very important. (Ayanshola, 2013).

A water distribution system must be precisely and efficiently designed in order to perform at its peak both immediately after installation and for many years to come. Numerous input variables, some of which are either impossible to measure directly are needed by numerous water distribution network modeling algorithms. Pressure, velocity and hydraulic gradient are the main factors to take into account when constructing the model of water supply distribution system of the specific town/city. A quick and effective method of anticipating network behavior is through the use of water network modeling, which calculates reservoir levels, reservoir inflows and outflows, pipe flows, velocities, head-losses, pressures, and heads. (Arsene,2004)

Over many years, computer programs like ephanet, GEM v8i and others have been developed for the modelling and simulating large water supply schemes distribution system which has been supporting technical staff of water utilities in practice as the system of pipes becomes increasingly complex, getting a precise estimate of the parameters mentioned becomes cumbersome. Since pressure/flow regulating devices are frequently used in multiple configurations (topological positions) and combinations in real-world water supply systems, modeling these pipe networks using ordinary computer programs is frequently challenging. (Ateş, S. (2016).)

The existing water distribution system of Bishoftu town water supply system is suffering with low water coverage and satisfaction, water loss and poor management of operation and maintenance. Hence, the aim of this research was to evaluate the hydraulic performance, water supply coverage and population satisfaction of the existing system. To undertake the modelling of existing water supply system of Bishoftu town had required a hydraulic modelling software like water GEM v8i that enable fast and efficient analyses and design of water distribution networks. Conventional and numerical solution methods used to solve pipe network flow equilibrium problems. (Ateş, S. (2016).)

For the case of water supply system evaluation like Bishoftu town the most fundamental data requirement is to have an accurate representation of the network topology, which details what the elements are and how they are interconnected. Moreover, collecting accurate data, digitalizing, organizing, and using of appropriate software to simulate would a base of accurate work, existing system performance evaluation. Moreover, after the basic elements and the network topology are defined, further refinement of the model can be done depending on its intended purpose.

In specific cases study like Bishoftu town water supply evaluation following considering both steady state and EPS simulation. It is strongly advised that a model be tested under steady-state conditions before dealing with extended period simulations due to the volume of data and the variety of possible actions that a modeler can take during calibration, analysis, and design. It is significantly simpler to move forward into EPSs after achieving satisfactory steady-state performance. (Walski, 2003).

Research revealed that the existing system has many challenges to perform for the intended plan. Constructed main pipelines, lack in proper operation of electromechanical equipment, poor operation and maintenance management, lack of valves and controlling points in the system were the major challenges of the system.

1.2 Problem Statement

One of the major challenges on the performance of water supply system in developing countries like Ethiopia is the demand of water supply increase from time to time due to the unexpected growth of population, expansion of industries, and urbanization of the town. The increase in population, and demand increase could create the shortage of supplied water from the source which intern create undesirable residual pressure in the system, and poor performance of the existing system. In Ethiopia, assessment on town like Bishoftu shows that access to potable water supply had been 76.7% nationally, disaggregated at 75.5% for rural and 84.5% for urban areas.) (Africa Development Bank Group, 2015). This data shows that the performance and objective of national level was not yet achieved.

On the other hand, poor institution and accountability, lack of community awareness, and technical constraints (Ali and Terfa, 2012) being the challenges to town water supply system performance in Ethiopia. These leads to water supply interruption, poor quality, and challenges of sustainability in town water supply. Bishoftu town is one of the town among similar town in Ethiopia suffering from all these challenges and problems. This result in underperformance of the system and the communities in the area.

In Bishoftu town case, Several industries operating in the town and there are significant number of agro-industry processing, hotels and tourism sectors and rapid increasing of population due to the improvements in road infrastructure, water supply, health facilities and greenery development. This is one of the factor contributing in poor performance of the towns in Ethiopia like Bishoftu. The population of cities and towns is expanding, and people are moving from rural areas to urban areas in pursuit of employment and a higher quality of life. As a result, there is a rising need for water in these locations. Bishoftu town is one of the town under pressure due to population increment, migration, industrial and commercial investment increase in the area.

During field observation, it has been noticed Bishoftu town water supply system has been operated by use of direct pumping and balancing reservoir system. However, pressure problem, technical constraints, nonfunctional boreholes and poor management system hampered the existing water supply system being under performance.

The low water coverage of Bishoftu town could be also related with the water losses in the distribution system, low water production, poor operation and management system, and not improving of existing infrastructures of the system on time based on the dynamic change of the demand. The hydraulic performance of the system was also found to be a big problem in addressing potable water at required quantity and quality. It was noticed that due to absence of required controlling valves, pressure reducing valves, oversizing of main pressure lines, and inappropriate use of electromechanical equipment had been a big problem within the system to deliver forecasted quantity of water. Hence, the research was identified the possible technical problems with regard to hydraulic performance, water losses, operation and maintenance of the Bishoftu town distribution system.

1.3 Objectives of the Study

1.3.1 General objective

The main objective of the study is to evaluate the performance water distribution system of Bishoftu Town.

1.3.2 Specific objectives

- To evaluate the hydraulic performance of water supply distribution network with Water GEMS V8i software
- To evaluate the water supply system coverage of the existing system.
- To evaluate the satisfaction level of the existing water supply system.
- To estimate the unaccounted water in the existing system

1.4 Research Questions

Under the above articulated problem, the researcher was intended to answer the following research questions.

- How the hydraulic performance behaves in the existing system?
- What is the status of current coverage of water supply in the system?
- What is the status satisfaction level of the existing water supply system?

1.5 Significance of the Study

The performance of the town of Bishoftu current water supply distribution infrastructure was thoroughly assessed in this study. the study was conducted a thorough investigation of the system using the facilities already in place, the data that was now gathered from the utilities, field measurement data, primary data, and secondary data sources. As a result, the research findings have identified performance deficiencies in the town of Bishoftu current distribution system. Therefore, there is a fantastic opportunity for business to apply the findings of this research to enhance the current water supply distribution system and assure system sustainability.

Based on the results of this study, utility professionals might also receive training that would aid in the timely and proper operation and maintenance of the system. Additionally, the results of this study may aid in future research in the field and ensure the viability of the town's water supply system.

1.6 Scope of the Study

The major goal of this research was to evaluate the status of hydraulic performance values of parameters, coverage of existing system, estimate unaccounted water in the system, and satisfaction level of the community in Bishoftu town and analyze the performance for better decision making and improvement of the system. In addition this research help to know how well the water supply and distribution systems in Bishoftu town performed in light of current future water demand. Hence, the study was limited to modeling of existing system from service reservoir and borehole to main distribution system of Bishoftu town water supply system due to financial and time constraints.

1.7 Limitations of the Study

This research has got limitations during the study. The limitation includes lack of existing secondary data (top map data) for some areas, lack of data on expansion done and ongoing projects for nearby rural kebeles. On the other hand, time, inadequacy of study area, and finance limits this research to investigate in details the existing infrastructures of Bishoftu town water supply system.

2 LITERATURE REVIEW

2.1 Introduction to Water Distribution Modeling

A number of researches have been made to study the water distribution systems, and to reach an ideal solution; improve the hydraulic performance and cost effective of the water supply networks.

The design of water distribution systems in general based on the assumption of continuous supply. However, in most of the developing countries, the water supply system is not continuous but intermittent (Khatri, 2007).

A study conducted by Thomas M. Walski, (2000) revealed that Water distribution systems represent a major portion of the investment in urban infrastructure and a critical component of public work. The main goal is to design water distribution systems to deliver potable water over spatially extensive areas in required quantities and under satisfactory pressures as a result hydraulic models for water distribution networks have become indispensable tools for understanding system behavior by simulating pressures and flows at different locations and times in the networks.

Other study made by Earle Brown Dr. Suite 629 Minneapolis -Distribution System Modeling Improves Water Network Progressive Consulting Engineers conclude that Water distribution system modeling has become a key tool in evaluating existing water networks and planning for future development. Modeling can show the weak links in a distribution system and using field data to calibrate the computer model is crucial part of water system modelling.

Shaher (2004) study revealed the hydraulic performance of water distribution systems under the action of cyclic pumping and its result shows that the network under consideration is exposed to relatively high-pressure values throughout; the velocity of the water through the network attained also high values. These high values of pressure and velocity have negative effects on the performance of the network. Unlike the transmission systems, these systems deal with water demand that varies considerably in the course of a day. Sources of Potable Water

The term "Source water" describes water bodies (such as rivers, streams, lakes, reservoirs, springs, and ground water) that supply water to both public and privates for drinking.

Most frequently, groundwater or surface water are used to provide public water systems. Large towns and cities typically use a combination of surface and ground water sources to supply their water needs. The only source of water for some tiny, rural villages is groundwater, which could or might not need to be treated to satisfy drinking water requirements. The type of source, the qualities of the raw water, the applicable drinking water standards, and the treatment methods employed, and the features of the distribution system all influence the degree of treatment that may be necessary (Walski, 2003).

The modeling was taking into account the sizing of the infrastructures, demand estimation, and infrastructure sizing because all of these processes require some infrastructures for the treatment process, disinfection, storage, and transportation of clean water to beneficiaries.

2.2 Customers of Potable Water

Accurate modeling depends not only on having a solid understanding of how water use is distributed across the system but also the number of connections within the blocks which plays a key role in determining the water demand at nodes across the whole distribution system. Water businesses must comprehend and evaluate service quality and customer satisfaction from the consumers' point of view in order to meet their needs. (Kassa, K. (2017).

2.3 Water Transporting Facilities

Transporting of water from source of extraction to end user needs different types of structures, and manufactured items for transporting the required amount of water.

(Trifunovic, 2006) studied that the infrastructures that are crucial to consider carefully during the design of water supply system includes clear water distribution, transportation facilities as well as raw water extraction, water treatment and storage processes included in the water supply system operation.

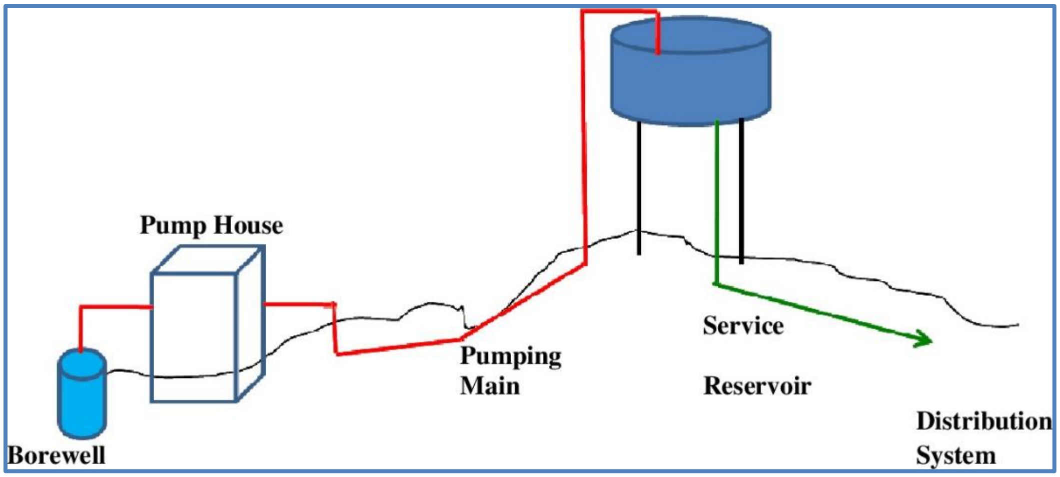


Figure 1: component of water system

2.4 Transmission and Distribution Mains

Distribution pipelines should made up of a main pipeline connected from secondary storage, a sub-main pipe connected from the main pipeline to branch pipes, and service/branch pipes connected from the sub-main for distribution to households. Distribution pipelines transport water from storage to its end users (water points, household tap, etc.). (Trifunovic, 2006).

2.5 Distribution System Configurations

The water supply system network setups can be classified in to four types in categories based on how the pipes are linked: combination, serial, branching, and grid (Trifunovic, 2006). The geography and street layout of each community have a significant influence on the construction of the water supply system networks. There are lots of network configuration systems but the main commons are branch and grid/looped systems.

Looped configuration

A grid or looped system which comprises of interconnected pipe loops throughout the serviced area is the most typical arrangement in big town. Grid or looped systems improve capacity for fighting fires and decrease water stagnation, but they may cause water quality issues in suburban areas.

For the various uses, the service area is divided into smaller zones, and each of these zones is supplied with a distribution reservoir from which water is radially transported to the distribution zone. It provides water at a high pressure and with minimum head loss (Kansakar B. R., 2015).

(Lindell Ormsbee, (2014).), Similar to grid systems loop structures usually involve a sizable number of smaller distribution loops. However, they also often consist of a number of bigger loops that might be constructed from transmission or mains. Loop configurations are generally associated with larger suburban and city distribution systems.

2.6 Water Distribution System Simulation

Simulation is the procedure of simulating the operations of one system using the behavior of another (Amdework, 2012). The water simulation model includes water supply infrastructure, demand sites, water distribution decisions, and hydrological conditions (MoWR, 2006).

Network simulations are widely used to imitate the dynamics of an existing or planned system. Simulating the system is crucial when it is impractical to directly experiment on the real system. There are two types of simulations: extended-period and steady-state. To ascertain how a system would behave in static circumstances, steady-state simulations are performed. They simulate a moment in time. To assess system performance over time, extended period simulations (EPS) are performed. (Walski, 2003)

2.7.1 Steady-state simulation

In a steady-state process, the system's response to stress, temperature, or other conditions remains constant across time. Every real-world process has both a steady-state and a transient phase, but depending on the desired outcomes, it is more suitable to concentrate on one or the other during the analysis. Computing the state of the system (flows velocity, pressures, pump operating attributes, and so on) assuming that hydraulic demands and boundary conditions do not change with respect to time. (Walski, 2003)

2.7.2 Extended-period simulation (EPS)

EPS examines the behavior of the hydraulic parameters of a system over time by simulating the state of the system using various scenarios system boundary conditions and hydraulic demands over time. By employing a daily curve that enables demand at the network's junction nodes to change in a predictable way throughout the day, the distribution network can be made more realistic for analyzing an extended period of operation. This kind of water demand variation is common and practical in town like Bishoftu, Ethiopia, hence the principle has

The daily demand curve illustrated below in Fig: 6 is typical one which commonly used for towns. The junction node's actual demand in a specific time period can be obtained by multiplying the demand peaking factors by the average base demand given for each node in the distribution network. (Mohamed, 2011.)

2.8 Methods of Water Distribution

(Swamee P. K., 2008), Water distribution system can be implemented in different systems; the major known methods to address the water demand of the communities are gravity system, pumping system that powered by generator or solar powered or combined system. Experience and study shows that the choice between these systems depend on a topography condition.

Bishoftu town water supply system found to be using combined system gravity and direct pumping system. Different studies revealed that this system preferred for better water distribution system. (Anisha, 2016)

2.8.1 Gravity distribution

Gravity system is feasible if the input point or source is at a higher elevation than all the withdrawal points, so that sufficient pressure can be maintained in the systems (Fig. 7). The main important of this method of water distribution system is saving power that needed for pumping.

2.8.2 Distribution by pumping without storage

Any topographic layout can be accommodated in the pumping system design. Water can be injected into the main distribution pipes using this distribution method without first going via a service reservoir. The rate of pumping ought to be adequate to meet the demand. This technique requires a constant supply of electricity, which is impractical for the majority of poor nations. (Swamee P. K., 2008)

2.8.3 Distribution by means of pumps with storage

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

2.9 Water distribution system components

The two primary parts of the water supply system are transmission and distribution systems. A transmission system consists of components designed to move large amounts of water over long distances, typically between the system's main facilities. Water that is transported through transmission pipelines is distributed to residential areas through the water distribution system. Service connections and distribution mains are both a part of the distribution system. Distribution mains, which act as a transitional stage in the delivery of water to users have smaller diameter than transmission mains. Distribution mains typically align themselves with and follow the overall pattern of city streets. (Trifunovic, 2006)

A distribution system is a network of water lines (pipes) that deliver treated water to consumers. The distribution system or infrastructures consists of the following major components;

- Pipes (transmission lines) for conveying water from the source.
- Pumps for building and sustaining pressure.
- Water flow-control valves.
- Water storage facilities like reservoirs and high tanks.
- Meters for measuring water supply volume.

Fire hydrants that can supply enough pressured water for combating fires.

2.10 Service Reservoir or storage tank

Water that has been treated in a water treatment facility is preserved in a service reservoir before it's distributed to end the public. The main aim of this is to provide the water delivery system as a measure of resilience so that water supplies can be kept up throughout periods of fluctuating demand. The following general purposes are served by reservoirs (or tanks): meeting variable supply to the network with constant water production,

- balancing variable demand in the network with its constant supply,
- providing a supply in emergency situations,
- Maintaining stable pressure (if sufficiently elevated).

In order to provide for security of supplies above the need for balancing purposes it is recommended that the minimum total reservoir storage capacity be in the range of 30% to 50% of the average daily demand. (MoWR, 2006)

Balancing reservoir capacity is determined by:

Tank capacity = Maximum cumulative surplus + Maximum cumulative deficit – total inflow + total demand.

Inflow > Outflow, reduce the tank by the difference of surplus or overflow occurs Inflow <= outflow, no consideration. (Modi D. P., 2014)

2.11 Pipes

A pipe conveys flow as it moves from one junction node to another in a network. In the actual world, individual pipes are usually manufactured in a variety of lengths, sizes, and specifications before they're connected together to form a pipeline. The fittings that connect the system line to the pipeline may vary in size, shape, and diameter. For modeling purposes, several pipe segments and associated fittings can be integrated into a single pipe unit. A model pipe should have uniform dimensions, materials, and other features along its whole length. (Walski, 2003).

Most simulation tools allow engineers to select either a scaled length or a user-defined length for pipes. The software scales lengths automatically or according to alignment with a digital background map.

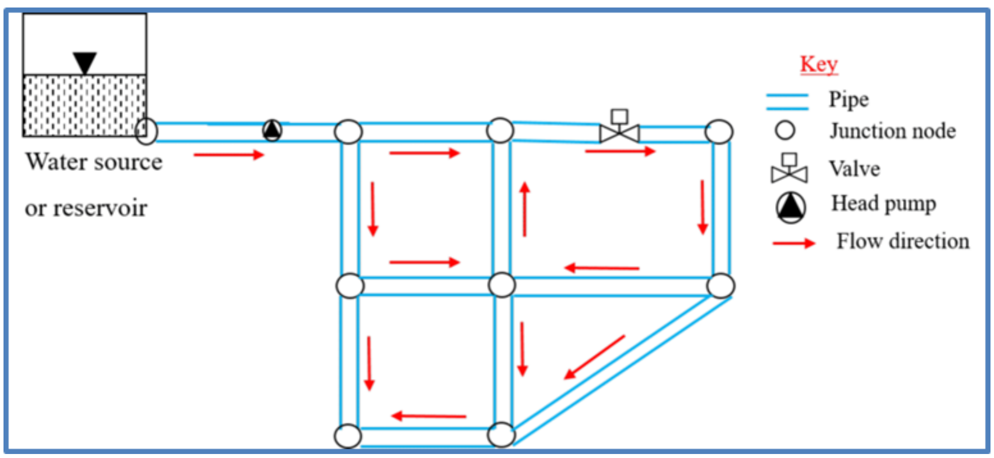


Figure 2: pipelines connection system

2.11 Water Demand

The consumption or use of water, also known as water demand, is the driving force behind the hydraulic dynamics occurring in water distribution systems. Anywhere that water can leave the system represents a point of consumption, including a customer's faucet, a leaky main, or an open fire hydrant. (Walski, 2003).

2.12.1 Types of water demand

Based on the customer, there are different water demand types.

Domestic water demand: Domestic water consumption is intended for toilet flushing, bathing and showering, laundry, dishwashing and other less water intensive or less frequent purposes: cooking, drinking, gardening, car washing, etc. (Swamee P. K., 2008)

Commercial and Institutional water demand: The water required for schools, hospitals, health center, Commercial Centers, hotels, government offices and services, religious institutions and other public facilities is categorized under this demand.

Industrial water demand: Although diversified, it generally consists of heat exchange, cooling, and cleaning. The amount of industrial water used and the community's population have no direct correlation, but 10 to 50 percent of the total amount of water consumed per person per day is typically attributed to industrial use.

Unaccounted for water (UFW): expressed as a percentage of the total water produced for the system. UFW arises from system leakage, water taken by illegal connections, inaccuracies in metering, overflowing of reservoirs, and legitimate unmetered use such as firefighting, flushing, etc. (MoWR, 2006) UFW cannot be assessed easily without adequate and reliable metering. Others have estimated that in Addis Ababa some 25% to 30% of the water produced might be unaccounted for. The situation in the other towns may be even worse given the generally lower levels of maintenance. A figure of 50% would not be without precedent. A figure of 15% is generally regarded as good, and uneconomical to try and reduce. (MoWR, 2006)

Fire Demand: It is the amount of water required for firefighting purposes if in case a fire breaks out in an area. This water is required to be available at a pressure of about 100 to 150 kN/m^2 or 10 to 15m head of water. Fire demand is not calculated for smaller towns where the population is less than 50,000. (Mostafa, 2023)

The average daily demand is therefore, the sum of domestic, commercial and institutional, industrial water demand and system losses.

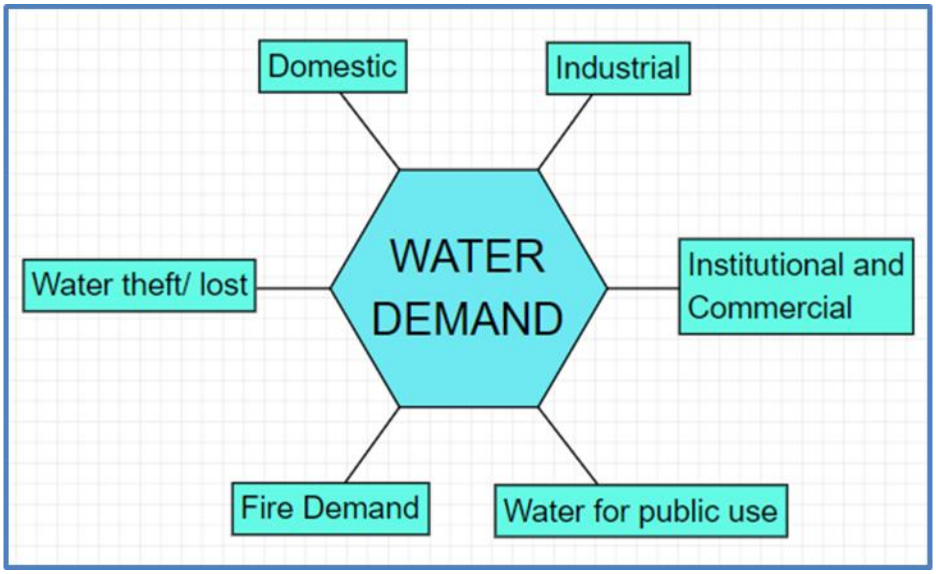


Figure 3: Types of water demand, Source: Mostafa, 2023

2.12.2 Water demand variations

Demand variations are commonly described by the peak factors. These are the ratios between the demand at particular moments and the average demand for the observed period (hour, day, week, year, etc.). (Trifunovic, 2006).

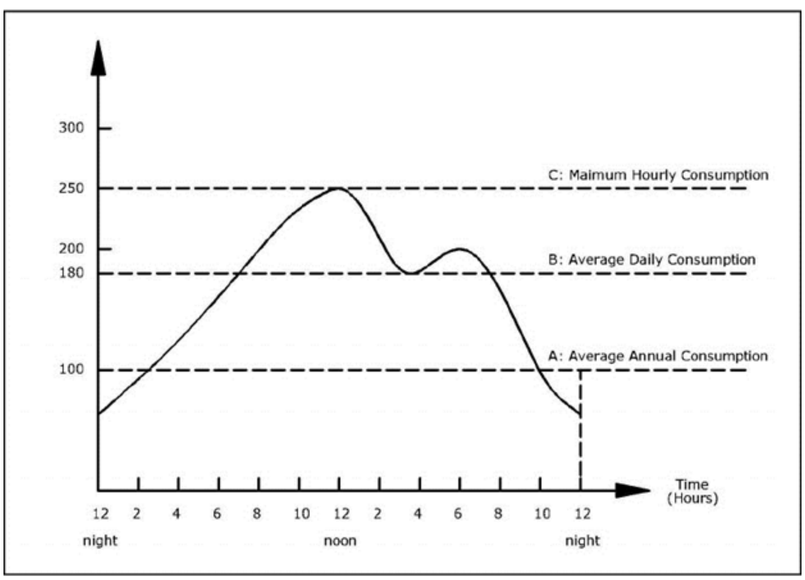


Figure 4: Water demand variation, source: Mustafa et al., 2013

For practical purposes, it is widely accepted to refer to the instantaneous peak factor within this time frame as the hourly (or diurnal) peak factor. The modelling of primary and secondary networks, specifically reservoirs and pumping stations, depends on daily demand trend.

With either permanent or temporary measurement equipment, flows at delivery points or network nodes (pressure boosting stations, reservoirs, and control points) are typically monitored to identify demand trends. With well-planned measures, the designs can even be seen on the premises of the consumers. A genuine consumption pattern will come from such an approach because it first allows the separation of different consumption categories and second, it excludes distribution system leakage.

The maximum day water demand is the highest demand of any one-hour in 24-hour period over any specified year. The maximum hour coefficients are taken from the design guideline that has been prepared by MoWR that is presented in Table 1 below.

Maximum daily demand (MDD)

$\mathbf{P_f} = Q_{max}/Q_{avg}$

Where: Q_{max} = maximum daily demand measured at different days

Q_{avg} = average daily demand

P_f = peak factor

Table 1: Maximum daily coefficient, Source: MoWR, 2006

Average Day Demand(m3 /d)	Maximum Daily Coefficient
200	2
3,000	1.5
40,000	1.45
300,000	1.5

A peak day factor needs to be used to adjust for different scenarios. Some engineers are using demand factors for peak days that range from 1.0 to 1.3. Each specific peak factor water supply system value must be consider consumer behavior as well as the knowledge of the community and the system operators. It is expected that any value selected for the peak day factor would not fall outside the above range. (MoWR, 2006)

The need for water differs significantly over the day time period. A peak hour factor is used to account for the peak demand, and the distribution system must be designed to cope with the demand. On top of this the seasonal variation must be considered. Hence, the peak hour factor is multiplied with the yearly average daily demand to get the peak demand. Logically, the size of the population has the inverse relationship with the peak hour factor.

In addition to peak hourly factor socio-economic factor should also considered to quantify the daily peak demand to design distribution system. Ministry of water resource of Ethiopia recommend the following peak factors as shown in table 2 below.

Table 2: Peak hourly factor values for towns, Source: MoWR, 2006

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

2.13 Hydraulic Design Parameters

It is necessary to have information of the size of pipes to transport water under a known pressure difference between the intake and output section before laying pipes and building a distribution system. It encompasses the design process, design criteria, and pipe hydraulics.

2.13.1 Design Criteria

Those criteria or conditions that need to be fulfilled during design so that the system will work in a proper manner is said to be design criteria. (MoWR, 2006)

a) Velocity:

Table 3: Design criteria for water flow velocity, source MoWR, 2006

Distribution type	**Velocity (m/s)**
Maximum transfer main velocity	2
Maximum velocity in distribution	2
Minimum velocity in distribution	0.6

b) Pressure:

According to the MoWR water supply design criteria (2006 E.C) recommendation the pressure range in distribution system to be 5-60m water head.

- The minimum static pressure at peak hour demand 20m.
- Maximum static pressure during low demand periods was limited to 60m.
- Minimum dynamic head was established at 15 m.

2.14 Satisfaction level of urban water supply distribution system

A successful water distribution system is able to provide the required amount of water under normal operating situations with sufficient pressure, quantity, and consistent levels of water quality. The water business must evaluate the functioning of the water distribution system in order to deliver competent levels of service. (Abdulkadir, 2012)

In addition, a reliable distribution network must be capable of supplying adequate water to meet a variety of demands at all service places within the required pressure head and velocity of flow. Hence, a survey could be conducted to assess the performance of the overall satisfaction of the system.

3 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Geographic locations

The study was carried out at Bishoftu town which is the capital of Ada'a Chukala woreda in East showa zone of Oromiya Regional state, Ethiopia. Bishoftu Town is located in the central part of Ethiopia in Oromia regional state, East shewa zone, at the distance of 45 km south East of Addis Ababa City and 55 km west of Adama Town. Bishoftu located at 08°44'N and 38°58'E, and an altitude ranging from 1900 m. to 1995ams. The town has 15 kebeles. Its topography is undulating and characterized by flat land on the north and east parts of the city, locked by several lakes, while the south is dominated by hills (Giannecchini & Taylor, 2018).

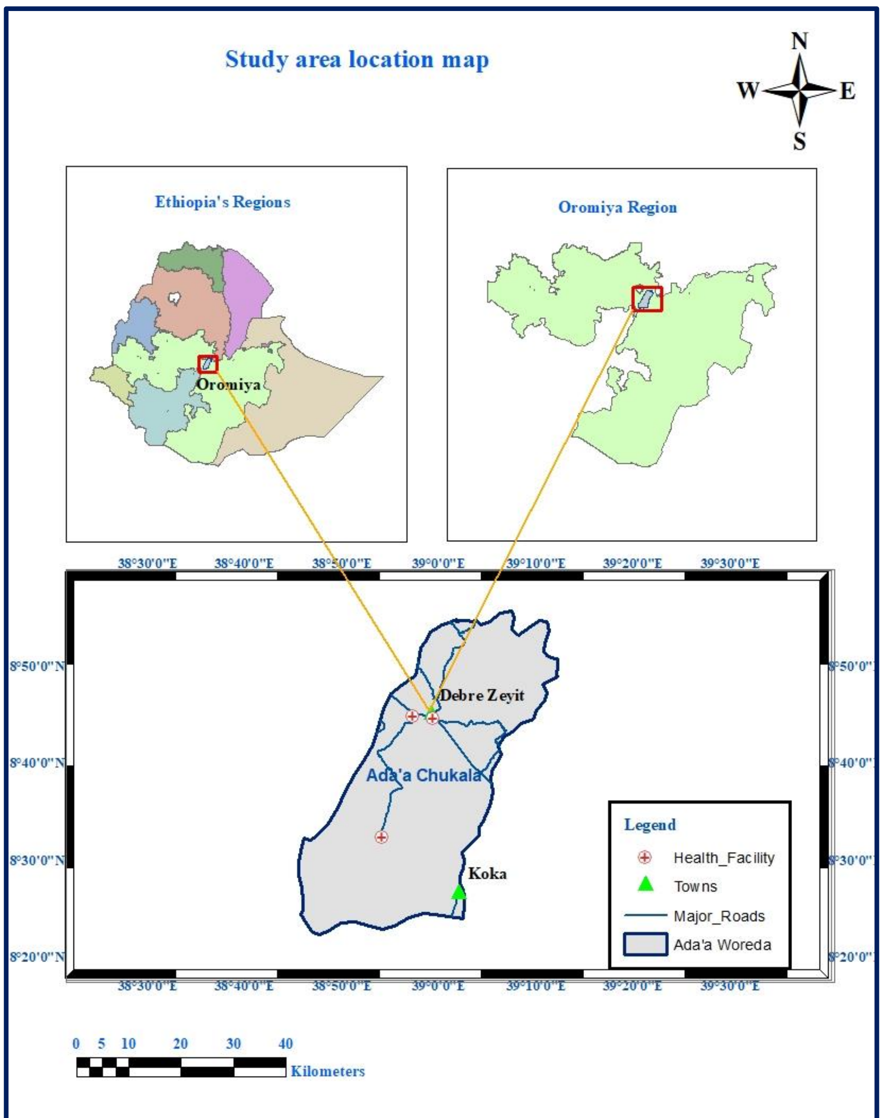


Figure 5: map of study area

3.1.2 Demography of the town

The population of Bishoftu town has been increasing rapidly due to different reasons. Investment, industry expansion, and migration were found to be the major cause for the rapid increment of population in the town. The population of the town is estimated 228,857 as per the finance and economic development office of the town and categorized as category 2.

Bishoftu town and surrounding encompasses about 6,400 ha's with neighboring 10 rural kebeles in Ada'a woreda. (BTWSSE Report, 2015)

3.1.3 Climatic condition of the town

Under the Köppen–Geiger climate classification Bishoftu features a subtropical climate (Cwb). Temperatures typically range between 17 °C (62 °F) and 21 °C (70 °F) through the year, but rarely can drop to 2 °C (36 °F) or can rise to as high as 32 °C (89 °F). The average annual precipitation amounts to about 902 mm (35.5 inches) and receives 138 rainy days on the 1 mm (0.04 inches) threshold annually. (Kottek, 2006)

3.1.4 Socio-Economic Activities of the town

Industrialization has caused significant socioeconomic changes in Bishoftu (Giannecchini & Taylor, 2018). Despite the many benefits, it has a big impact on existing livelihood of the town. Numerous social, economic, and political effects result from the town expansion. (Mohamed et al., 2020). But there is no clear and enough information on this area.

3.2 Description of Bishoftu Town Water Supply System

3.3.1 Available Water Sources

The development of Bishoftu town water supply system had been commenced twenty years ago. The development of the source was commenced by drilling of deep well at different sites which has abundant ground water source. The well fields of Bishoftu town water supply system are shumbura meda, Cheleleka, Dembi, and Kurkura Areas. The existing water supply system of Bishoftu town was designed and constructed in 2014/2015 and designed for 30 years. Currently there are **22 deep well** over the well field which has been used as source for supply of safe water for Bishoftu town population.

Below table 4 shows the details available water sources and their status for Bishoftu water supply system.

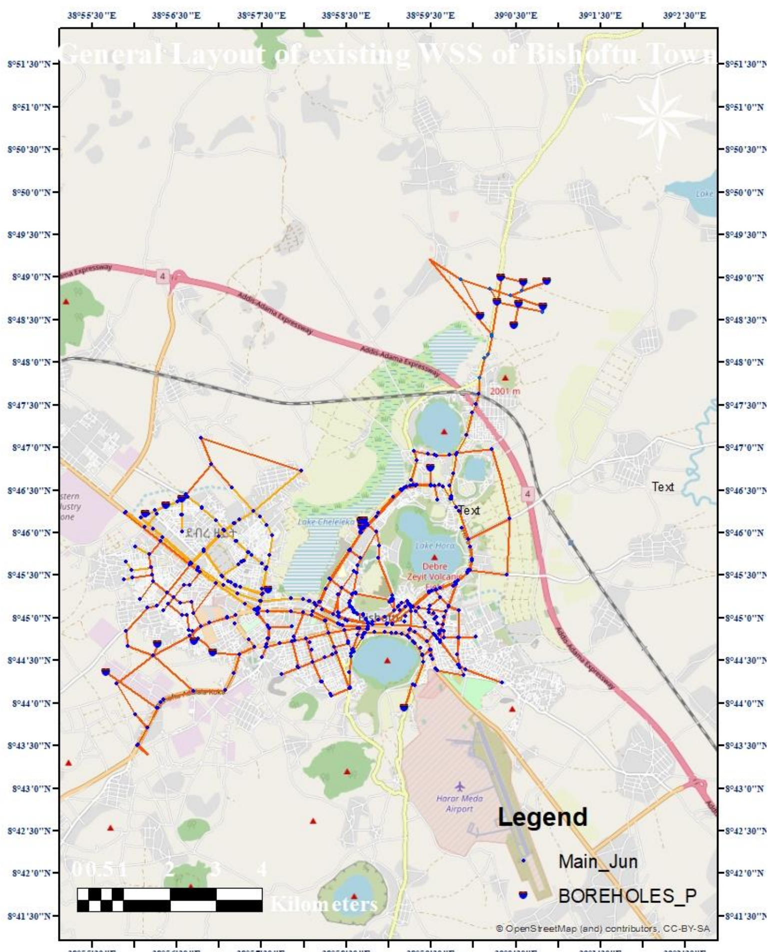


Figure 6: Water source Locations (BHs)

Table 4: Boreholes location and current status; Source: BTWSSE, 2023

s.no	Source Name	Depth (m)	BH_ Elev (m)	X	Y	Pump Pos (m)	Status	Pump_ Dis (l/sec)	Well-Dis (L/sec)
1	SHUM_BH1	76.5	1903.25	500601.42	974578.85	48	NF	5	5
2	SHUM_BH8	400	1895.91	501580.91	974487.33	110	NF	50	50
3	SHUM_BH3	70.67	1897.74	501092.54	974470.29	42	F	15	15
4	SHUM_BH5	76.15	1898.94	501511.21	973940.08	48	F	15	15
5	DAMBI_BH1	180	1897.79	492907.78	969462.26	0	F	6	6
6	DAMBI_BH2	260	1895.98	493350.60	969651.79	0	F	20	10
7	DAMBI_BH3	350	1897.75	493710.37	969782.97	0	F	30	30
8	CHELK_BH2	36	1900.94	495569.51	967820.03	30	F	5	5
9	CHELK_BH1	41	1861.15	497602.81	969309.93	36	F	5	5
10	CHELK_BH3	200	1863.66	497583.57	969292.13	106	F	20	10
11	CHELK_BH4	438	1862.41	497597.53	969178.15	97	F	82	50
12	KUR_ BH1	450	1964.50	492067.30	966024.13	0	F	35	12
13	KUR_BH2	350	1965.36	493961.01	966694.33	0	F	20	10
14	KUR_BH3	400	1987.57	494371.79	966466.42	0	F	20	10
15	KUR_BH4	500	1983.70	493184.58	966634.64	0	F	30	30
16	SHUM_BH4	76.6	1895.35	500517.41	974041.43	48	NF	15	15
17	SHUM_BH7	426	1893.74	500140.76	973731.10	110	F	50	46
18	SHUM_BH6	74.1	1897.91	500880.98	973537.97	39	NF	5	5
19	SHUM_BH2	72.65	1902.14	500987.75	974000.98	42	NF	5	5
20	BABO_BH1	382	1890.07	499069.46	970463.07	0	F	100	50
21	GODG_BH1	382	1918.49	498513.22	965269.95	0	F	30	30
22	CHELK_BH5	N/A	1862.50	497628.82	969317.10	0	NF	0	0

3.3.2 Storage Reservoir

Bishoftu Town water supply system has got **seven/07/** different water storage balancing reservoirs. The maximum capacity of the reservoir is **1000m^3** and the minimum volume is 500 m3.

Below data of existing reservoir were collected from secondary data and confirmed during field work.

Table 5: Existing water storage reservoir (Source: BTWSSE)

S.no	**Reservoir Location**	**Elevation**	**X**	**Y**	**Capacity(m^3)**
1	Gand Gorba	1933.1	499208.0	969754.6	1000
2	Hora Hado	1955.1	498670.2	965786.5	500
3	RES_3	1988.7	499038.9	974966.1	1000
4	Dabeso_1	1965.6	498266.5	967611.2	1000
5	Dabeso_2	1965.6	498243.4	967608.9	1000
6	Debayu_RS_1	1996.5	492979.6	964247.2	200
7	Debayu_RS_2	1988.5	492958.3	964239.2	500
	Total				**5200**

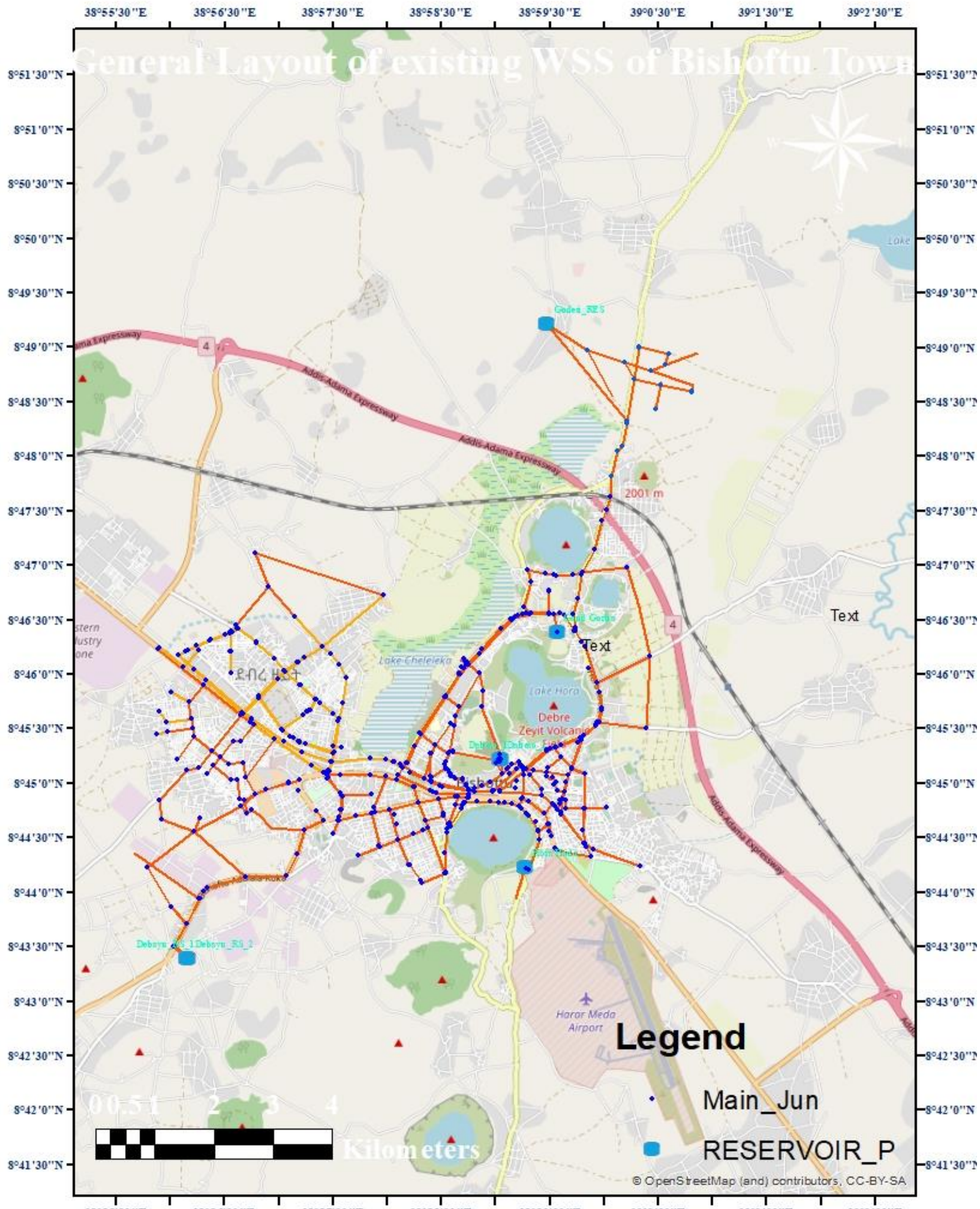


Figure 7: Locations of water storage Reservoirs of Bishoftu Town WSS

3.3.3 Existing Pressure and Distribution Pipes

This is one of the major, and crucial component of the water supply system to deliver water to all customers of the system in sufficient quantity for domestic water demand, and fire demand. The existing pipes of the town linking all well field source to pumps, existing reservoirs, and Junctions, fire hydrants, and water collection points.

The pressure main as well as distribution lines of Bishoftu town constructed of different types of materials like DCI, UPVC, HDPE, and GS pipes.

Below table shows detail pipe length, size and type collected from the enterprise from secondary data sources

Table 6: Existing pressure and distribution lines

S.no	Pipe Type	Length(m)
1	DCI	24,621
2	UPVC	94,171
3	HDPE	20,339
4	GS	24,962
	TOTAL LENGTH	164,093

3.4 Methods of data collections

Data collection has been the crucial and top important part of this research. Water supply system modeling and required accurate topographic survey data overall the service area. Accordingly, the primary collection methods, secondary data collection, interview with responsible bodies had been conducted in details on existing system line in the town. All required data were collected from all sources to evaluate the existing system functionality and future performance, and point out improvement required for better service delivery. Both primary and secondary data collection methods were used to obtain the required information.

3.4.1 Secondary data collection techniques

Data collection on the existing pipelines system was conducted after official discussion made with the Bishoftu town water supply and sewerage enterprise officials on the objective of the research on the existing system.

The following steps followed to undertake the assessment on the existing system

- ✓ Existing GPS waypoints taken from the office and mapping done using ARCGIS and locate the major pipelines (pressure and distribution) route, Boreholes sites, manholes, Junctions, and reservoirs locations.
- ✓ Following the preparation of the map, each boreholes, pipelines junctions, route of main distribution lines, pressure mains from boreholes to reservoir, manholes, pumping houses were checked and confirmed on the ground.
- ✓ Current water consumption data, no of current beneficiaries by category, and existing connection by category. All collected data were collected from the enterprise database and shown in tables and map format.

3.4.2 Primary data collection

Primary data were collected through topographic surveying instrument GPS Garmin 64.

After visited and confirmation made on all the available secondary data all the locations of missed topographic data on pipelines end, manholes, junctions, uncovered service area, borehole sites, and reservoir sites were collected and reconsidered on the existing water supply system network. Accordingly coordinates (longitude, latitude, and elevation) for pipe junctions, nodes, reservoir locations, borehole sites and uncovered service area were collected directly from field measurement and reconsidered for modeling of the existing WSS. All the collected information being the important parameter s for the simulation of the any water supply system.

Bishoftu town WSS system has used a combined system where the direct pumping system connected with the distribution system as well as to the balancing reservoir. Due to this reason the pipeline distribution system is installed in looping system in the existing system. Below data shows the type, size and length of pipelines installed years ago.

Following tables and map illustrate location of data measurement done and values of data collected which has been considered as input for the modelling of existing water supply system of Bishoftu town WSS.

3.4.3 Key Informant Discussion

This activity was being key to assess the existing system and collect available data at BTWSSE. Including the Facilities manager, technicians, and IT experts, planning experts, electromechanical technicians and plumbers and tap stand attendant has been interviewed and all necessary information has been collected and utilized for the study of Bishoftu town water supply system.

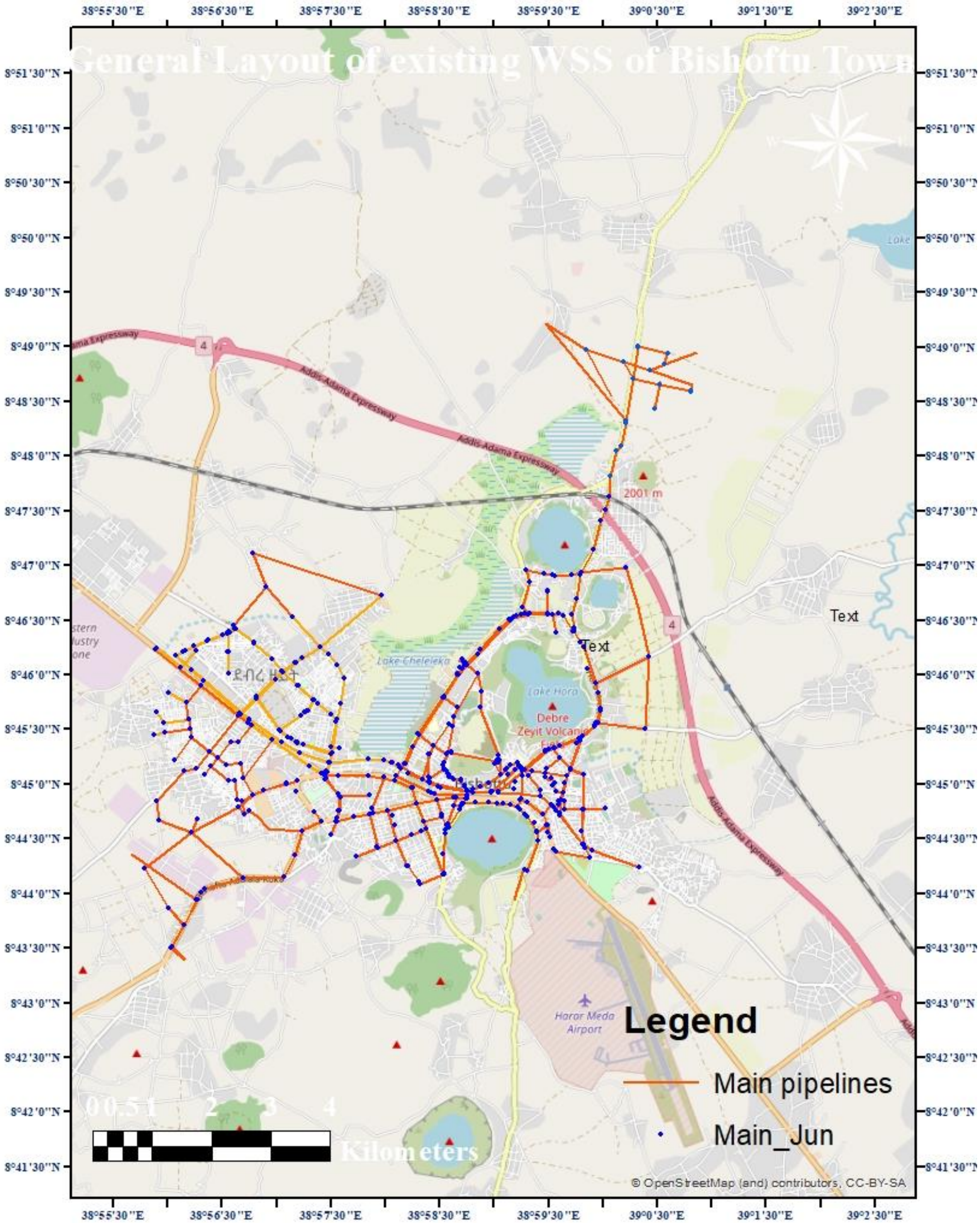


Figure 8: Existing pressure and distribution pipeline (Source: BTWSSE)

3.4.4 Collected topographic data

This work had been done with the enterprise experts after the secondary data found to be limitation in some areas of the town. The data collection includes borehole sites, reservoir sites, new connected distribution lines, and water distribution points. Accordingly, 47 points had been collected and included during modelling of the water supply system. The area covered during field data collection shown below on fig 17 and 18 and see Annex 25.1 for collected data.

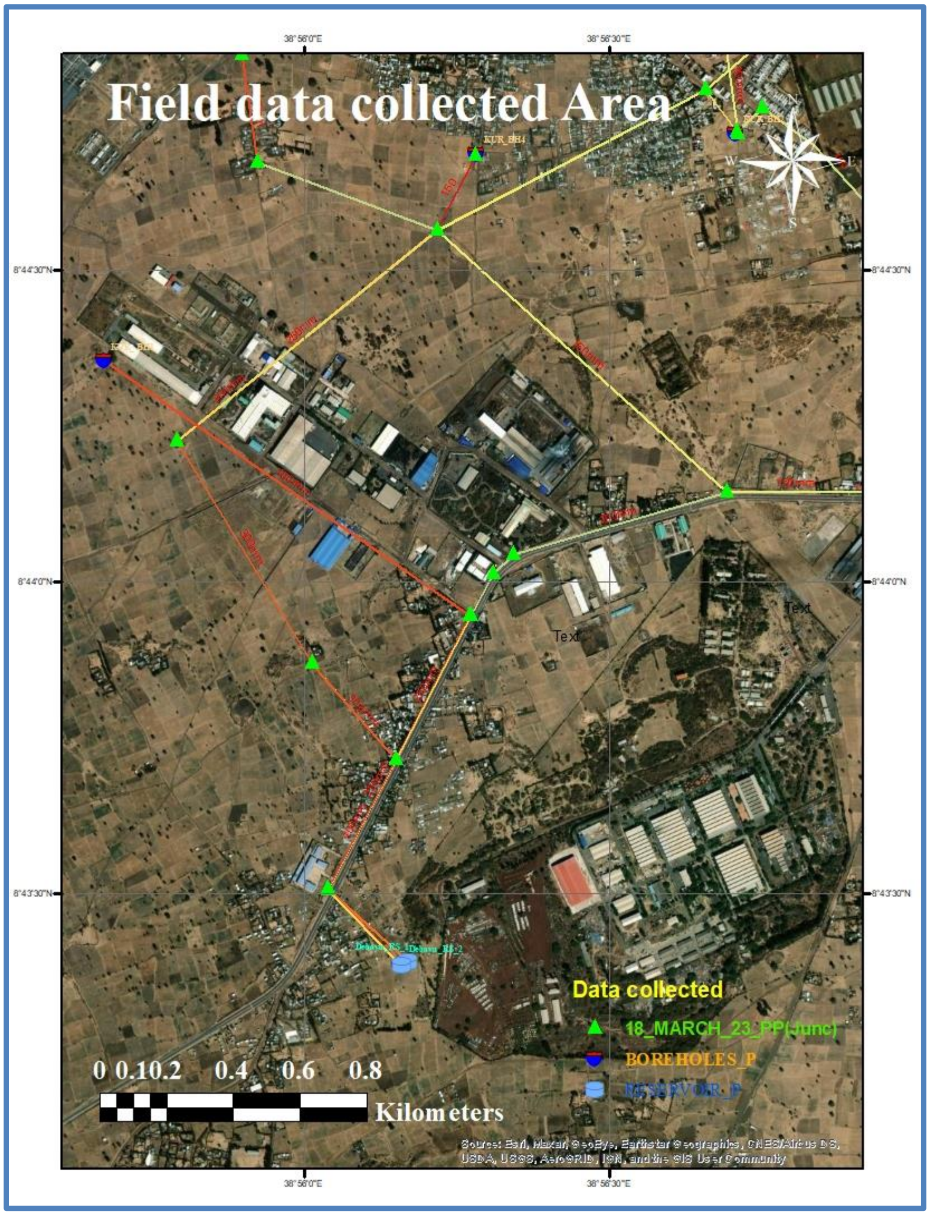


Figure 9: Topographic data collected area

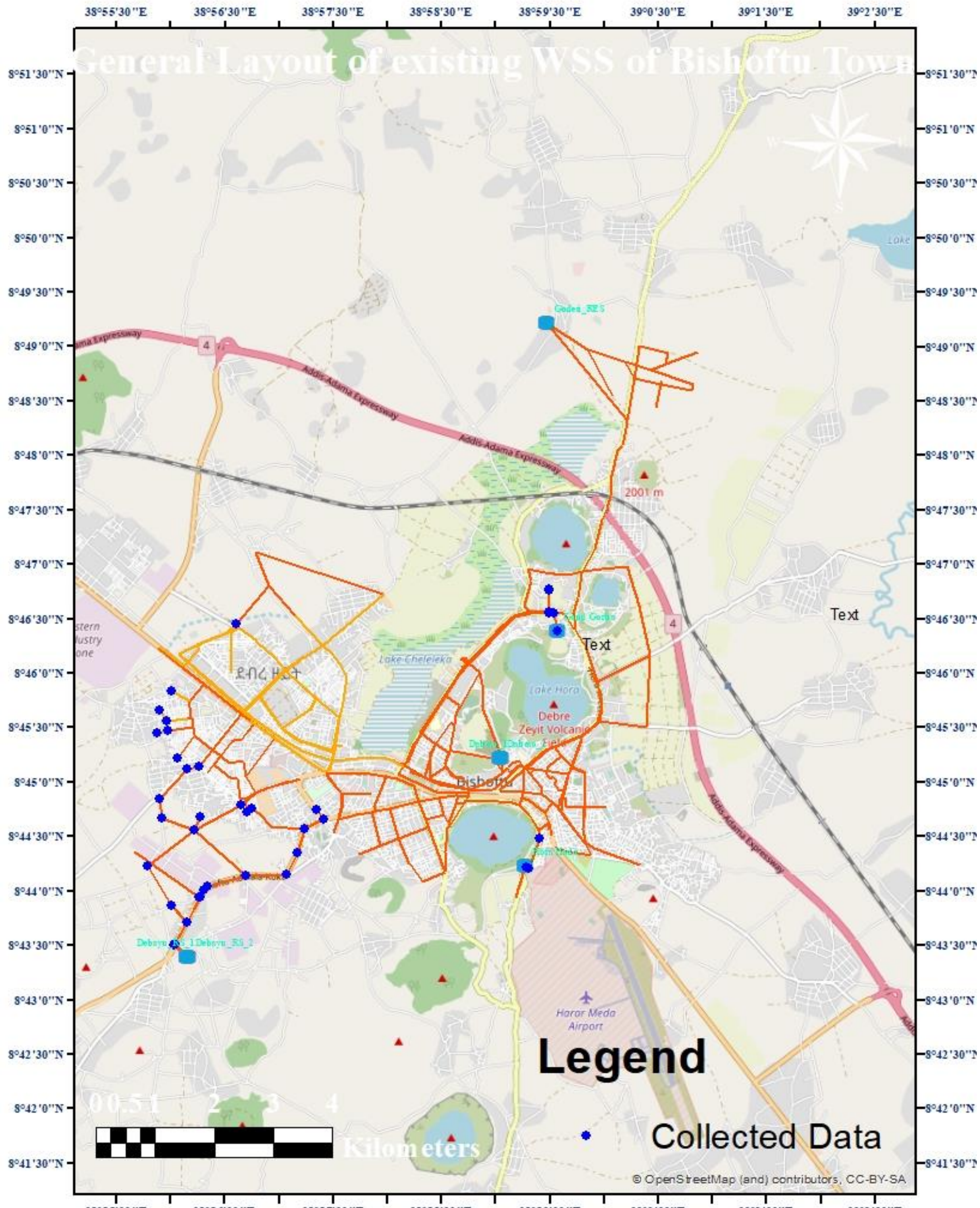


Figure 10: Topographic data collected area

3.5 Current water Production status

Documentation and current service confirmation report was collected from Bishoftu Town Water Supply and Sewerage Enterprise (BTWSSE) on population data, current water production, current billing tariff, and current water consumption data.

The population of the town is estimated to be about 228,857 in the year 2017 as per the finance and Economic development office of the town and is categorized as Category 2 town. The water demand of the town as estimated by GTP target is about 18,309 CMD and 45,239 CMD for the years 2017 and 2027 respectively.

The water production rate of Bishoftu town was about 22,378 CMD from 19 boreholes in the year 2017 which is about 83% water coverage. However, the quantity water produced was not adequate to cover the losses, system maintenance gap and alternative water supply source was identified and six additional boreholes were drilled connected to the system.

3.6 Water Demand (WD) Projection

3.6.1 Current population Forecasting

This research consider the population in 2017 which was estimated 228,857. This number of population was estimated the finance and Economic development office of the town and used for emergency water source development during the period. Afterwards, the number of population estimation has been updated till the current year. Therefore, considering this scenario in to account the population projection was calculated using geometric increase method for the year 2023 and 2043.

$$\mathbf{P_n = P_o (1+r)^n}$$

Where P_o= base population, P_n = population at n decades or year, n = decade or year, r = rate (percent increase).

Table 7: Population data of Bishoftu town (Source: BTWSSE)

.no	Settlement Name(Urban and Ada districts)	Population in the year 2017	Population in the year 2027
1	Bishoftu Town	228,000	306413
2	Kajimana Dibayu rural kebele	8660	11639
3	Kurkurana Dembi rural kebele	5599	7524
4	Industry Workers	43907	59007
	Total	**286,166**	**384,583**

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 usedas in the table 8 below.

Table 8: CSA's Country level population growth rate Source: Ministry of Water Resource (MoWR), 2014)

CSA's Country Level Population Growth Rates	
Year	Urban Growth rate %
1995-2000	4.3
2000-2005	4.1
2005-2010	4.06
2010-2015	3.88
2015-2020	3.69
2020-2025	3.51
2025-2030	3.35

3.6.2 Current water consumption

The analysis of future water demand of a particular community should be always beginning by considering the present water consumption. This involves, estimating the population of the service area, per capita water consumption and accounting the different adjustment factors (Climate and Socio-economic factors) that affect the water demand. To the extent possible, consumption should be broken down by classes of users (domestic, commercial, industrial, and public), area of the village, economic level of the users, seasons of the years, etc. The first step in the planning and designing of water supply schemes is to examine carefully the various types of water demands. Average water demand is considered as the sum of domestic, public and commercial, industrial, livestock's demands, fire requirements and water loss, as it is indicated in the Water Sector Development Programme document for urban areas prepared by the Ministry of Water Resource.

As per Annual report of the utility the water consumption of Bishoftu town found was recorded to be **6,714,540**m^3 and annual production of was **9,791,928**m^3.

3.6.3 Domestic Water Demand

The domestic water demand is the quantity of water required for drinking, bathing, cooking and washing, etc. This water demand highly depends on the availability of water, climate condition, culture of the inhabitants, etc. In general the main factor that affects the water demand in the target area is the climate.

The Domestic water consumption of town depend on different scenarios like connection type, climatic conditions, socio economic condition and of the town, development of the town and other factors. Accordingly, Bishoftu town had been considered as category 2 as per the finance and Economic development office the per capita demand is set to **80l/p/d**. See table 9 below

Table 9: Domestic water demand categories source: GTP2 Minimum Service level in l/c/d per Town and rural category

Domestic water demand based on categories		
Mode of service	**Stage 1**	**Stage 2**
- House connection (HC).	50 l/c/day	**70 l/c/day**
- Yard connection, own (YCO).	25 l/c/day	**30 l/c/day**
- Yard connection, shared (YCS).	30 l/c/day	**40 l/c/day**
- Public tap supplies (PT).	20 l/c/day	**25 l/c/day**

3.6.4 Variation of Water Use

The rate of water use varies from season to season, from day to day and hour to hour. Water requirements in the dry seasons are more than in wet seasons. 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 at normal working hours. Therefore, to satisfy this variation of demand the average daily demand is scaled up by certain factors to get the maximum day demand and peak hour demand, see table 10 below[1].

Table 10: Variation of water use with population size

Table 10: Variation of Water Use **Population Size**	**Maximum day factor**	**Peak hour factor**
<2,000	**1.3-1.5**	**2.6**
2,000-10,000		**2.4-2.2**
10,000-50,000		**2.2-1.8**
50,000-80,000	**1.2**	**1.8-1.7**
>80,000		**<1.7**

[1] Source: The World Bank Issue Paper for water supply project design, Draft Final Report (2013)

3.7 Tools, modelling and Analysis procedures

3.7.1 Materials used to the study

The following tools and software's were used to simulate and analyze the collected field data.

- ✓ Bentley **waterJEMSV8i**
- ✓ GPS Garmin 64
- ✓ ArcGIS version 10.8
- ✓ Pressure gauge

3.7.2 Modelling procedure

Creating and working with model required several steps such data construction of distribution network, network layout digitalization, integrating map software with waterJEMSVi8, collecting, checking and adding attribute data, demand allocation and calibration with data. Below Schematic flowchart shows the overall modelling processes of water distribution network in any system.

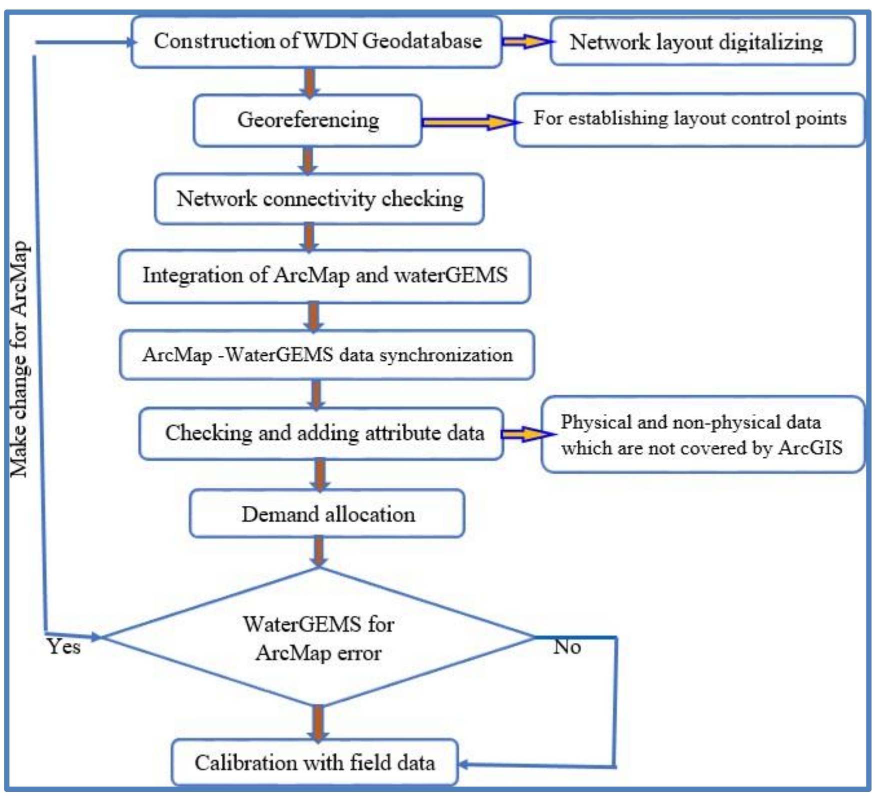


Figure 11: Modelling procedure for water supply simulation

3.6.3 Create Model in WaterJEMSV8i

Before creating the model the secondary data and primary data collected were mapped and analyzed on **ArcMAP 10.8** and also **QGIS**. The data includes elevation of structures and points like, nodes, reservoirs, water points, hydrants, valve boxes, boreholes, reducer points, expansion points, bends, ends, and crossing tees.

The detail network was mapped on the ArcMAP and overlaid the Google earth as a base map and later on checked on the ground through field visit.

All the work had been accomplished and saved properly as shape file and Autocad file to export proper water software.

The **WaterJEMS V8i** had been chosen for the analysis of Bishoftu town water supply distribution system and all the Arcmap work in shape file imported to the **WaterJems V8i** by model builder tools.

After importing the data and set specifications of ***nodes elevation, pipe length, pipe diameter, pump curve, reservoir elevation, pump elevation,*** reservoir physical specification the analysis had been done in different selected scenarios.

3.6.4 Model representation

System distribution networks are drawn as a combination of various system components. The model is commonly, in water distribution system represented by system elements, such as reservoir, tank, pipe, node, pump and valves.

3.6.5 Nodal demand calculation

The node demand calculation was found using excel table by use of number of household at the nearest node and water meter connected among the beneficiaries. This method was based on the assumption of evenly distribution of the service connections or costumers.

To assign base demand to each supply node, the secondary data collected on number of beneficiaries in each block along the distribution line and nodes. Each kebele with specific place analyzed in detail assigned for each nodes. This work has been supported by means of Google earth image for the town of Bishoftu, and number of beneficiaries counted and confirmed by use of number of beneficiaries taken on ARCGIS from Bishoftu town water supply and sewerage Enterprise. Nodal demand is calculated using the following formulae:

$$N_d = \sum_{k=0}^{n} Pidj$$

Where $\mathbf{N_d}$ = nodal demand, $\mathbf{p_i}$ = population supplied by the nearest node of the service area, $\mathbf{d_j}$ = per capita demand assigned for the study area, **i** = subscript referring to the **i**$^{\text{th}}$ – node in the service area**,** **j** = subscript referring to the **j**$^{\text{th}}$ – pressure zone in the service area.

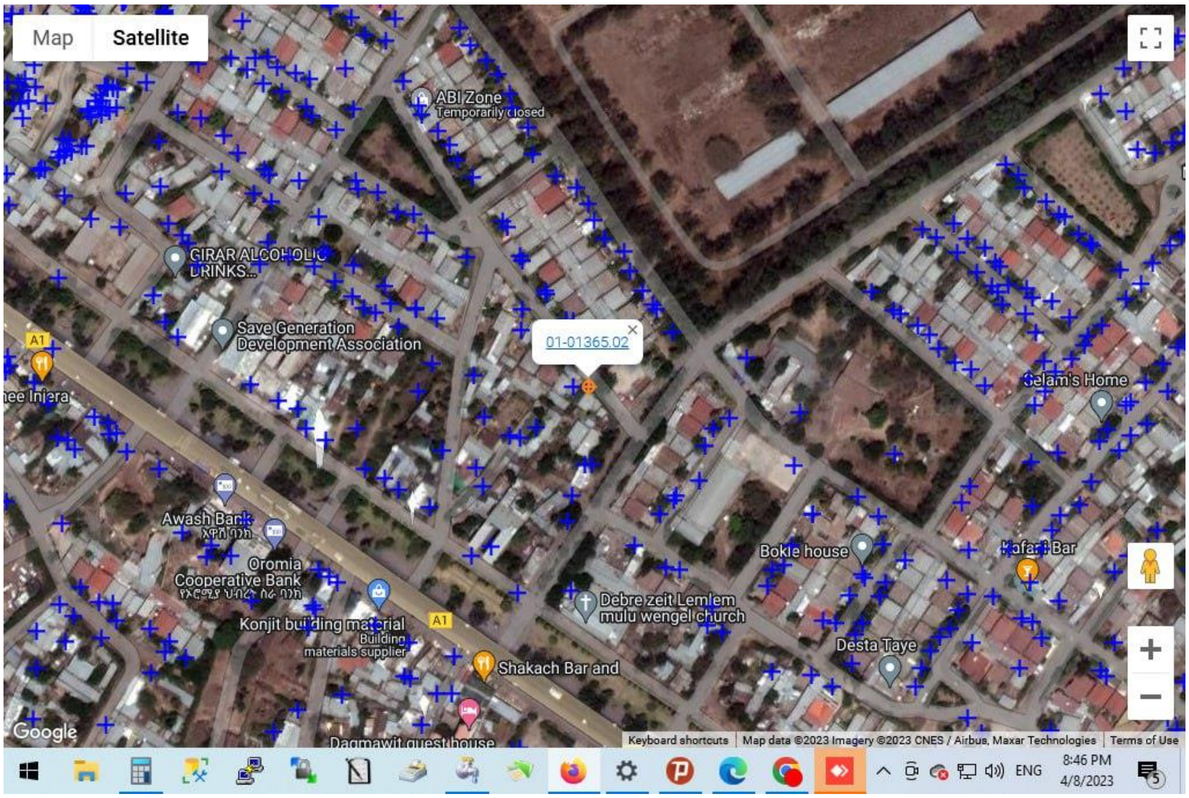


Figure 12: House hold connection GPS locations (Source: BTWSSE)

3.6.6 Analysis of the Distribution Network

The distribution network analysis was conducted using WaterJEMS V8i software by building distribution system model. The analysis was model based using model equations or empirical formulas. Hazen–Williams equation was used for this research since this equation is commonly used in water supply pipe network analysis. By simulating this model, hydraulic parameters like pressure & velocity in the system were computed. The hydraulic performance of the water supply distribution network was evaluated by comparing these hydraulic parameters with design criteria of distribution network. From analysis, areas of high or low pressure zone and flow velocity were identified by determining the nodal pressure and pipe flow velocity.

3.6.7 Pressure and velocity in distribution system

Mainly these hydraulic parameters were determined by simulating the model. The pressure at a node depends on the adopted minimum and maximum pressure within the network, topographic circumstances, and the size of the network. The static pressure in the distribution piping system is the pressure head in the network is equal to the height to which the column of liquid could be raise (Swamee P.and Sharma A., 2008). The value of maximum and minimum adopted pressure may not be the same for cities (towns) and can be found in local design guidelines. Most designer use 15m water column as minimum nodal pressure, the reason for this is that most residential buildings are two stories.

The MoWR water supply design criteria (2006 E.C) recommended the pressure range in distribution system to be 15-60m water head.

Adopted optimum operating pressure for this study was used to evaluate system hydraulic performances.

- ✓ The minimum pressure at peak hour demand 15m of water column (15mwc) was required to serve up to two stories high.
- ✓ Maximum pressure adopted during low demand periods was 60m of water column (60mwc).

Velocity is other hydraulic parameter which can affect hydraulic performance of distribution system. For this study velocity standard given by MoWR water supply design criteria (2006 E.C) was used to compare model output velocity because of it works at country level. Minimum velocity 0.6m/s and maximum velocity of 2m/s was used.

3.6.8 Steady State Simulation analysis

The model was analyzed in steady state simulation analysis for the average daily demand, which is the demand at every node not changing throughout 24 hours of a day. Steady state analysis determines the operating behavior of the system at specific point in time or under steady state conditions (flow rates and hydraulic grades remain constant over time).

3.6.9 Extended period simulation (EPS) analysis

In reality, steady state or constant boundary condition is not common. Therefore, to analyze pressure and flow velocity change in the system in response to variable demand and supply, EPS was mainly used. Under EPS, the status of the system at every 24 hours was determined and evaluated.

The model simulation have been computed over twenty-four hours with a specified time increment of one hour and starting model run time at 12:00 AM. The software simulates dynamic hydraulic calculation for variable demands based on mass and energy conservation principle.

The model was simulated for every one-hour time setup in the twenty-four hour duration. However, for the analysis the peak and minimum hours demand have been simulated to identify the current problems of the system and then to redesign the model based on the design criteria of the water distribution system.

3.6.10 Model Calibration and Validation

After the first run, the model was calibrated using **Darwin calibrator** by adjusting sensitive parameters related with flow; like pipe roughness coefficient and water demand until it becomes within the acceptable limit. Therefore, for this study the model data quality was analyzed by comparing and calibrating the computed pressure data with the actually measured one. Pressure readings were taken at specific time using pressure gauge from 10 sample points for calibration and 10 samples for validation.

Once the first simulation run is completed the immediate concern is whether the results match the reality. Several runs have to be executed to confirm that:

- The model gives a logical response to any altering input data (model validation)
- The model’s behavior corresponds to the reality (model calibration) For model calibration and validation effort data were collected from field visit. Calibration data includes: nodal elevation, pipe diameter (pipe size), material types.

For this study pipe roughness was taken as model parameter to be adjusted. Model accuracy can be evaluated using pressure criteria. Lingereddy (1997) showed that the most common criteria are absolute pressure difference or relative pressure difference. In most cases relative pressure difference criteria is preferred.

The acceptable level of pressure criteria has been presented by Lingireddy (1997) as follows: 1. 85% of field test measurements should be within ±0.5m or ±5% of the maximum head loss across the system, whichever is greater. 2. 95% of field test measurements should be within

±0.75m or ±7.5% of the maximum head loss across the system whichever is greater 3.1% of field test measurements should be within ±2m or ±15% of the maximum head loss across the system, whichever is greater. Sampling sites the water supply office of the town uses two pressure zones for the sake of water distribution management. Based on the pressure zones ten representative sample nodes were selected for calibration.

For the calibration, the head loss between sample main nodes and the site where pressure was measured has been considered which include only the elevation head. Pipe friction loss has been ignored since the distance between the points was 10-20m and friction losses were insignificant.

3.6.11 Hydraulic parameter calculation

The main hydraulic parameters in water distribution networks are the pressure and the flow rate, other relevant design factors are the pipe diameters, velocities, and the hydraulic gradients. The performance of the distribution system was evaluated by comparing model output hydraulic parameters with design criteria of distribution network.

3.6.12 Modify the distribution network

After analyzing and identifying the distribution network problems, the model was modified by adjusting the following parameters.

- By Providing pressure reducing valves (PRV) to reduce pressure
- By applying alternative pipe connections to nodes
- By increase or decrease pipe diameter
- And improve pumps operation time

3.8 User Satisfaction

3.8.1 Sample size determination

The sample size was determined by using 76% of urban population have access to water supply, and taking 5% marginal error and 95% Confidence interval and with a non- response rate of 10%, the actual sample size for the study will be calculated by using the formula for single population proportion:

n= (z) 2 p(1-p)/w2

Where: n- Sample size

Z= 1-a/2, 1.96 at 95% confidence interval

P= the proportion of the target population estimated to have particular characteristics

W= margin of error .05 (5% expected deviation from the estimated Proportion).

Therefore: n = (1.96)2 0.76(1-0.76)/(0.05)2

= 280

Adding 10% for non-response rate the final sample size will 308 which is the minimum sample size.

Sampling procedure

The calculated sample size will proportionally allocated to each kebeles in Bishoftu city based on the number of house hold .To select study subjects from each kebeles, systematic random sampling will be applied by using household registration number found in each kebeles.

First skip interval (k^{th}) will be calculated, then random point will be determined. Beginning at starting point every (k^{th}) unit registered household number will be taken from registration until the needed sample size will be achieved.

$$K = \frac{N}{n} = \frac{23,000}{308}$$

K = 74

kebeles	Total HH	Proportional allocation
K-01	10,972	n1=308*10972/23,000= **147**
K-02	2,185	n2=308*2185/23,000= **29**
K-03	738	n3=308*738/23,000= **10**
K-04	357	n4=308*357/23,000= **5**
K-05	1,724	n5=308*1724/23,000= **23**
K-06	410	n6=308*410/23,000= **5**
K-07	235	n7=308*235/23,000= **3**
K-08	548	n8=308*548/23,000= **7**

K-09	377	n9=308*377/23,000= **5**
K-10	467	n10=308*467/23,000= **6**
K-11	432	n11=308*432/23,000= **6**
K-12	1,681	n12=308*1681/23,000= **23**
K-13	369	n13=308*369/23,000= **5**
K-14	450	n14=308*450/23,000= **6**
K-15	2,055	n15=308*2055/23,000= **28**
Total HH	23,000	**N=308**

3.8.2 Sample Analysis

By using this sample size in each kebele the data was collected in all as per the specification and required protocol. Finally all the data organized and entered to stat software to undertake the analysis of the satisfaction of population on the existing water supply for Bishoftu town.

4 Result and Discussion

4.1 Overview

The study's primary findings are covered in details and discussed in this section. By contrasting model results with MoWR's standard design standards and technical indicators used in the water supply design sectors, the hydraulic performance of the distribution system was assessed.

4.2 Population forecasting

The study area's population was collected from the design document done in 2017 during the development of the town's improved water delivery system. Based on the fact that the Ethiopian Central Statistical Agency's housing census report from 2007 was used to estimate the population, the growth rates are displayed in the table below.

Table 11: population forecast growth rate source: Population growth rate for the towns (Ministry of water, 2006 E.C)

Year	**Urban population growth rate**
2010-2015	3.88
2015-2020	3.69
2020-2025	3.51
2025-2030	3.35

Using the Geometric progression method the population had been projected up to the end of 2033. Accordingly the population of the current year 2023 estimated to be **410,158** and **561,761** by **2033.** The study used the current estimated population to evaluate the current water system performance.(see table 12 below)

Table 12: Population projection detail Calculation

Bishoftu Town water supply and sewerage Enterprise						
Population projection from 2017 - 2033						
Pop. N. (3.69 - 3.35% yearly increase)						
Year	**Bishoftu Town**	**Kajimana Dibayu kebele**	**Kurkurana Dembin kebele**	**Industry Workers**	**Total**	Pn = Po (1+r) n
2017	280000	8660	5599	43907	338166	
2018	290332	8980	5806	43995	349113	
2019	301045	9311	6020	44083	360459	
2020	312154	9655	6242	44171	372222	
2021	323672	10011	6472	44259	384414	
2022	335615	10380	6711	44348	397054	
2023	**347999**	**10,763**	**6,959**	**44437**	**410,158**	**Current year**
2024	360214	11160	7216	44526	423116	
2025	372858	11552	7469	44615	**436494**	
2026	385945	11957	7731	44704	450337	
2027	399492	12377	8002	44793	464664	
2028	413514	12811	8283	44883	479491	
2029	428028	13261	8574	44973	494836	
2030	443052	13726	8875	45063	510716	
2031	458603	14208	9187	45153	527151	
2032	474700	14707	9509	45243	544159	
2033	**491362**	**15223**	**9843**	**45333**	**561761**	

Based on the base population data of 2017 and CSA growth rates established at national level for every 5 years interval the current population of Bishoftu town is found to be about **410,158** and **561,761** for 2023 and 2033 respectively. Hence, Bishoftu town water demand had been estimated based on the finding of this projection.

4.3 Demand projection

Water demand forecast was carried out using predicted demographic statistics and information on daily water consumption per capita that was established by MoWR in 2014. Using this information, the table below shows the results of calculations for average water demand, peak hour water demand, and maximum water day demand from 2017 to 2033.

The result shows that the average water demand, maximum water day demand, and peak hour water demand are **18,581m^3/d**, **22, 298 m^3/d**, and **31,588 m^3/d** respectively. Detail calculation of water demand was done based on projected number of population starting the year 2017 as baseline, no of population by mode of service, average water demand based on categories, and factor adjustment. Accordingly the following table show detail step done to estimate water average demand, demand at maximum day demand, and peak demand.

Summary of Domestic Average water Demand

Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031		2032		2033
Projected no of population	338,166	349,113	360,459	372,222	384,414	397,054	**410,158**	423,116	436,494	450,337	464,664	479,491	494,836	510,716	527,151		544,159		561,761
% of population by mode service:																			
							3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90		3.90		3.90
							95.81	95.81	95.81	95.81	95.81	95.81	95.81	95.81	95.81		95.81		95.81
							0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29		0.29		0.29
No of population by mode service:							**15,983**	16,488	17,010	17,549	18,107	18,685	19,283	19,902	20,542		21,205		21,891
							392,965	405,380	418,198	431,460	445,187	459,392	474,094	489,308	505,055		521,350		538,214
							1,209	1,247	1,287	1,328	1,370	1,414	1,459	1,506	1,554		1,604		1,656
							410,158	**423,116**	**436,494**	**450,337**	**464,664**	**479,491**	**494,836**	**510,716**	**527,151**		**544,159**		**561,761**
% of Average water demand by level of servic																			
	70	71	73	74	76	77	**79**	80	82	84	85	87	89	91	92		94		96
	30	31	31	32	32	33	**34**	34	35	36	37	37	38	39	40		40		41
	40	41	42	42	43	44	**45**	46	47	48	49	50	51	52	53		54		55
Average water demand by service type (m3/d)																			
							1,260	1,326	1,395	1,468	1,545	1,626	1,712	1,802	1,897		1,998		2,104
							13,276	13,970	14,700	15,469	16,280	17,136	18,038	18,989	19,992		21,050		22,166
							54	57	60	63	67	70	74	78	82		86		91
Total Average water demand by service type (							**14,591**	**15,353**	**16,155**	**17,001**	**17,892**	**18,832**	**19,824**	**20,869**	**21,972**		**23,134**		**24,360**
water leakage and wastage adjustment factor							**25%**	25%	25%	25%	25%	25%	25%	25%	25%		25%		25%
Socio-economic adjustment factor							**1.05%**	1.05%	1.05%	1.05%	1.05%	1.05%	1.05%	1.05%	1.05%				
Climatic adjustment factor							**1.30%**	1.30%	1.30%	1.30%	1.30%	1.30%	1.30%	1.30%	1.30%				
Total Average water demand(m3/d)							**18,581**	**19,552**	**20,573**	**21,650**	**22,786**	**23,983**	**25,246**	**26,577**	**27,981**		**28,918**		**30,450**
Total Average water demand(l/sec)							**215**	**226**	**238**	**251**	**264**	**278**	**292**	**308**	**324**		**335**		**352**
Maximum day factor							**1.2**	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2		1.2		1.2
Peak hour factor							**1.7**	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7		1.7		1.7
Maximum day Demand(MDD) (m3/d)							**22,298**	**23,462**	**24,688**	**25,980**	**27,343**	**28,780**	**30,295**	**31,892**	**33,577**		**34,701**		**36,540**
Peak hour Demand(PHD) (m3/d)							**31,588**	**33,238**	**34,975**	**36,805**	**38,736**	**40,771**	**42,918**	**45,181**	**47,568**		**49,160**		**51,765**

4.4 Water Production and Consumption

The study data shows that all the existing boreholes can deliver up to **556l/sec** while the current operation report shows the boreholes are delivering up to **414l/sec**. Due to different reasons the enterprise has been used low capacity pumps which is less than the design capacities of the boreholes. One of the main reason is unavailability of required pumps on in the country market. Out of twenty **two/22/** about **73%/16BH/** found to be functional and the remaining **six/06/** being non-functional as the assessment made during the study time. Besides operation and on time maintenance being a major problem of the utility.

The existing system used various pump capacities ranging from **5.5kw – 110kw** pump capacity to impart energy to the water in order to boost it to higher elevations/reservoirs/ or to increase pressure in the distribution lines as the case of Bishoftu Town WSS. The distribution system of Bishoftu Town used a mixed supply from borehole and balancing reservoirs, and hence the existing pump considered to model the existing.

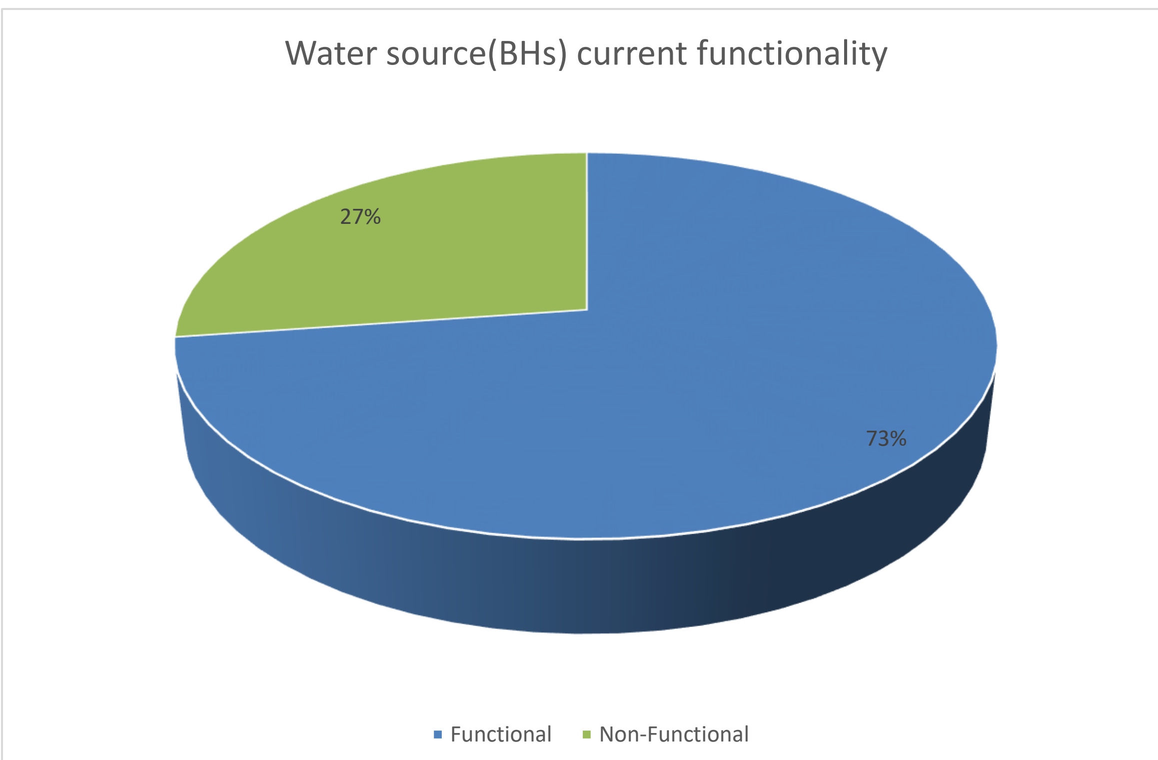


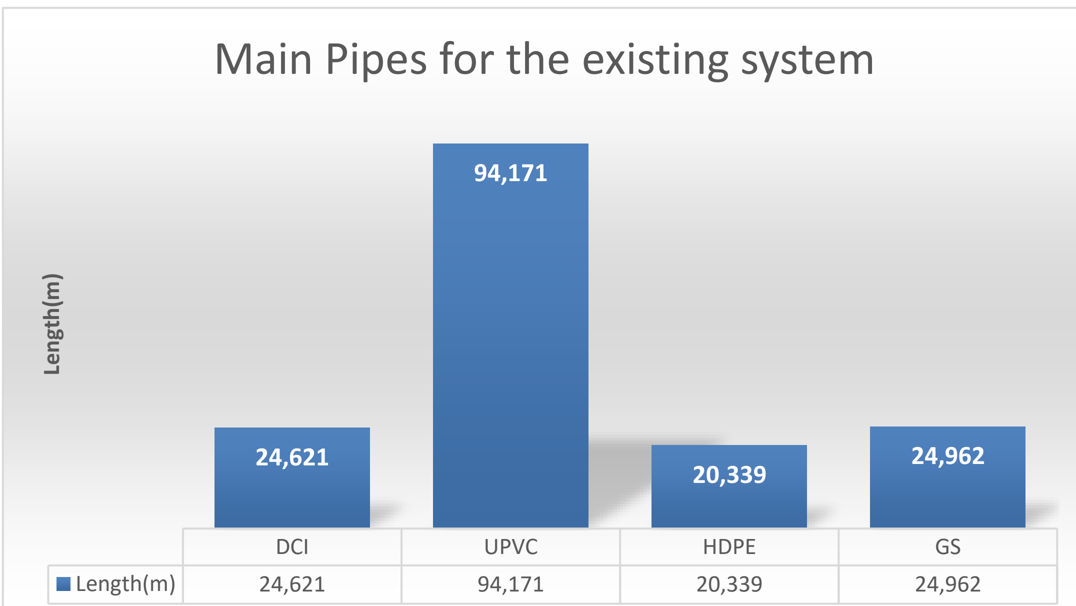
Figure 13: Water source current status (source BTWSSE)

4.5 Storage Reservoir

Bishoftu Town water supply system has got **seven/07/** different water storage balancing reservoirs. The maximum capacity of the reservoir is **1000m^3** and the minimum volume is **500 m3**. Based on the size, the number of existing reservoirs are **04/four/ 1000m^3**, **02/Two/ 500 m^3** and **01/one/ 200 m^3**. The utility had been using these reservoir to supply adequate amount of water to the beneficiaries. The total Capacity of the reservoirs found to be **5200 m^3**. During this time 06/five of the reservoir are functional and the 01 is under construction to connect to the system. The storage reservoir connected to water supply system in looping system.

4.6 Existing pipelines

Bishoftu town is a big town where the water supply system encompasses hundreds of km of water distribution system. According to the assessment and gathered information from secondary source a total of **164,093m** of pipe laid in the town. Out of these **24,621m DCI**, **94,171m UPVC**, **20,339m** of **HDPE**, and **24,962m** of GS pipes had been installed for the WSS.



4.7 Current WSS mode of service

Bishoftu town has been delivering water in different ways. The current system being delivering through Yard connection, House connection, and shared connection. Below table 13 show the current number connection. The study it shows that about 96% of the population used house hold connection and the rest 4% population got water from Yard and shared connection.

Table 13: Mode of service (Source BTWSSE)

Percentage of population by Mode of service for 2023			
S.no	**Connection type**	**Total Connection**	**% of Population by mode of service**
1	Yard connection	1454	3.90
2	House connection	35748	95.81
3	Shared connection	110	0.29
		37312	**100**

According to the enterprise, the current percentage of people using a house connection is **95.81%**, yard connection **3.90%,** and shared connection is **0.29%.**

4.8 Water Supply Coverage

More than one in four persons in the developing countries do not have access to clean water, according to the WHO/UNICEF Joint Monitoring Program (WHO/UNICEF 2004). The second development and transformation plan (GTP-2) for the years 2016 to 2020 seeks to reach a 75% coverage rate for urban water supplies.

The number of persons who have access to water can be estimated with the use of water supply coverage measurements. People's or families' access to a water supply can be used to measure it.

Using equation below the annual water coverage of Bishoftu town has been calculated as follows;

$$\boldsymbol{annual\ water\ supply\ coverage}_{(\boldsymbol{Year2023})} = \frac{\textbf{Annual Production}}{\boldsymbol{Annual\ Demand}} \times \mathbf{100}\%$$

$$\boldsymbol{annual\ water\ supply\ coverage}_{(\boldsymbol{Year2023})} = \frac{\mathbf{9{,}791{,}928}\boldsymbol{M}^{\mathbf{3}}}{\mathbf{11{,}529{,}620}*\mathbf{365}\boldsymbol{M}^{\mathbf{3}}} \times \mathbf{100}\% = \mathbf{84.9\%}$$

From the above calculation, the current water production needs to be increased by the 17% to full fill the demand.

On the other hand water supply coverage of the town can also calculated by using amount of water consumed and level of connection. As per the assessment done the current population of Bishoftu town has been estimated to be **410,158** and water consumed **18,396 m^3/d**.

Hence, the current per capita consumption can be calculated by using annually water consumption report for year 2020. The value is for both domestic and non-domestic water demand.

$$per\ capital\ consumption(l/c/d) = \frac{annual\ consumption(m^3) \times 1000L/m^3}{population \times 365}$$

$$per\ capital\ consumption\left(\frac{l}{\frac{c}{d}}\right) = \frac{6{,}714{,}540(m^3) \times \frac{1000L}{m^3}}{410{,}158 \times 365} = \mathbf{44.85}$$

- From the report 2020 annual consumption recorded **6,714,540m^3**
- Annual production **9,791,928m^3**

Unaccounted for water (NRW) = ***Total Annual production – Total Annual water consumption recorded***

= 9,791,928 m3 – 6, 714,540 m3 = **<u>3,077,388</u> m3**

From the finding above about 31.4% of the water wasted in the system.

4.9 User Satisfaction

This study compromises the evaluation of general satisfaction of the resident of Bishoftu town by undertaking data collection by use of prepared questionnaires for the purpose.

The respondent rate was 100%. Among the study participant of 308, 209 (67.86%) were female and 99 (32.14%) were male. According to the finding of this study the mean age of respondent was 31.72 with standard deviation of 7.88 and the average family size is 4.30 with standard deviation 1.29. The finding from this showed that more than half of the respondents 171(55.52%) are job holders and about one third have some kind of business as their source of income.

Educational level	Frequency	Percent (%)
illiterate	3	0.97
Able to read and write	6	1.95
Primary school	42	13.64
Secondary school	108	35.06
Above grade	149	48.38
Sex		
Male	99	32.14
Female	209	67.86
Source of income		
Business or peaty trade	106	34.42
Farming	9	2.92
Daily labor	17	5.52
Job holder or government employer	171	55.52
Retired if other specify	5	1.62

According to the finding this study, the overall satisfaction level on the existing water supply system about 88(28.57%) were satisfied, 129 (41.88%) were neutral and 91(29.55%) were unsatisfied.

The result of study showed that among the households who received adequate quantity of water 83(47.70%), 66 (37.96) were satisfied and neutral respectively, and of those who do not have adequate water supply 63(47.01%) were neutral and 66(49.25%) were unsatisfied. About 25(14.37%) were for other unsatisfied with water service for other reasons. About 83(29.43%) were satisfied and 117(41.49%) were neutral regarding the quality of water they receive and 9(34.62%) were unsatisfied with quality of water.

Concerning the continuity of water supply, more than half of the individuals 165(57.58%) receive water twice daily; off those house hold who have continuous water supply 19(54.55%) were satisfied, 12(36.36%) were neutral and only 2(6.06%) were unsatisfied. On the other hand among the households who have interrupt water supply 88(28.57%), 129(41.88%) and 91(29.55%) were satisfied, neutral and unsatisfied respectively.

Regarding the satisfaction level on water service payment about more than two third of the individuals 235(76.30%) were neutral, 43(13.96%) were satisfied and only 30(9.74%) were unsatisfied.

The result from chi square test showed that the quantity of water the house hold receive, continuity of water supply, water service payment and educational level of the respondents have association with customers satisfaction level with existing water service system at p -value of 0.000,0.000,0.032 and 0.002 respectively. While source of income, quality of water they receive, gender and family size don't have association with overall satisfaction level of customers.

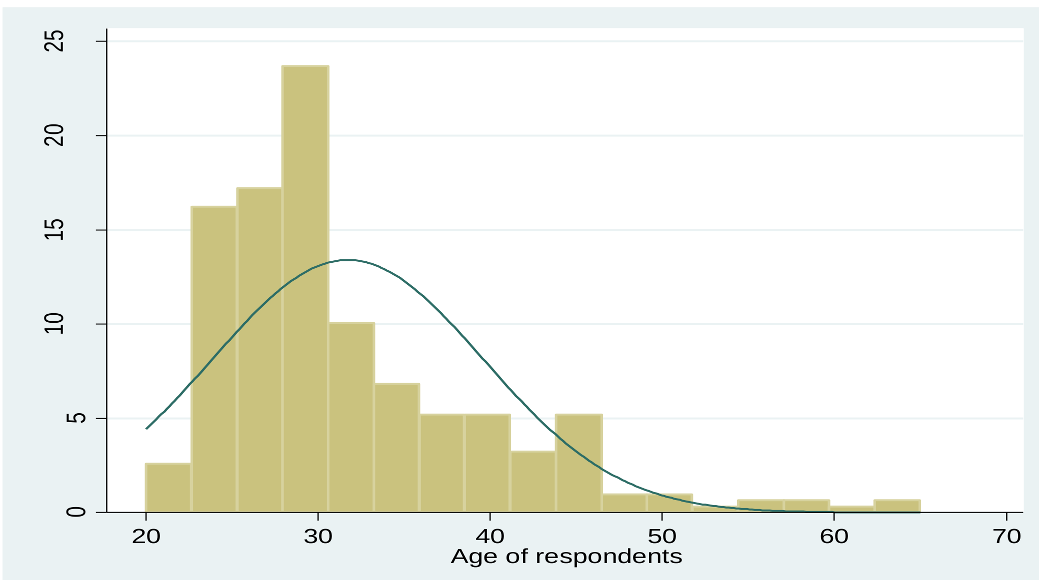


Figure 14: percentage of respondent by ages

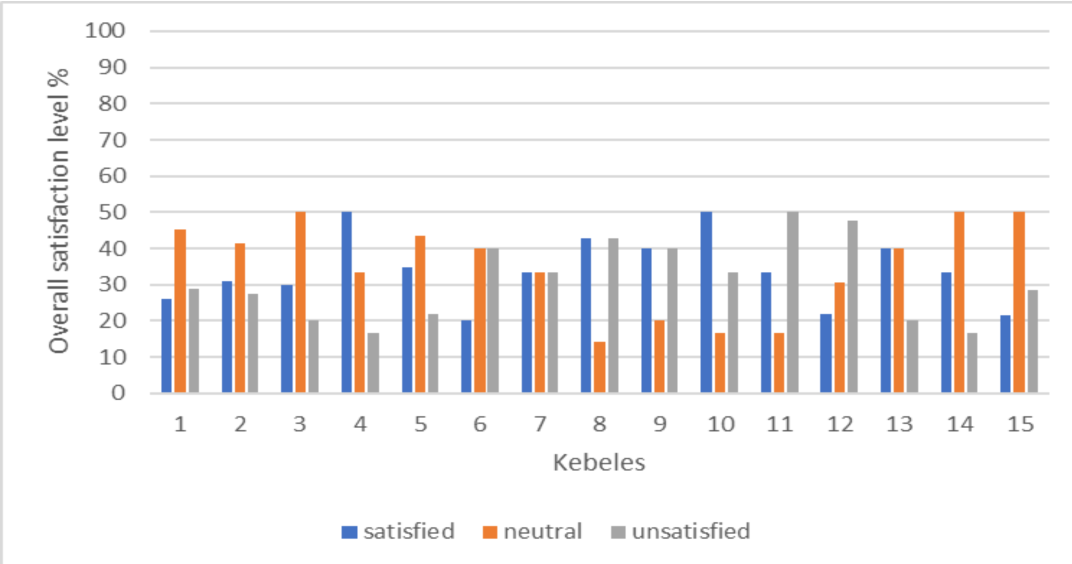


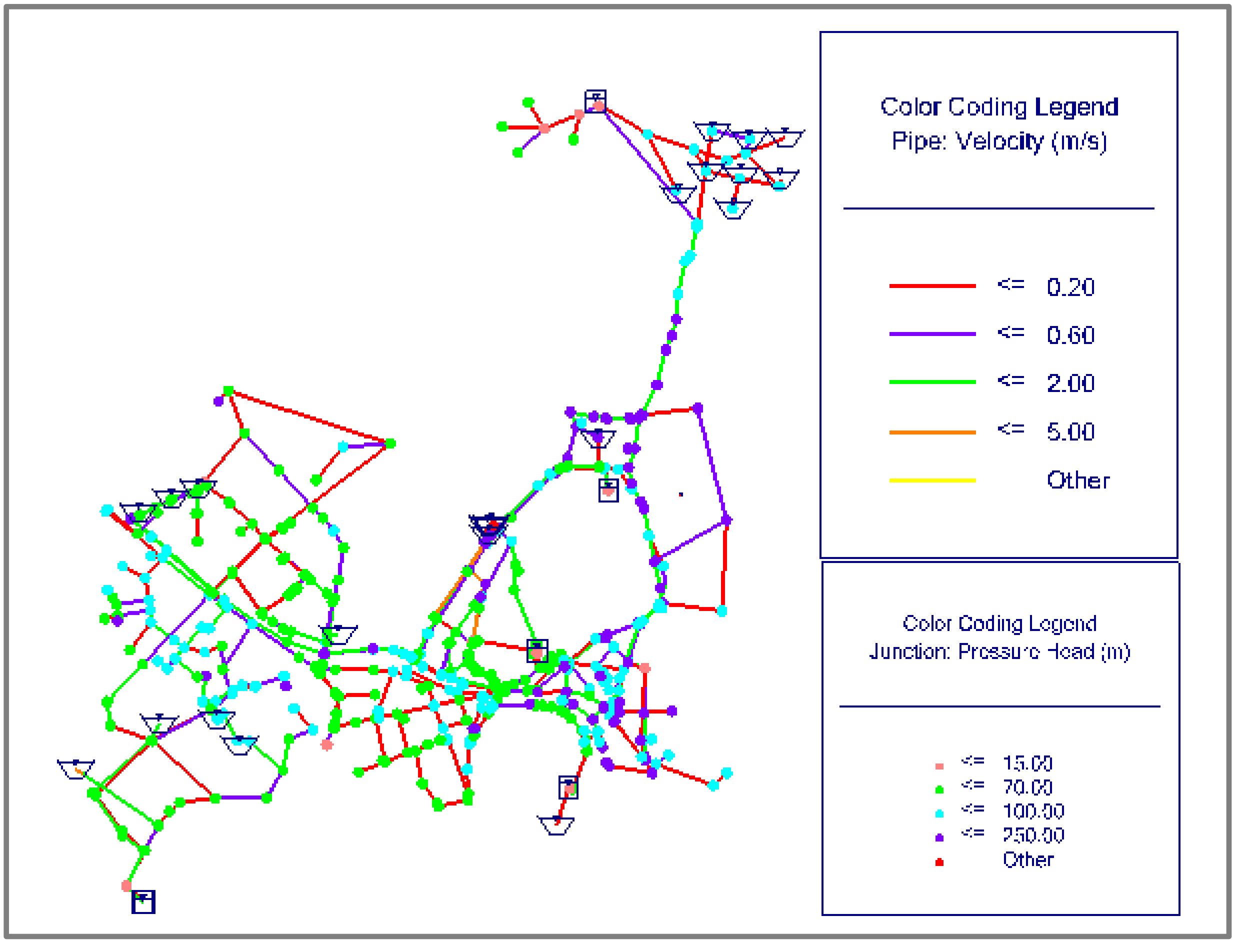
Figure 15: Satisfaction level of population Bishoftu town (Source BTWSEE)

4.10 Water Distribution system Modelling

During the study, it was possible to examined the level of pressures and velocity inside the distribution system and determine the carrying capacity of the current system with the use of modeling. One can determine whether or not the system is sustainable for the intended design time by using the model's output results.

The system conditions has been evaluated for year 2023 on average daily water demand and peak hourly demand. The model includes 514 junctions, different size and type of pipes and seven/**07**/ tanks. The pipes types includes DCI, uPVC, HDPE, and GS. The minimum diameter of the main pipe is GS 80mm and the maximum pipe size in system is found to be 600mm DCI. For steady state condition of the system the result obtained using water WATERJEMS software analysis shows that only **47.43%** of the node pressure is within range recommended **(15m- 70m)**

Pressure head and **24.45%** of pipes were experienced flow velocity of 0.6m/s – 2m/s. overall the system of Bishoftu town is suffering from high pressure head and low flow velocity for steady state condition. The configuration of the system were found to be a looping system and it operated with a mixed operation direct pumping and gravity system. This allow the system to be pressurized above the allowable value and velocity of flow became very low due to looping system. The same scenarios had been observed for EPS simulation and detail result discussed in section 4.13 below.


Color Coding Legend
Pipe: Velocity (m/s)
<= 0.20
<= 0.60
<= 2.00
<= 5.00
Other
Color Coding Legend
Junction: Pressure Head (m)
<= 15.00
<= 70.00
<= 100.00
<= 250.00
Other

4.11 Model Calibration and Validation

4.11.1 Model Calibration

From the above model, information about pressure and flows are reported. After model parameters have been estimated, the accuracy of the model parameters can be assessed. This is done by executing the computer model using the estimated parametric values and observed boundary conditions and by comparing the model results with the results from actual field observation. .

On this research the distribution model contain 508 junctions. For the purpose of calibration moderate level of detail (5% of nodes/junction) sample taken. Sampling locations condition can normally be met either using data from fire flow tests or by collecting flow or pressure readings during periods of high stress (e.g. peak hour demand periods).. Sampling points should be at the extremities of the network, a considerable distance from the boundary nodes in the network (reservoirs and tanks), selected points should also have relatively high discharges and pressures and the actual values of the minimum distance from boundary nodes, minimum discharge, and minimum pressure are relative and unique to a given model.

To meet the location criteria sample locations are selected at upstream, downstream and middle point of the system and observation were taken at peak, average and minimum consumption hours. For the calibration, the head loss between the supply main nodes and the site where pressure is measured had been considered. The head loss included the elevation head and pipe friction loss between a two corresponding locations. These head losses and the total head loss are shown in table below.

Table 14: simulated pressure and measured pressure at selected nodes

Name	Time	Simulated model pressure (m)	Measured pressure at node (m)	Head losses between the two points (m)	Corrected measured pressure(m)	Error(m)
J_338	8:20	59.14	55	0.76	55.76	-3.38
J_345	9:20	66.64	63	0.8	63.8	-2.84
J_418	10:10	66.36	68	0.83	68.83	2.47
J_55	11:20	106.56	105	0.32	105.32	-1.24
J_45	12:10	155.03	152	0.21	152.21	-2.82

J_454	13:00	181.41	178	0.65	178.65	-2.76
J_226	14:10	95.64	90	0.98	90.98	-4.66
J_227	15:00	102.66	98	0.53	98.53	-4.13
J_235	16:10	140.39	145	-0.33	144.67	4.28
J_360	17:00	72.64	70	0.06	70.06	-2.58
J_231	18:30	93.45	95	1.47	96.47	3.02
J_453	19:05	149.91	147	0.69	147.69	-2.22
J_29	20:10	70.5	65	0.89	65.89	-4.61
J_375	21:00	58.52	53	0.92	53.92	-4.6
J_221	22:10	128.57	126	0.26	126.26	-2.31
J_164	23:00	106.68	104	0.1	104.1	-2.58
J_251	7:15	95.61	98	0.36	98.36	2.75
J_245	5:00	87.65	85	0.12	85.12	-2.53
J_499	6:00	64.84	64	0.49	64.49	-0.35
J_404	24:00:00	77.96	75	1.1	76.1	-1.86
					Average	**-1.60**

From the above simulation the average error (difference between model simulated pressure and filed measured pressure) reported (-1.6 m). The error is within the acceptable level of calibration which is under average level (to the maximum ±5m).

After calibration, the model was validated using correlation coefficient equation (R^2) and scatter plot of observed vs. simulated pressure.

4.11.2 Model Validation

After calibration, the model was validated using correlation coefficient equation (R^2) and scatter plot of observed vs. simulated pressure.

In this research correlation coefficient (R2) value is used for the validation. The correlation coefficient is a statistical measure of the strength of the relationship between the relative movements of two variables. The coefficient is computed by using Microsoft excel. In the Microsoft excel, filed observed pressure is considered as (x- axis value) and Simulated pressure as (Y-axis value).

If the computed R2 value range between 0 and 1 it indicate low variance error. The result of correlation value (R2) is presented in the figure 26 below.

From the above figures the result of the correlation value for both peak and minimum hour consumption indicate with in the acceptable standard. Therefore the calibration is well calibrated.

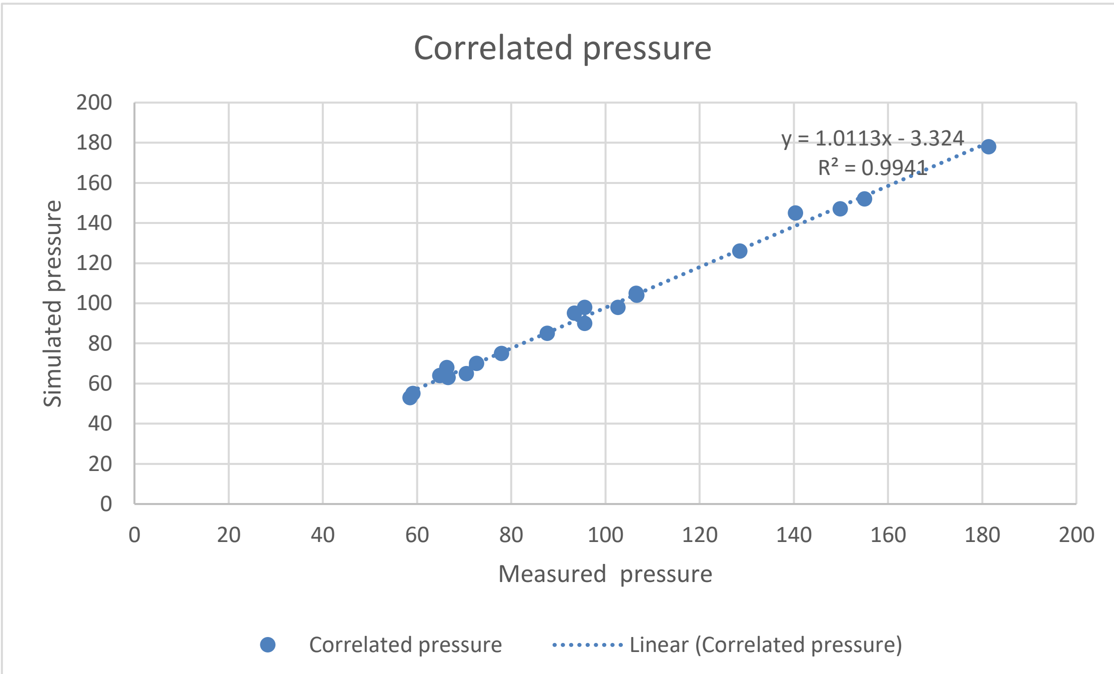


Figure 16: Simulated vs measured pressure

4.12 Pressure and Velocity of the existing distribution system

4.12.1 Pressure for steady state analysis

In Ethiopia, the distribution network's water velocity must adhere to design requirements that range from **0.6 m/s** to **2 m/s**. typically, the distribution network's operational pressure should range from **15m** to 70m of water head.

The analysis is carried out using the average daily water consumption. The figure 27 below displays a brief overview of the current performance of the distribution regarding pressure head and velocity in the pipe for Bishoftu town water supply system.

The model has been analyzed in steady state run for the average daily demand of 215l/sec, which is the demand at every node not changing throughout **24** hours of a day.

As shown in the figure 27 below nodes with red color represent pressure <=**15m H_2O**, nodes with green color show pressure in the range **15-70m**, nodes with blue-green color represent pressure **70 - 100mwc** and nodes with pink color represent pressure **with > 100mwc** .

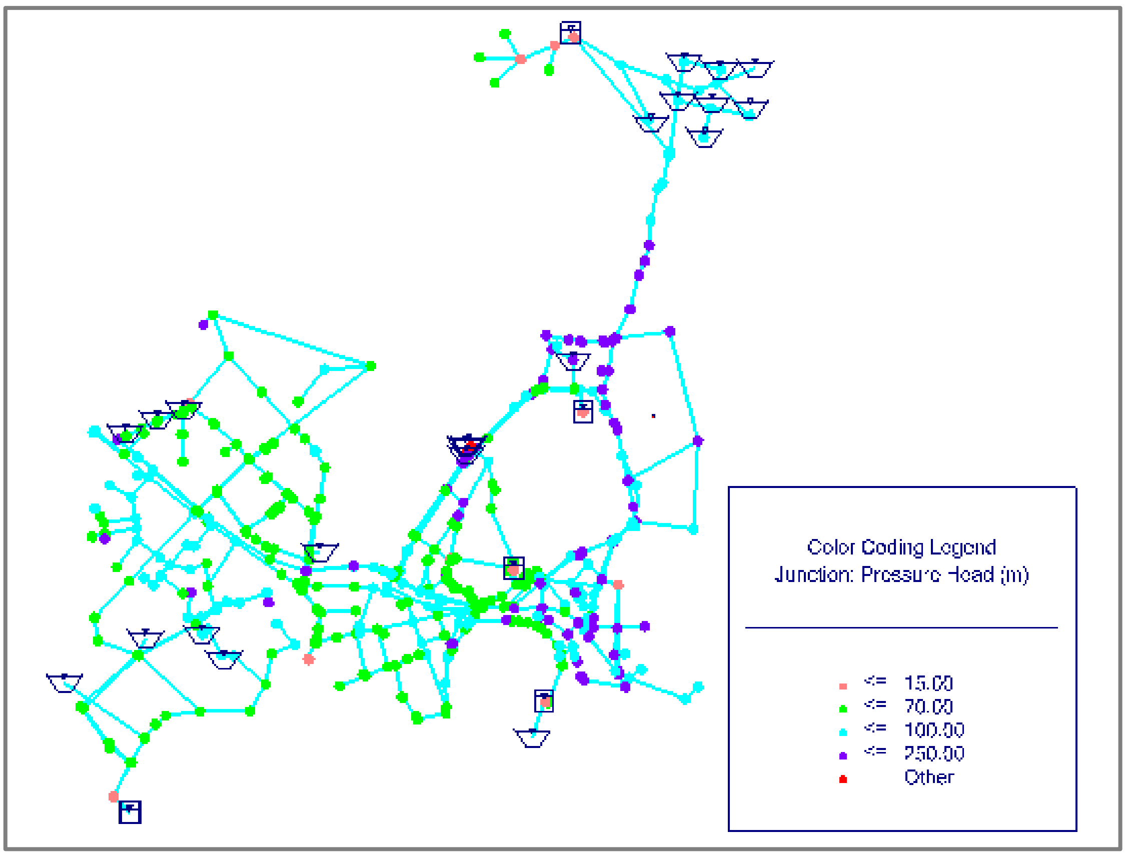


Figure 17: Pressure head illustration for steady state condition

From simulated result for steady state analysis; the following result were drawn as shown in

Accordingly, ***2.96% (15)*** nodes found to have pressure below 15m, ***47.43% (240)*** nodes have pressure range from 15 – 70m, ***49.61% (258)*** nodes experience the pressure above 70meters. Looping system of the existing reservoir and direct pumping to the distribution system had been the reason behind the increase in pressure of the system. This over pressurized system causes lots of **water losses** and **water quality deterioration** in Bishoftu town water supply system. There had been a clear criticism from the beneficiaries during our field work and surveying done for satisfaction on the existing system.

Pressure Category	**Percentage (%)**
< 15m	**2.96%**
15-70m	**47.43%**
70-100m	**33.40%**
>100	**16.21%**
	100%

4.12.2 Pipe flow Velocity

Velocity is another parameter to evaluate hydraulic performance of water supply distribution system. The minimum adopted velocity for this study is 0.6m/s and the maximum flow velocity to be 2m/s. during simulation of Bishoftu town water supply system the following result had been found under steady state condition. See ***table 16*** and ***figure 30*** below.

It has been found that the flow velocity of the existing system was not as per the design criteria set by the national ministry of water resource. Only about ***28.45%*** of the pipes showed the flow velocity is within the specifications and about ***71.55%*** of the pipes were out of the design criteria specifications. This research found out that the water supply system used a mixed system to distribute the water to the consumer through gravity and pumping system simultaneously and the network system is looping system. As the result the pressure developed in distribution system became very high and velocity of flow very low. This cause the deterioration of water quality on the existing system. This result in accumulation of silt in the distribution system. Even though silt removal system expected to be implemented in low service areas, there was no such infrastructures connected to the system and the problem became very serious in some area.

Table 15: Flow Velocity under steady state condition

Velocity Categories(m/sec)	Percentage (%)
0-0.19	**45.09%**
0.2-0.6	**28.45%**
0.7-2.00	**22.63%**
2.10-8.12	**3.83%**
	100%

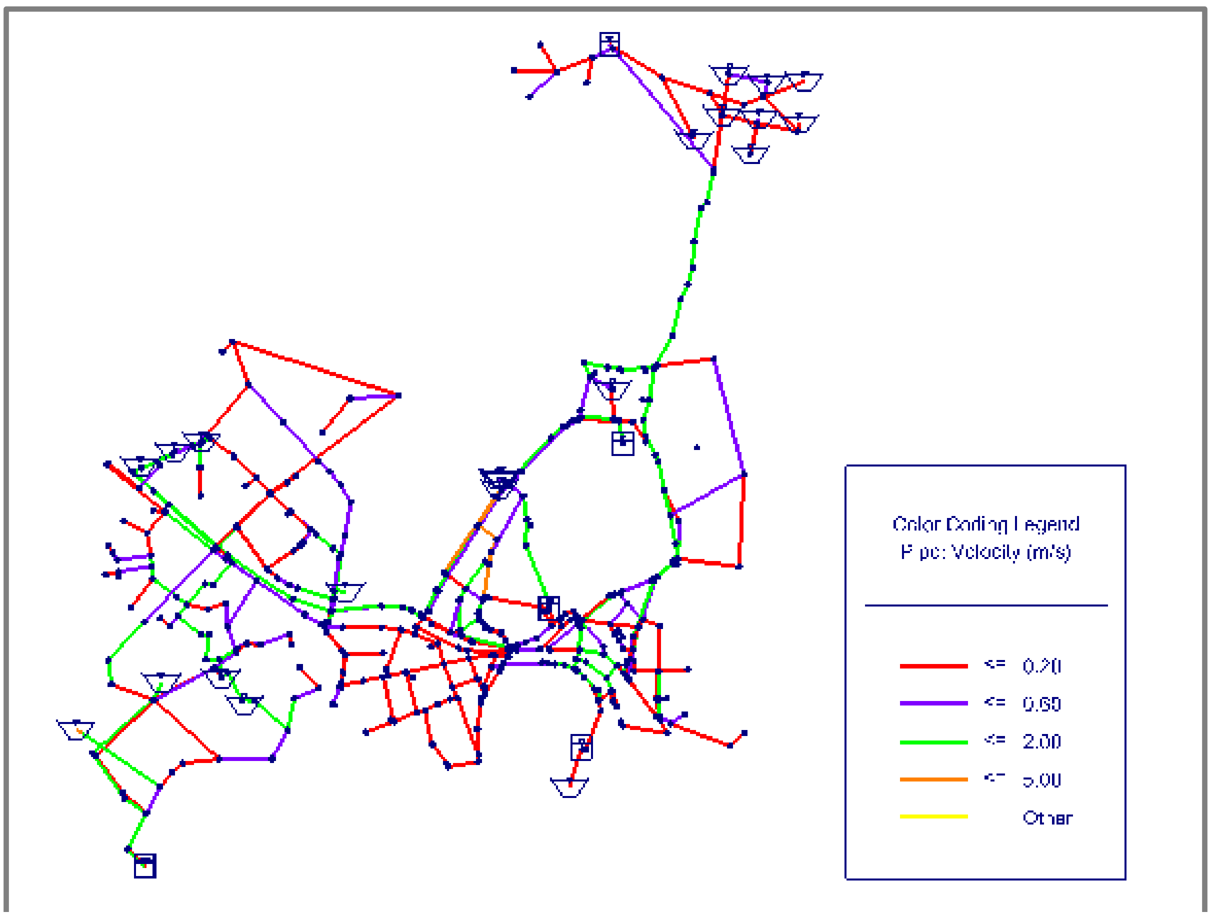


Figure 18: velocity status of existing water supply system in steady state condition

4.13 Pressure and velocity performance for extended period simulation

4.13.1 Pressure under EPS simulation

The extended period simulation analysis had been conducted using the by use of demand variation specifications set by ministry of water resource for towns in Ethiopia. Accordingly the analysis had been simulated based on the collected data, and specifications of ministry of water resource for town by use of WaterJEMSVi8.

The result showed that the maximum pressure was 421mwc at J-100 Cheleleka BH site and the minimum pressure has been observed in the distribution system with negative pressure -1.85mwc at J-477 and -4.66 at J-137. According to the analysis done for extended period simulation the following result had been observed for the whole system over 24 hours period of demand variation. The pressure in whole system found to be very high about **40.91%** of the node were within the national standard **15m – 70m** while the rest **55.93%** were greater than 70mwc and **3.16%** below 15mwc. As explained earlier for steady the situation is similar and the pressure head in the system remain high with extended period simulation in the distribution system even though it low compared steady state. Because of peak hour consumption the pressure had been reduced in some areas and being high during low consumption. The result shows that pressure reducing valve should have been implemented in some area to reduce the high pressure in the system; however there is no such infrastructures in Bishoftu case. As the result

- The water loss/leakage expected to very high
- The system requires high operation and maintenance cost due to breakage of pipelines.

Table 16: Pressure categories based on EPS analysis

Pressure Category(mwc)	Percentage (%)
< 15m	**3.16**
15-70m	**40.91**
70-100m	**31.62**
>100	**24.31**
	100

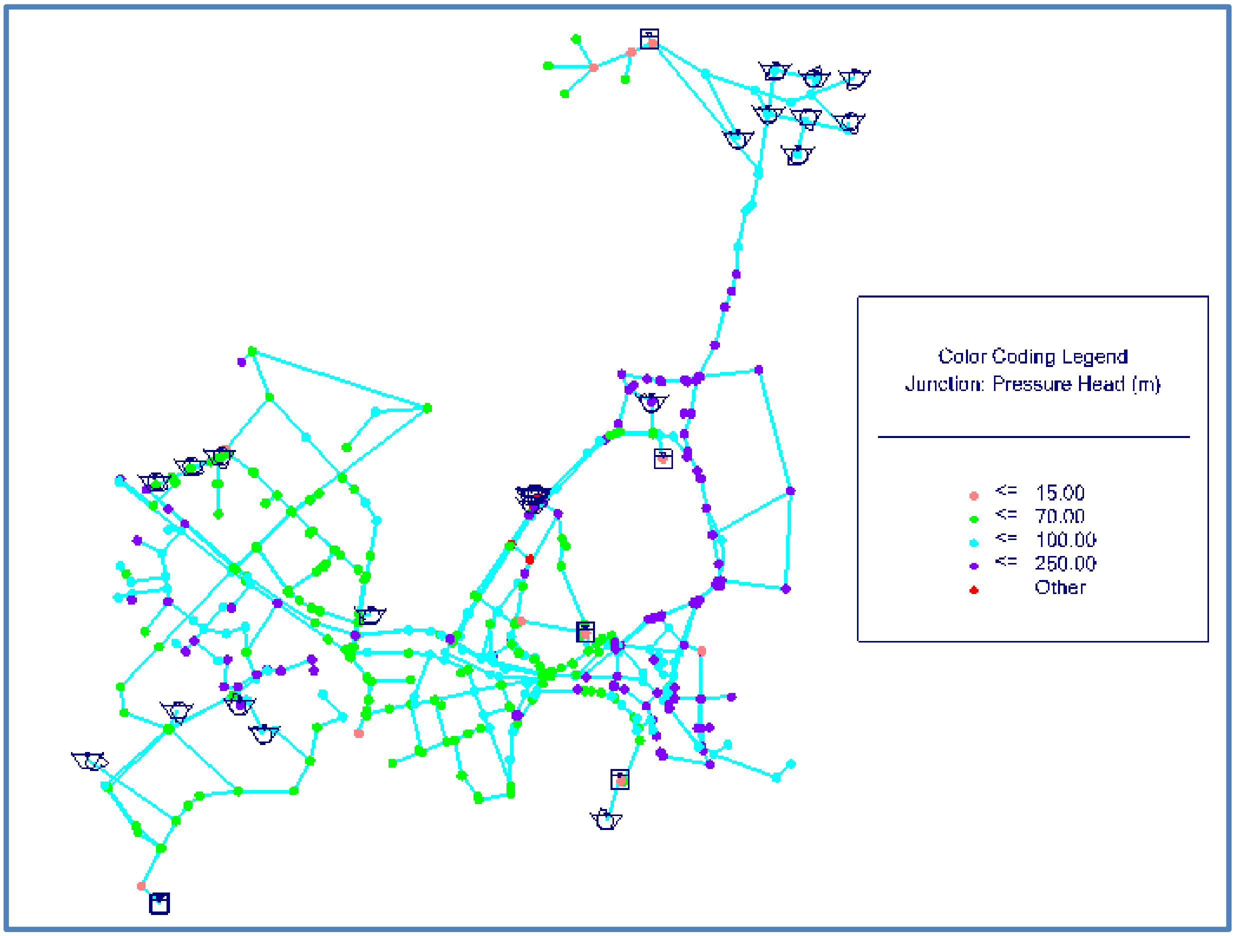


Figure 19: Layout of pressure performance based on EPS analysis

4.13.2 Flow velocity under EPS simulation

As per the analysis made under EPS condition the maximum velocity is found to be 6.82m/s in P-545 at high demand hours and the minimum velocity is 0.0 m/s. As indicated in fig. 33 Pipes with red color shows velocity with less than **0.20m/sec**, pipes with blue color shows the flow velocity is between **0.2- 0.6m/sec**, system with velocity range **0.6 – 2m/sec** designated with green color and light red color represent pipes with flow velocity of **2 -5m/sec**.

On the other hand about **51.17%** of the nodes acquired less than 0.19m/s of flow velocity, **24.50%** of the nodes acquired velocity ranging from 0.2m/s – 0.6m/s and **24.33%** of the nodes showed velocity of flow greater than **0.7m/s**.

Under EPS analysis even though percentage of velocity flow being out of range decrease the still the flow velocity out of recommended range which shows the flow velocity remain low as the pressure in the system is very high as the velocity result is inversely proportional to the pressure head in the system.

This scenario result in the following situations

- System infrastructures like pipeline life time will be reduced
- Population of Bishoftu town suffering from water quality issues
- The system requires high operation and maintenance cost due to breakage of pipelines.

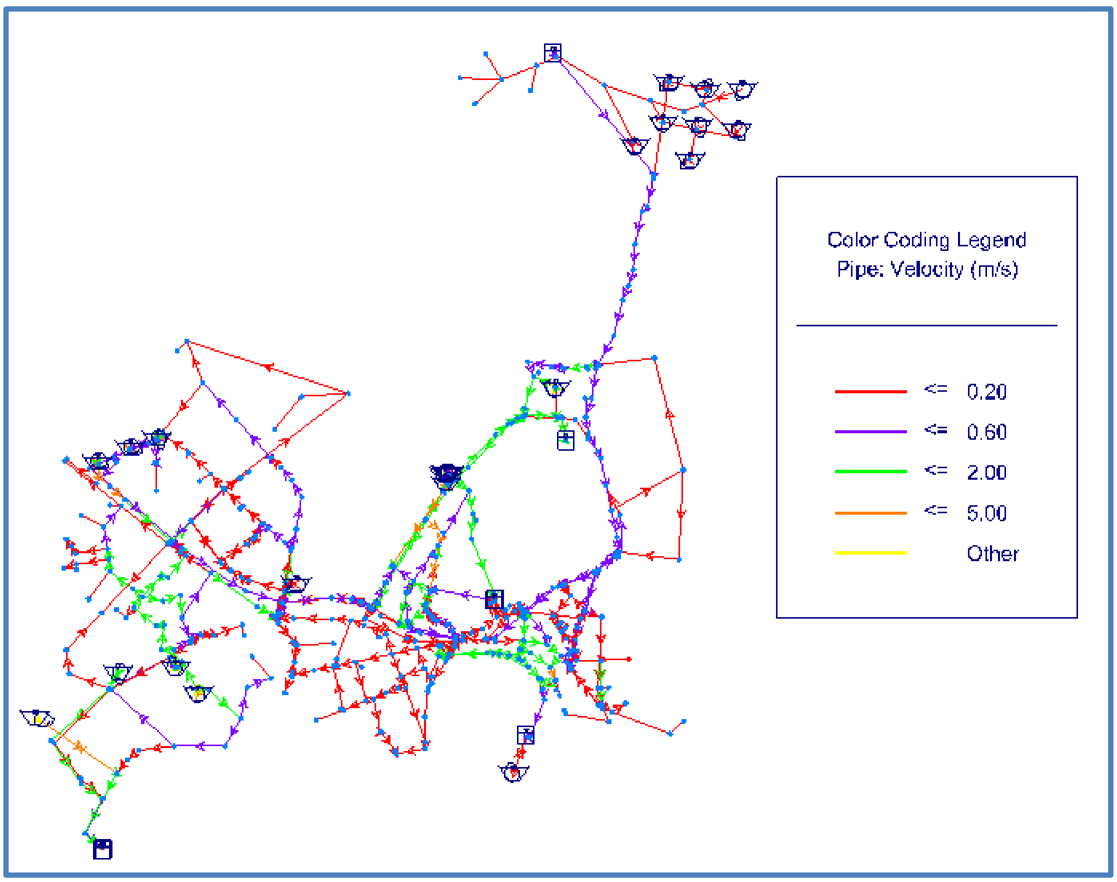


Figure 20: Flow velocity of the system under EPS condition

Table 17: Percentage of velocity categories under EPS conditions

velocity categories	Percentage (%)
0-0.19	**51.17**
0.2-0.6	**24.50**
0.7-2.00	**19.50**
2.10-6.82	**4.83**
	100

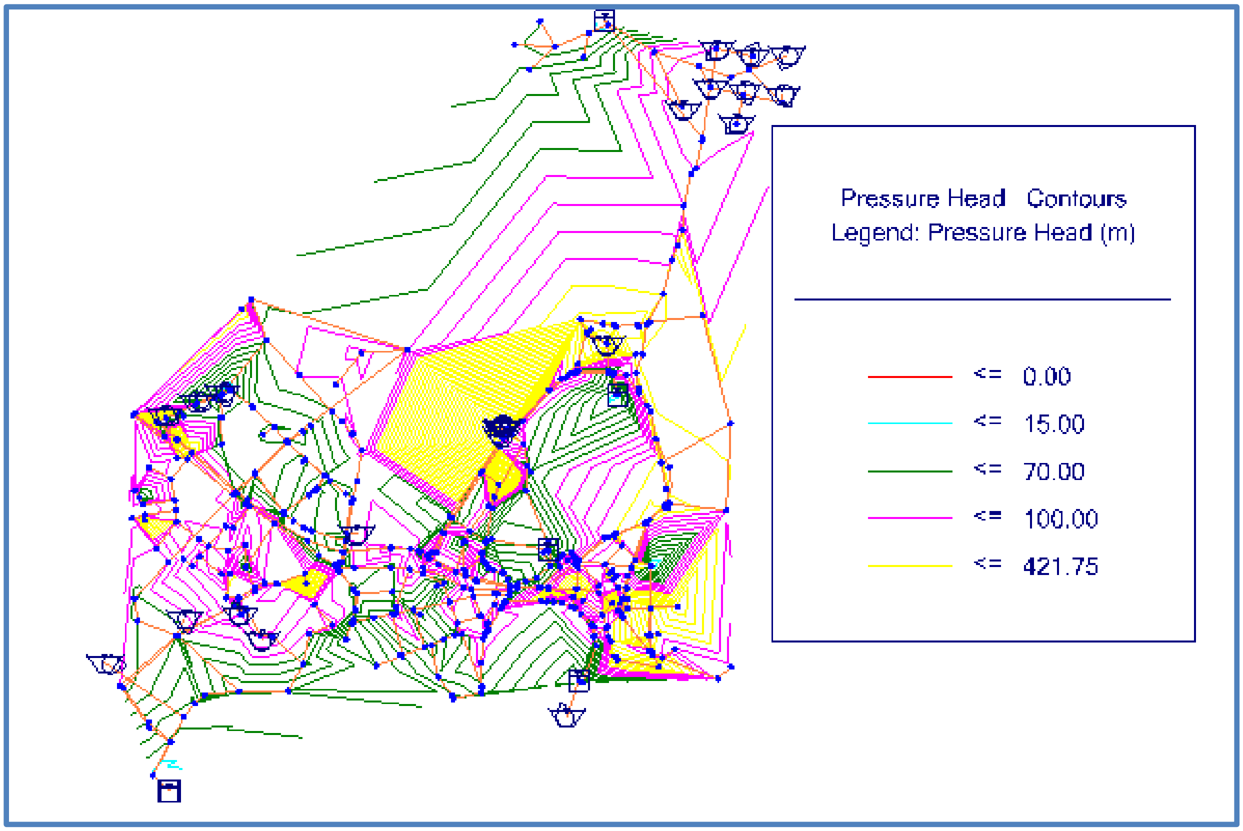
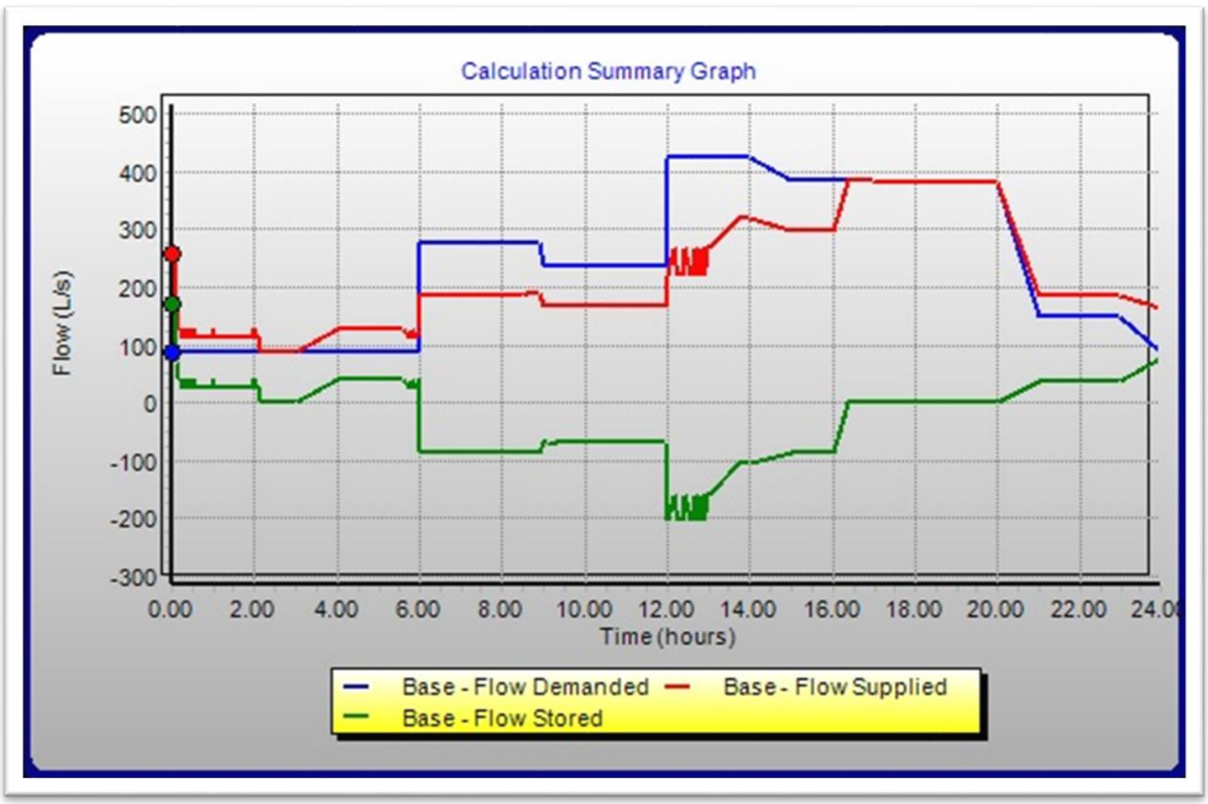


Figure 21: Pressure distribution contour of Bishoftu water supply system

4.14 Demand, supply and tank storage fluctuation in extended period simulation

Extended period simulation shows more detail variation of hydraulic parameters, demand, supply, and tank level fluctuation in 24 hours of a day. Figure4.9 above shows that base flow demanded is peak at 12:00 (424 l/s) and flow supplied is 223 l/s which is less than flow demanded. So, tank storage is -202 l/s. The negative sign indicates that the tank draining 16:00 to balance the demand. From 21:00 to 24:00 and 00:00 to 6:00 flow stored is positive which mean the tank is filling.



4.15 Modification of the distribution network

The distribution system can be adjusted to minimize observed high pressure and to boost low pressure by providing pressure reducing valves (PRV) at selected zones and changing the existing pipes with economical pipe sizes. By using 11 PRV (PRV-3, PRV-5, PRV-6, PRV-7, PRV-8, PRV-9, PRV-10, PRV-11, PRV-13, PRV-14, and PRV-16).

Based on the analysis made under EPS condition a modification on network system had been done through the following design criteria's;

- Changing some of the old pipes to economical nominal pipe diameter
- Installing the pressure reducing valve at selected areas as shown on fig. 37 below.

Based on this scenarios it was possible to make about 87.5% of the nodes acquired the pressure head within the standard and the rest 20% made in the range of 70m – 100mwc.

On the other hand the resizing of pipe done specially for old pipes and needs replacement during maintenance on as per operational schedule. Accordingly the following pipes have need resized to reduce the pressure and increase flow velocity in the system line. The pipes resized were P-580, P-581,P-554,P-582,P-453,P-583,P-451,P-584,P-591, P-4665, P-585, P-452, P-45891), P-460, P-457, P-450, P-461, P-471, P-459, P-568, P-208, P-567, P-270, P560, and P-586.

After modification done on pipe resizing on the distribution system and installation of PRVs at selected points the system pressure head became as shown in figure 38 below and also the low velocity value increased accordingly.

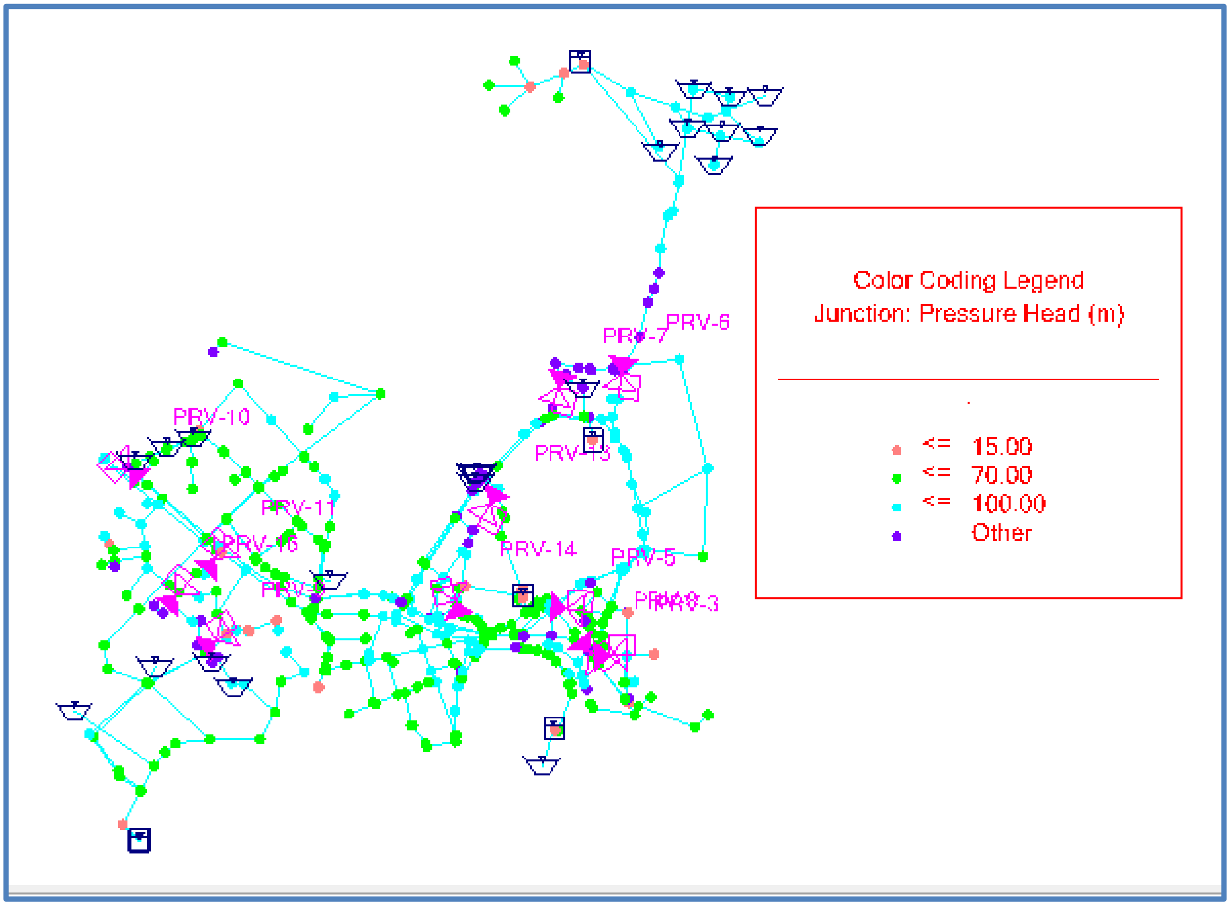
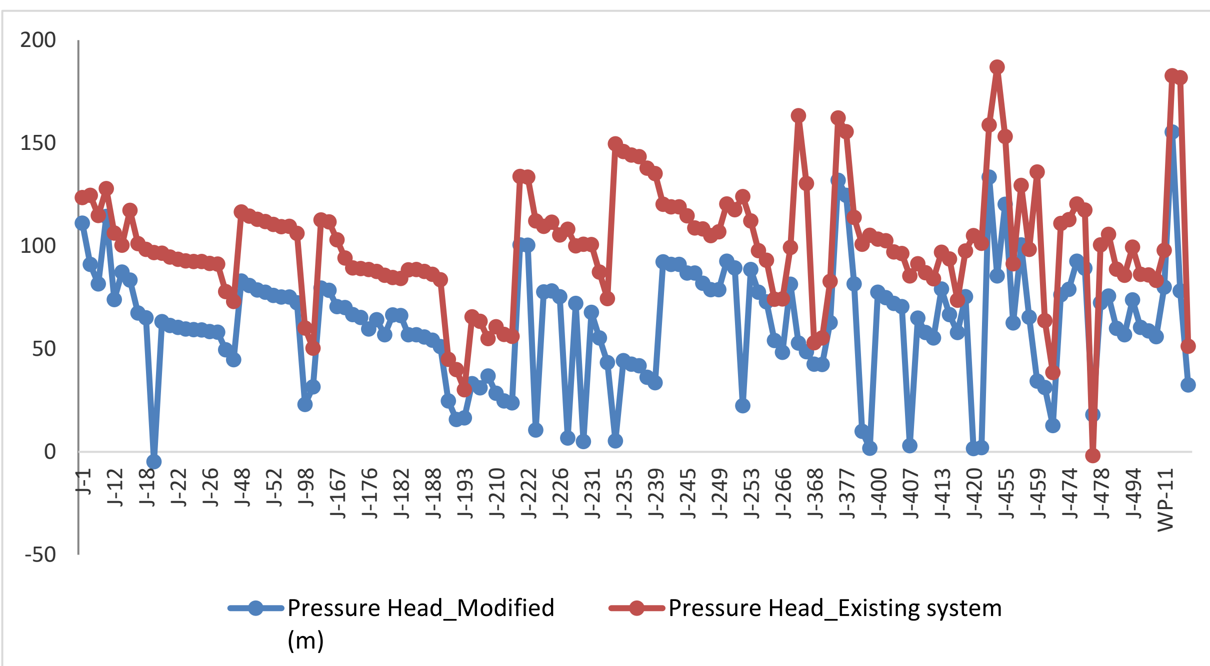


Figure 23: selected points for PRVs installation



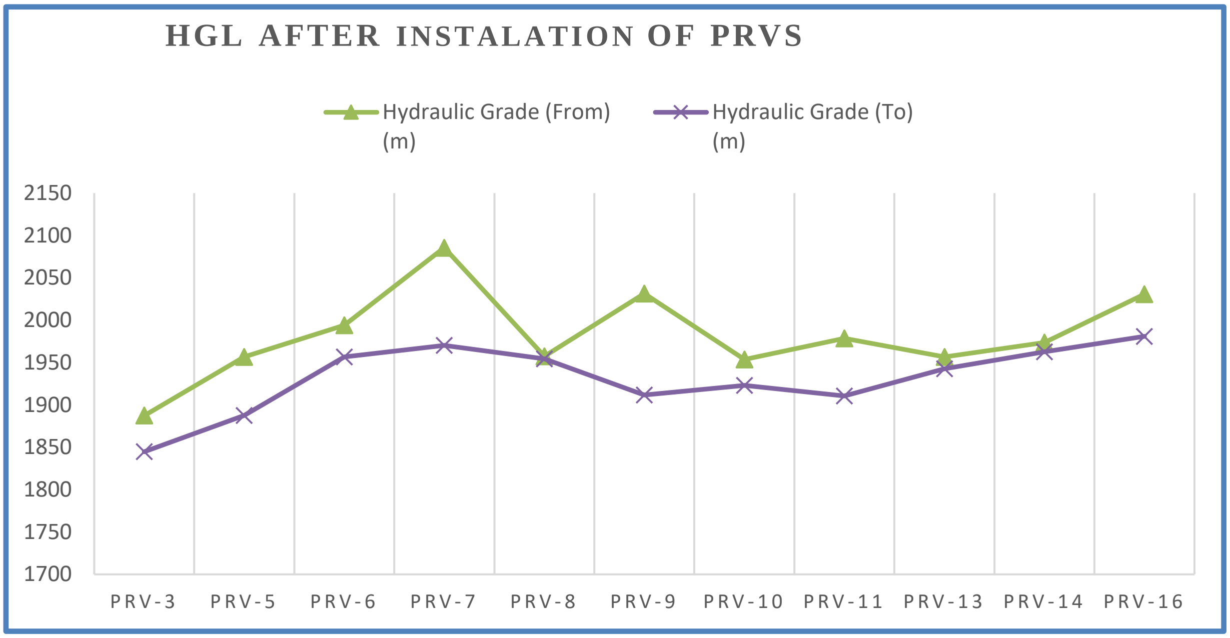


Figure 24: Hydraulic grad line before and after modification

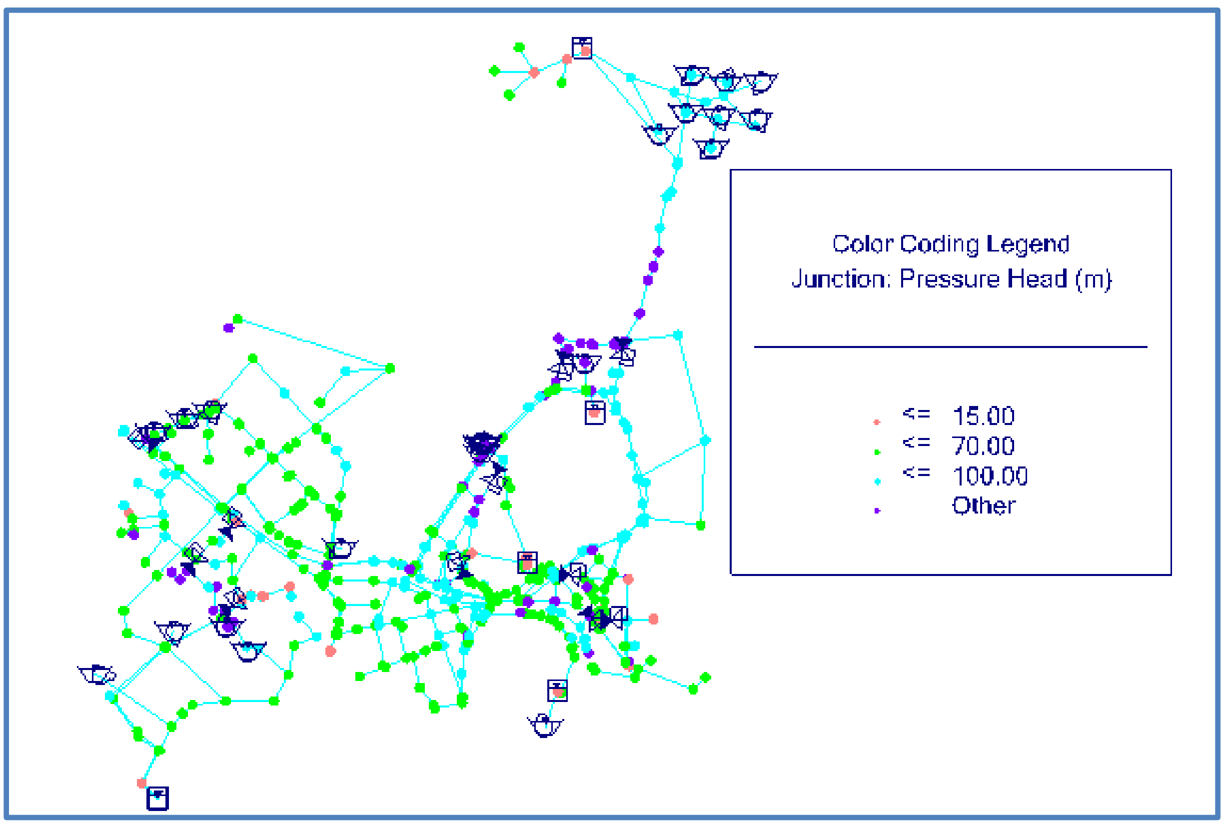


Figure 25: Pressure head after network modification

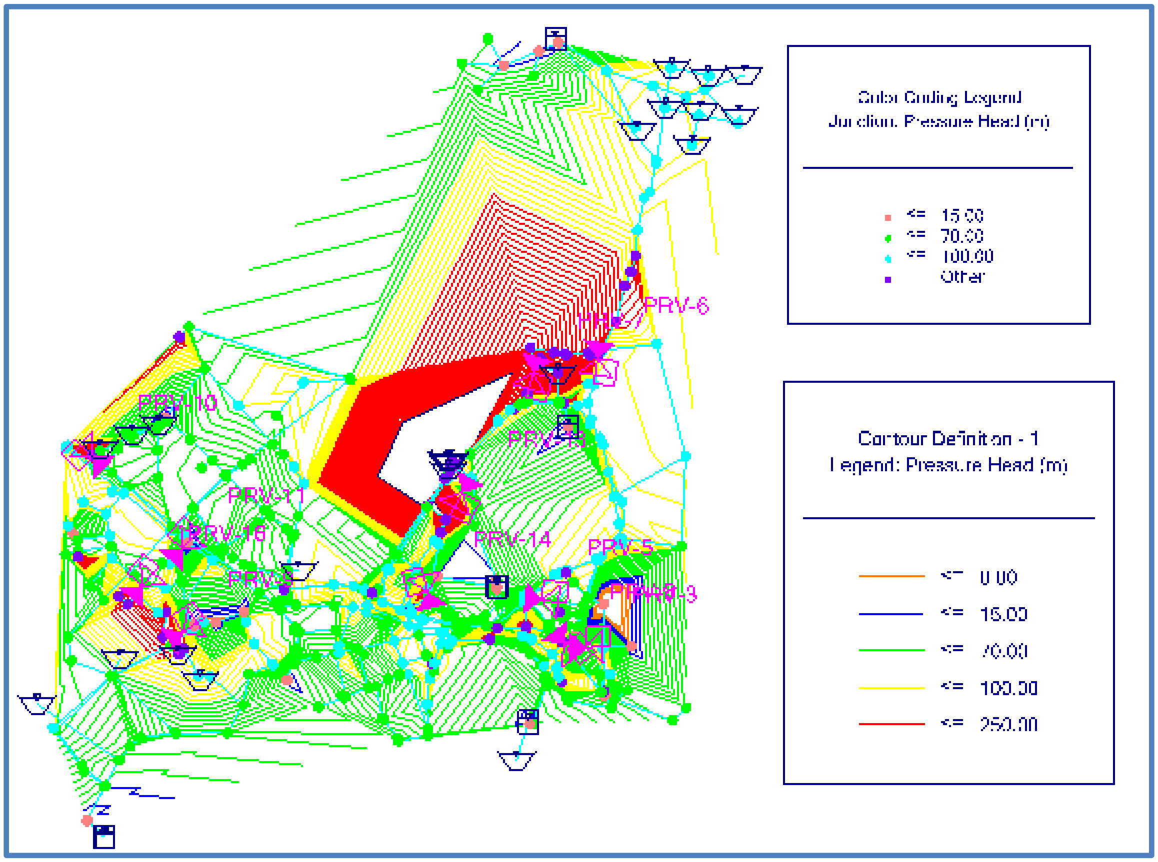


Figure 26: pressure head of modified network contour

5 Conclusion and Recommendation

The research had been focused on focused on model building and simulation in steady and ESP conditions, evaluating hydraulic parameters velocity in pipelines , and water pressure head at nodes, and produce modified system for standard operational to be in place. On top of this the study compromises the evaluation of customer satisfaction level on quantity, Quality, Continuity, and payment service of the existing water supply system of Bishoftu Town. Water supply coverage status of Bishoftu town water supply system was also evaluated based on the current water production and consumption scenarios.

The research revealed that insufficient pressure head recorded (<15m) at **2.96%** of the nodes and **16.21%** of the nodes acquires pressure **>100m** in the system over steady state conditions. On the other hand, **3.61%** of the nodes experienced pressure head below **15m** and **24.31%** of the nodes acquires pressure **>100m** in the system over Extended period simulation condition.
On the other hand, the velocity of flow has been found to be below standard at different zones. Accordingly, **45.09%** of the pipes experienced velocity of flow below 0.2m/s, **28.45%** of the pipes experienced velocity of flow in the range **0.2m/s – 0.6m/s** and **3.83%** of the pipes showed velocity of flow above **2m/s** for the steady state condition simulation. While, **51.17%** of the pipes experienced velocity of flow below **0.2m/s**, **24.5%** of the pipes experienced velocity of flow in the range **0.2m/s – 0.6m/s** and **4.83%** of the pipes showed velocity of flow above 2m/s for Extended period simulation. In general, Bishoftu town water supply system has acquired water pressure value of greater than **70m**, which is above standard. Hence system optimization had been undertaken by this research about **87.5%** of nodes made to acquire pressure head below **100 meters** by use of pressure reducing valve and pipe resizing in the system.

Consequently, the research found out that Bishoftu town water supply being suffering from high pressure head and low flow velocity over the service area of the town. This scenario might brought high percentage of water loss and deterioration of water quality.

The town water utility's satisfaction level was also evaluated using different performance indicators. Accordingly, the result of study suggests that among the households who receive adequate quantity of water **83(47.70%), 66 (37.96)** were satisfied and neutral respectively, and of those who do not have adequate water supply **63(47.01%)** were neutral and **66(49.25%)** were unsatisfied. About **25(14.37%)** were for other unsatisfied with water service for other reasons. About **83(29.43%)** were satisfied and **117(41.49%)** were neutral regarding the quality of water they receive and **9(34.62%)** were unsatisfied with quality of water.

Concerning the continuity of water supply, more than half of the individuals **165(57.58%)** receive water twice daily; off those house hold who have continuous water supply **19(54.55%)** were satisfied, **12(36.36%)** were neutral and only **2(6.06%)** were unsatisfied. On the other hand among the households who have interrupt water supply **88(28.57%)**, **129(41.88%)** and **91(29.55%)** were satisfied, neutral and unsatisfied respectively.

On the other hand, the study point out that the average daily per capita water consumption and water supply coverage of the town found to be **44.85%** and **84.9%,** respectively.

The high pressure resulted due to looping system of **main pipelines** and two methods of water distribution system pumping and gravity system; this might result in water wastage in the secondary and water collection point. On the other hand, low velocity in the main pipeline system is due to looping system which similar research also revealed that looping system of main pipelines in the town result in low velocity which bring the source of water quality deterioration.

From the research, it is recommended that the enterprise could undertake improvement of the system through connecting pressure reducing valve, Gate valve, and use of appropriate pumps specifications and changing old pipes with new ones at recommended areas. In addition, the enterprise should establish water loss monitoring system like leakage detection technology so that to reduce water loss in the system.

Finally, Bishoftu town could improve the existing system considering this research as a reference. The improvement infrastructural development, rehabilitation work, capacity building, improvement on operation and maintenance of the system. On top of this. The Enterprise can undertake detail assessment on nonfunctional water sources which was not consider during the system analysis, assessment on new connected service area, and evaluation of water quality issues. Hence, this will help the enterprise to bring and run the sustainable and profitable water supply system for the future.

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7 Annexes:

6.1 Collected field data

Collected node topographic data				
S.no	**Description of Location**	**X**	**Y**	**Z**
1	Jun	493179.74	966630.99	1934.51
2	Jun	493065.42	966408.02	1939.39
3	Babogay_BH	499069.46	970463.08	1877.72
4	Jun	499065.61	970476.01	1878.02
5	Reservoir	499213.19	969760.60	1876.47
6	Jun	499085.51	970069.06	1889.49
7	Jun	499084.96	970068.28	1889.55
8	Jun	499153.92	970069.17	1893.11
9	Jun	499153.26	970068.95	1893.12
10	Jun	499082.87	970085.75	1887.38
11	Godgoden_BH	498687.24	965765.02	1923.81
12	Jun	498727.17	965757.83	1917.32
13	Resrvoir	498918.02	966264.73	1914.97
14	Jun	492942.52	964846.00	1995.43
15	Jun	492691.67	965128.18	1969.93
16	Jun	492692.51	965128.52	1969.94
17	Jun	492286.47	965784.84	1939.58
18	Jun	492286.36	965784.95	1939.57
19	Jun	493871.72	966825.24	1930.34
20	Jun	493962.88	966700.30	1928.42
21	Jun	493965.19	966700.41	1928.28
22	Jun	493967.83	966695.77	1928.18
23	Jun	494041.75	966772.48	1919.71

24	Jun	495272.08	966579.18	1915.95
25	Jun	495145.94	966746.14	1921.00
26	Jun	494929.44	966412.39	1935.16
27	Jun	494824.02	966017.61	1951.74
28	Jun	494626.97	965638.54	1969.06
29	Jun	493935.45	965636.09	1957.60
30	Kurkura_BH	493295.04	965451.68	1975.78
31	Jun	493233.54	965394.09	1981.80
32	Jun	493166.87	965270.27	1980.66
33	Jun	493163.35	965271.93	1981.09
34	Jun	492738.52	964461.19	1995.29
35	Jun	492737.09	964459.31	1995.55
36	Jun	492739.29	964462.63	1995.12
37	Jun	492527.39	966610.32	1942.00
38	Jun	492481.36	966929.17	1945.14
39	Jun	492957.92	967429.79	1932.12
40	Jun	493162.72	967474.31	1923.66
41	Jun	492621.78	968085.48	1919.74
42	Jun	492608.55	968234.31	1917.91
43	Jun	492482.88	968429.44	1904.64
44	Jun	492687.93	968750.25	1897.16
45	Jun	492449.80	968039.18	1922.37
46	Jun	492785.60	967616.33	1937.15
47	Jun	493782.75	969876.26	1885.18

6.2 Existing pipelines

S.no	Diameter(mm)	Materi als	Length(m)	"Zone_na me	"kebele_ na	"Specific Location
1	200mm	DCI	10	Bishoftu	15	Shumbura meda
2	150mm	UPVC	195	Bishoftu	15	Shumbura Meda
3	200mm	UPVC	753	Bishoftu	15	Shumbura meda
4	300mm	UPVC	268	Bishoftu	15	Shumbura Meda
5	300mm	UPVC	469	Bishoftu	15	Shumbura Meda
6	300mm	UPVC	338	Bishoftu	15	shumbura Meda
7	350mm	UPVC	656	Bishoftu	15	Shumbura Meda
8	200mm	UPVC	909	Bishoftu	15	Shumbura Meda
9	600mm	DCI	809	Bishoftu	15	Shumbura meda
10	150mm	DCI	104	Bishoftu	15	Shumbura Meda
11	150mm	DCI	11	Bishoftu	15	Shumbura Meda
12	150mm	DCI	540	Bishoftu	15	Shumbura Meda
13	100mm	DCI	10	Bishoftu	15	Shumbura meda
14	100mm	DCI	415	Bishoftu	15	Shumbura Meda
15	100mm	DCI	63	Bishoftu	15	Shumbura Meda
16	150mm	DCI	4	Bishoftu	15	Shumbura Meda
17	250mm	DCI	462	Bishoftu	15	Shumbura Meda
18	200mm	DCI	521	Bishoftu	15	Shumbura Meda
19	100mm	DCI	9	Bishoftu	15	Shumbura Meda
20	300mm	DCI	7	Bishoftu	15	Shumbura Meda
21	300mm	DCI	545	Bishoftu	15	Shumbura Meda
22	250mm	DCI	7	Bishoftu	15	Shumbura Meda
23	400mm	DCI	713	Bishoftu	15	Shumbura meda
24	500mm	UPVC	2122	Bishoftu	15	Shumbura Meda
25	400mm	DCI	49	Bishoftu	15	Shumbura Meda
26	400mm	DCI	391	Bishoftu	15	Shumbura Meda
27	400mm	DCI	100	Bishoftu	15	Shumbura Meda
28	400mm	DCI	451	Bishoftu	15	Shumbura Meda
29	200mm	UPVC	282	bishoftu	15	koda fabrika
30	200mm	UPVC	58	bishoftu	15	koda fabirika
31	200mm	UPVC	1038	bishoftu	15	05 kondominyem(mes erete kiristos collage)
32	100mm	HDPE	165	bishoftu	15	elka circle
33	100mm	HDPE	444	bishoftu	15	car traning area
34	100mm	HDPE	205	bishoftu	15	alka fronte

35	200mm	UPVC	313	bishoftu	15	kula dabi
36	200mm	UPVC	154	bishoftu	15	kula dabi
37	100mm	HDPE	185	bishoftu	15	kula dabi
38	100mm	HDPE	293	bishoftu	15	kula dabi
39	100mm	HDPE	161	bishoftu	15	galila center
40	100mm	HDPE	649	bishoftu	15	management
41	100mm	HDPE	477	bishoftu	15	veternary
42	400mm	DCI	192	bisfoftu	15	def
43	400mm	DCI	346	bishoftu	15	high waye brige
44	400mm	DCI	225	bishoftu	15	high way brige
45	400mm	DCI	212	bishoftu	15	high waye brige
46	400mm	DCI	3148	bishoftu	15	kuriftu resort
47	400mm	DCI	1005	bishoftu	15	gurage amba end
48	150mm	UPVC	2018	bishoftu	15	def back
49	200mm	UPVC	428	bishoftu	15	tenis meda
50	200mm	UPVC	451	bishoftu	15	old mazagaja
51	400mm	DCI	35	bishoftu	14	vanjerican
52	80mm	DCI	130	bishoftu	13	meskid
53	80mm	DCI	96	bishoftu	13	meskid jerba
54	200mm	UPVC	732	bishoftu	14	vanjerikan sefer
55	150mm	UPVC	121	bishoftu	13	rufaeal church
56	150mm	UPVC	295	bishoftu	13	Shambel suk(godine tera
57	100mm	UPVC	130	bishoftu	13	Godino era
58	80mm	UPVC	326	bishoftu	13	tsige metal shop(market)
59	100mm	UPVC	95	bishoftu	9	market center
60	80mm	UPVC	747	bishoftu	14	endiriyas school
61	80mm	UPVC	131	bishoftu	13	godino tera
62	80mm	UPVC	459	bishoftu	14	rurael rode
63	300mm	DCI	619	bishoftu	14	mokoninoch no 1
64	200mm	DCI	8	bishoftu	11	fatno police
65	200mm	DCI	600	bishoftu	13	rufael rode
66	200mm	DCI	16	Bishoftu	sm	sm
67	100mm	GS	242	Bishoftu	15	rufael church
68	150mm	UPVC	147	Bishoftu	11	qoraliyo tera
69	150mm	UPVC	215	Bishoftu	11	fares kote
70	100mm	UPVC	434	Bishoftu	9	kesel tera
71	1500mm	UPVC	652	Bishoftu	11	kebele 11&12 brige
72	200mm	UPVC	440	Bishoftu	11	koraliyo tera

73	200mm	UPVC	895	Bishoftu	12	farm meda
74	100mm	UPVC	585	Bishoftu	10	air force
75	100mm	UPVC	120	Bishoftu	10	air force
76	80mm	UPVC	426	Bishoftu	10	zoma hotel
77	100mm	UPVC	217	Bishoftu	9	woba mekelakeya
78	80mm	UPVC	39	Bishoftu	7	vanjerican
79	80mm	UPVC	146	Bishoftu	7	shibo gibi
80	80mm	UPVC	236	Bishoftu	7	mesi sper
81	100mm	UPVC	328	Bishoftu	7	legda shop
82	150mm	UPVC	231	Bishoftu	9	belete fanta hotel
83	50mm	UPVC	467	Bishoftu	9	weba mekelalekeya
84	80mm	UPVC	180	Bishoftu	10	wajira mariya
85	100mm	UPVC	210	Bishoftu	8	bishoftu afaf
86	100mm	UPVC	306	Bishoftu	4	sevene hotel
87	100mm	UPVC	221	Bishoftu	8	old liybirary
88	100mm	UPVC	922	Bishoftu	4	turist hotel back
89	200mm	UPVC	92	Bishoftu	4	turist
90	200mm	UPVC	489	Bishoftu	3	pr. mesfin house
91	150mm	UPVC	219	Bishoftu	3	hibret school
92	50mm	UPVC	302	Bishoftu	3	wulegeb street
93	150mm	UPVC	325	Bishoftu	3	hebret school
94	150mm	UPVC	133	Bishoftu	2	shi semaniya mazoriya
95	100mm	UPVC	319	Bishoftu	2	hailu tej house
96	300mm	UPVC	343	Bishoftu	3	wulgeb
97	300mm	UPVC	336	Bishoftu	3	old bus stetion
98	300mm	UPVC	162	Bishoftu	3	old bus station
99	400mm	DCI	17	Bishoftu	4	turist hotel front
100	100mm	DCI	6	Bishoftu	4	turit hotel front
101	400mm	DCI	56	Bishoftu	4	eat frut
102	400mm	DCI	46	Bishoftu	4	libledingil school front
103	400mm	DCI	432	Bishoftu	4	hospital
104	300mm	DCI	441	Bishoftu	6	tedros school
105	400mm	DCI	108	Bishoftu	6	vanjerican front
106	300mm	DCI	222	Bishoftu	6	hisb edget back
107	400mm	DCI	250	Bishoftu	6	hisb edget gerba
108	400mm	DCI	2	Bishoftu	6	comminity develepment back
109	700mm	UPVC	211	Bishoftu	6	6 reservior

110	700mm	UPVC	94	Bishoftu	6	6 reservior
111	400mm	UPVC	233	Bishoftu	6	6 reservior in and our
112	150mm	DCI	815	Bishoftu	2	02 condominiyem
113	100mm	DCI	339	Bishoftu	3	olde bus station
114	100mm	DCI	584	Bishoftu	4	primid resort
115	100mm	DCI	880	Bishoftu	8	bishoftu afaf
116	100mm	UPVC	3	Bishoftu	8	bishoftu afaf
117	100mm	HDPE	312	Bishoftu	8	60 bus station
118	100mm	HDPE	1299	Bishoftu	14	engenering college
119	200mm	HDPE	555	Bishoftu	14	fetno polis
120	100mm	UPVC	836	Bishoftu	14	rufael church
121	100mm	HDPE	694	Bishoftu	11	feres kote
122	100mm	GS	624	Bishoftu	11	brige
123	100mm	GS	1015	Bishoftu	12	keta school
124	150mm	UPVC	350	Bishoftu	11	rufael back
125	150mm	GS	595	Bishoftu	11	rufael back road
126	100mm	GS	596	Bishoftu	11	rufael back road
127	80mm	GS	613	Bishoftu	11	11&12 brige
128	200mm	GS	647	Bishoftu	11	11&12 brige
129	200mm	UPVC	194	Bishoftu	12	11&12 brige
130	150mm	GS	937	Bishoftu	11	fares kote akebabi
131	80mm	UPVC	525	Bishoftu	7	circle
132	80mm	UPVC	388	Bishoftu	3	old bus station road
133	80mm	UPVC	835	Bishoftu	2	gara baru
134	200mm	UPVC	56	Bishoftu	9	belete fanta road
135	200mm	UPVC	318	Bishoftu	9	belete fanta road
136	100mm	UPVC	414	Bishoftu	14	mezegaja
137	80mm	HDPE	856	Bishoftu	14	mokoninoch no1
138	80mm	HDPE	661	Bishoftu	6	fatno police
139	65mm	UPVC	1068	Bishoftu	5	etibe
140	150mm	UPVC	658	Bishoftu	5	migib drigit
141	100mm	GS	409	Bishoftu	5	migib drigit
142	65mm	GS	571	Bishoftu	5	alemu cid
143	700mm	GS	40	Bishoftu	6	6 reservoir
144	80mm	GS	875	Bishoftu	5	Jerusalem Sefer
145	80mm	UPVC	38	Zone 2	5	celeleca water source
146	100mm	UPVC	849	Zone 2	5	kidane miret
147	100mm	GS	1534	Zone 2	5	golba

148	150mm	DCI	93	Zone 1	2	alema metatefiya
149	100mm	UPVC	451	Zone 1	2	alema rode
150	100mm	UPVC	8	Zone 1	2	alema rode
151	80mm	UPVC	329	Zone 1	2	alema rode
152	100mm	UPVC	389	Zone 1	2	alema farm
153	100mm	HDPE	804	Zone 1	2	payilet
154	80mm	HDPE	458	Zone 1	2	payilet
155	50mm	HDPE	601	Zone 1	2	misgana church
156	100mm	UPVC	539	Zone 1	2	kebele 2 mehal
157	250mm	UPVC	506	Zone 1	2	mikael church
158	200mm	UPVC	881	Zone 1	2	xy
159	100mm	UPVC	249	Zone 1	2	xy
160	100mm	HDPE	866	Zone 2	5	around shugute shop
161	100mm	HDPE	613	Zone 2	5	around tenaye shop
162	250mm	HDPE	805	Zone 2	5	aound golba in let to resourvior
163	200mm	UPVC	2083	Zone 2	5	celeleka
164	250mm	UPVC	648	Zone 2	5	celeleka
165	65mm	UPVC	405	Zone 2	5	joba cherch
166	65mm	UPVC	59	Zone 2	5	joba church
167	400mm	UPVC	1279	Zone 2	5	from Eatfrut to hirna
168	400mm	UPVC	149	Zone 1	5	memiran godana
169	100mm	UPVC	461	Zone 2	5	mendube school
170	100mm	UPVC	179	Zone 2	5	shugute shop
171	100mm	UPVC	508	Zone 2	5	tena science colege
172	100mm	UPVC	609	Zone 2	5	around golba
173	100mm	HDPE	180	Zone 2	5	around golba
174	100mm	HDPE	681	Zone 2	5	joba church
175	80mm	DCI	826	Zone 2	5	aroun kidane miret
176	250mm	DCI	371	Zone 3	5	from golba to kingo shop
177	250mm	HDPE	332	Zone 3	5	from golba to kingo shop
178	400mm	HDPE	489	Bishoftu	15	babogaya
179	400mm	HDPE	446	Bishoftu	15	babogaya
180	100mm	HDPE	41	Zone 3	1	zukala brige
181	100mm	HDPE	261	zone 2	1	zukala to awash hotel

182	150mm	HDPE	1281	zone 2	2	awash hotel to rosmery
183	200mm	UPVC	276	Bishoftu	1	rosmery to hayilu tej bet
184	100mm	UPVC	381	zone 4	1	zukala to beteliyem
185	150mm	UPVC	480	zone 4	1	beteliyem to kajima dildiy
186	400mm	DCI	323	zone 4	1	Dhibayu
187	100mm	DCI	312	zone 4	1	Dhibayu
188	250mm	DCI	313	zone 4	1	Dhibayu in late
189	400mm	HDPE	434	zone 4	1	Dhibayu rode
190	250mm	UPVC	774	zone 4	1	dhibayu farm area
191	100mm	UPVC	436	zone 4	1	Dhibayu rode
192	300mm	UPVC	339	zone 4	1	Dhibayu farm area
193	250mm	UPVC	39	zone 4	1	Dhibayu farm area
194	300mm	UPVC	42	zone 4	1	Dhibayu farm area
195	250mm	DCI	772	zone 4	1	Dhibayu industry zone
196	300mm	DCI	770	zone 4	1	ahadu industry zone
197	200mm	GS	998	zone 4	1	ahadu industry zone
198	250mm	UPVC	997	zone 4	1	ahadu industry zone
199	100mm	DCI	1809	zone 4	1	Industry zone
200	250mm	UPVC	484	zone 4	1	Industry zone
201	150mm	GS	1163	zone 4	1	Industry zone
202	200mm	UPVC	575	zone 4	1	kurkura 1 Farm area
203	200mm	UPVC	225	zone 4	1	industry zone
204	200mm	UPVC	666	zone 4	1	industry zone
205	150mm	UPVC	1527	zone 4	1	industry zone rode
206	100mm	UPVC	2349	zone 4	1	arsema to getshet
207	250mm	UPVC	1066	zone 4	1	industry zone to borhol
208	65mm	UPVC	6	zone 4	1	borhol 2
209	100mm	GS	560	zone 4	1	borhol 3 to Bole vilage
210	150mm	UPVC	1208	zone 4	1	elfora
211	100mm	UPVC	603	zone 4	1	Elfora

212	100mm	UPVC	1190	zone 4	1	elfora to kurkura 2 30m rode
213	65mm	UPVC	595	zone 4	1	bole to goje house
214	65mm	UPVC	596	zone 4	1	bole to goje house
215	150mm	UPVC	1363	zone 4	1	BCI school
216	80mm	HDPE	170	zone 4	1	kurkura
217	80mm	UPVC	172	zone 4	1	kurkura 30 m
218	50mm	GS	848	zone 4	1	hagemaf to BCI school
219	100mm	UPVC	898	zone 4	1	kurkura house con. office to 140 kare meter vilage
220	80mm	UPVC	367	zone 4	1	kurkura 2 vilage
221	100mm	UPVC	216	zone 4	1	relstate kurkura
222	65mm	HDPE	481	zone 4	1	relstete to inova
223	80mm	HDPE	444	zone 4	1	dinkitu vilage
224	80mm	HDPE	979	zone 4	1	inova to est africa
225	80	HDPE	806	zone 4	1	inova to getshet
226	100	UPVC	1175	zone 4	1	elfora back
227	80	HDPE	822	zone 4	1	mekelakeya to konjit building
228	80	UPVC	696	zone 4	1	getshet to konjit building
229	100	UPVC	618	Bishoftu	1	rift valy back
230	50	UPVC	817	Bishoftu	1	zukala to kajima
231	65	GS	501	Bishoftu	1	around beteliyem
232	250	UPVC	3736	Zone 3	1	yatu farm
233	150	HDPE	673	Zone 3	1	abo bach
234	400	UPVC	23	Bishoftu	15	BH TO Jun
235	65	GS	1588	Zone 3	1	denbi source to getshet
236	65	GS	497	Zone 1	1	
237	65mm	GS	1624	Zone 3	1	denbi ti getshet
238	200mm	UPVC	1574	Zone 3	1	denbi n02 to etenu shop
239	200mm	UPVC	757	Zone 3	1	etu shop to asama erbata
240	200mm	UPVC	1358	Zone 1	1	asama erbata to maranata
241	200mm	UPVC	1965	Zone 3	1	celeleka kodominiyem to asama erbata

242	200mm	UPVC	1204	Zone 3	1	etenu shop to agemaf
243	80mm	GS	206	Zone 3	1	agemaf front
244	80mm	GS	52	Zone 3	1	agemaf front
245	80mm	GS	1	Zone 3	1	agemaf
246	100mm	GS	52	Zone 3	1	agemaf
247	100mm	UPVC	1258	Zone 3	1	agemaf to zukala
248	100mm	UPVC	252	Zone 3	1	around primid hotel
249	80mm	GS	276	Zone 3	1	zukala front
250	100mm	UPVC	663	Zone 3	1	01 migib drijit
251	150mm	UPVC	290	Zone 3	1	around lem milk
252	350mm	UPVC	975	Zone 3	1	megib drijit to lem
253	250mm	UPVC	682	Zone 3	1	lema milk to sunshine kondominiyem
254	250mm	UPVC	5407	Zone 3	1	alemu cid to debi pump source
255	100mm	UPVC	178	Zone 3	1	aound zukala
256	400mm	DCI	1229	Zone 3	1	around new era
257	400mm	DCI	161	Zone 3	1	admas colleg
258	80mm	GS	1001	Zone 3	1	getshet to etenu shoop
259	65mm	GS	408	Zone 3	1	etenu shoop to denbi elfora
260	200mm	UPVC	1224	Zone 3	1	genesis to etenu shoop
261	80mm	UPVC	547	Zone 3	1	jenesis to celeleka condominiyem
262	80mm	UPVC	141	Zone 3	1	celeleka condominiyem
263	100mm	HDPE	1752	Zone 3	1	Denbi pump source
264	100mm	UPVC	118	Zone 3	1	BH3 conection dunbi source
265	65mm	GS	721	Zone 3	1	sunshine vilage
266	150mm	UPVC	686	Zone 3	1	abo church
267	65mm	GS	848	Zone 3	1	kondominiyem to lema milk
268	65mm	GS	430	Zone 3	1	around lema milk
269	80mm	UPVC	1052	Zone 3	1	lema milk to etenu shoop

270	150mm	UPVC	784	Zone 3	1	lema milk to jenesis condominiyem
271	100mm	UPVC	354	Zone 3	1	
272	100mm	UPVC	232	Zone 3	1	
273	100mm	UPVC	342	Zone 3	1	
274	100mm	UPVC	178	Zone 3	1	

6.3 Pressure Head result under EPS condition

Label	**Demand (L/s)**	**Elevation (m)**	**Pressure Head (m)**	**Hydraulic Grade (m)**
J-1	0	1859.19	111.88	1971.07
J-2	3	1862.56	119.77	1982.33
J-3	1	1862.96	114.21	1977.17
J-4	0	1864	108.78	1972.78
J-5	0	1864.55	112.23	1976.78
J-6	2	1865.41	119.52	1984.93
J-7	1	1869.83	119.95	1989.78
J-8	0	1869.98	119.43	1989.41
J-9	2	1872.1	102.73	1974.83
J-10	0	1874.95	109.74	1984.69
J-11	0	1856	115.19	1971.19
J-12	1	1882.61	100.86	1983.47
J-13	0	1883	88.13	1971.13
J-14	1	1883.1	107.08	1990.18
J-15	0	1873	112.47	1985.47
J-16	0	1896	75.13	1971.13
J-17	0	1889	96.4	1985.4
J-18	0	1891.31	92.76	1984.07
J-19	0	1892.1	91.32	1983.42
J-20	0	1893.21	90.51	1983.72
J-21	2	1895.03	88.82	1983.85
J-22	2	1895.9	86.66	1982.56
J-23	0	1896.64	85.95	1982.59
J-24	1	1897.04	85.84	1982.88
J-25	1	1897.09	85.53	1982.62

J-26	1	1897.97	84.59	1982.56
J-27	0	1898.34	84.47	1982.81
J-29	0	1907.5	70.5	1978
J-30	1	1912.3	65.55	1977.85
J-31	0	1895.47	97.58	1993.05
J-32	0	1895.66	97.3	1992.96
J-33	0	1896.23	96.93	1993.16
J-34	0	1896.87	96.25	1993.12
J-35	0	1897.18	95.94	1993.12
J-36	0	1897.43	95.71	1993.14
J-37	0	1897.9	95.25	1993.15
J-38	0	1898.34	94.82	1993.16
J-39	0	1899.47	93.69	1993.16
J-40	0	1900.81	92.35	1993.16
J-41	0	1901.02	92.36	1993.38
J-42	0	1902.75	90.4	1993.15
J-43	0	1903.15	88.7	1991.85
J-44	0	1903.25	89.9	1993.15
J-45	0	1904.57	87.08	1991.65
J-46	0	1910.65	82.49	1993.14
J-47	1	1912.47	78.34	1990.81
J-48	0	1873.57	111.8	1985.37
J-49	0	1875.69	109.83	1985.52
J-50	0	1877.86	108.96	1986.82
J-51	1	1878.91	107.64	1986.55
J-52	0	1880.54	106.77	1987.31
J-53	3	1881.31	105.14	1986.45
J-54	1	1881.36	105.68	1987.04
J-55	1	1882.01	106.56	1988.57
J-56	0	1884	100.68	1984.68
J-57	2	1885.49	85.64	1971.13
J-58	0	1885.6	84.79	1970.39
J-59	0	1886.53	83.79	1970.32
J-60	0	1887.05	83.27	1970.32
J-61	0	1887.32	100.48	1987.8
J-62	0	1887.67	100.08	1987.75
J-63	0	1890.82	79.88	1970.7
J-64	0	1889	82.13	1971.13
J-65	0	1889.12	82.43	1971.55

J-66	0	1898.33	73.22	1971.55
J-67	0	1898.35	40.3	1938.65
J-68	0	1898.36	73.19	1971.55
J-69	0	1898.87	39.9	1938.77
J-70	0	1930.59	29.64	1960.23
J-71	0	1932.21	5.96	1938.17
J-72	0	1943.45	16.74	1960.19
J-73	0	1981.09	20.65	2001.74
J-74	0	1951.84	8.34	1960.18
J-75	0	1928.42	79.81	2008.23
J-76	0	1969.93	34.01	2003.94
J-77	1	1919.71	89.08	2008.79
J-78	0	1960	48.22	2008.22
J-79	0	1964	1.13	1965.13
J-80	0	1964.83	43.37	2008.2
J-81	0	1980.66	21.07	2001.73
J-82	0	1972	29.78	2001.78
J-83	0	1974	28.11	2002.11
J-84	1	1951.74	50.58	2002.32
J-85	0	1995.82	5.76	2001.58
J-86	0	1928.18	80.05	2008.23
J-87	0	1995.55	6.78	2002.33
J-88	0	1855	85.17	1940.17
J-89	0	1858	81.84	1939.84
J-90	0	1879	60.62	1939.62
J-91	0	1882.32	57.2	1939.52
J-92	0	1905.43	59.72	1965.15
J-93	2	1912.56	52.58	1965.14
J-94	0	1896.34	73.97	1970.31
J-95	1	1905.79	65.01	1970.8
J-96	0	1914.48	55.8	1970.28
J-97	1	1920.16	41.98	1962.14
J-98	0	1928.85	54.55	1983.4
J-99	0	1861.15	251.71	2112.86
J-100	0	1862.41	252.44	2114.85
J-101	0	1863.47	97.92	1961.39
J-102	0	1863.5	106.8	1970.3
J-103	0	1863.71	249.12	2112.83
J-104	0	1864.33	248.52	2112.85

J-105	0	1864.64	95.68	1960.32
J-106	0	1865.75	75.67	1941.42
J-107	0	1873.19	86.62	1959.81
J-108	0	1878.1	163.16	2041.26
J-109	0	1878.11	89.58	1967.69
J-110	0	1885.11	75.28	1960.39
J-111	0	1886.62	179.79	2066.41
J-112	0	1887.62	55.09	1942.71
J-113	0	1887.68	54.11	1941.79
J-114	0	1888.84	213.44	2102.28
J-115	0	1899.21	66.83	1966.04
J-116	0	1901.28	69.7	1970.98
J-117	0	1901.51	68.29	1969.8
J-118	0	1901.69	59.81	1961.5
J-119	0	1901.73	42.49	1944.22
J-120	0	1902.85	58.54	1961.39
J-121	1	1903.19	67.93	1971.12
J-122	0	1903.89	57.5	1961.39
J-123	0	1905.84	55.55	1961.39
J-124	0	1906.77	54.66	1961.43
J-125	0	1906.8	54.59	1961.39
J-126	0	1919.04	25.21	1944.25
J-127	0	1901.42	42.76	1944.18
J-128	1	1906.66	94.44	2001.1
J-129	0	1913.55	56.74	1970.29
J-130	0	1921.98	34.26	1956.24
J-131	0	1927.84	17.54	1945.38
J-132	1	1933.88	37.81	1971.69
J-133	0	1934.39	9.86	1944.25
J-134	0	1935.7	25.69	1961.39
J-135	0	1937.61	23.78	1961.39
J-136	0	1939.6	21.79	1961.39
J-137	0	1947.28	-2.93	1944.35
J-138	0	1853	91.9	1944.9
J-139	0	1883	62.79	1945.79
J-140	1	1887.78	82.6	1970.38
J-141	0	1888.12	82.25	1970.37
J-143	0	1892.68	77.52	1970.2
J-144	0	1893.05	77.19	1970.24

J-145	0	1894.83	51.7	1946.53
J-146	0	1895.81	74.46	1970.27
J-147	0	1902.78	43.33	1946.11
J-148	0	1904.1	59.76	1963.86
J-149	0	1904.23	57.43	1961.66
J-150	0	1904.4	69.91	1974.31
J-151	0	1905.33	58.48	1963.81
J-152	0	1910.64	114.73	2025.37
J-153	0	1911.92	49.46	1961.38
J-154	0	1912.13	38.43	1950.56
J-155	0	1914.01	47.59	1961.6
J-156	0	1918.92	42.64	1961.56
J-157	0	1924.75	36.64	1961.39
J-158	0	1927.44	16.82	1944.26
J-159	1	1933.84	27.55	1961.39
J-160	0	1935	17.96	1952.96
J-161	0	1945	19.57	1964.57
J-163	1	1877	107.49	1984.49
J-164	0	1878	106.68	1984.68
J-165	0	1883.07	83.28	1966.35
J-166	0	1884.11	86.49	1970.6
J-167	0	1886	97.49	1983.49
J-168	0	1887.28	79.07	1966.35
J-169	0	1888.56	82.04	1970.6
J-170	1	1889.03	71.45	1960.48
J-171	0	1890.66	79.79	1970.45
J-172	0	1892.18	78.27	1970.45
J-173	0	1892.79	73.56	1966.35
J-174	0	1893.83	66.76	1960.59
J-175	0	1894.23	66.29	1960.52
J-176	0	1894.85	78.19	1973.04
J-177	0	1894.85	75.6	1970.45
J-178	0	1895.6	64.93	1960.53
J-179	0	1897.59	72.89	1970.48
J-180	0	1897.68	75.2	1972.88
J-181	0	1898.37	62.55	1960.92
J-182	0	1898.87	62.07	1960.94
J-183	0	1899.51	76.81	1976.32
J-184	0	1899.54	77.6	1977.14

J-185	0	1900.6	76.88	1977.48
J-186	0	1901.12	69.32	1970.44
J-187	0	1901.45	69.01	1970.46
J-188	0	1902.19	76.31	1978.5
J-189	0	1902.74	58.72	1961.46
J-190	0	1905.36	75.08	1980.44
J-191	0	1933.62	40.57	1974.19
J-192	0	1942.41	34.89	1977.3
J-193	0	1947.43	26.54	1973.97
J-194	1	1885.8	84.57	1970.37
J-195	1	1886.08	84.21	1970.29
J-197	0	1891.37	79.08	1970.45
J-198	0	1896.4	74.02	1970.42
J-199	0	1897.42	73.03	1970.45
J-200	0	1898.46	71.99	1970.45
J-201	1	1916.5	53.73	1970.23
J-202	0	1916.92	53.53	1970.45
J-203	0	1923.42	60.04	1983.46
J-204	0	1924.02	46.61	1970.63
J-205	0	1924.3	46.15	1970.45
J-206	0	1925.51	57.95	1983.46
J-207	0	1926.08	44.38	1970.46
J-208	0	1927.58	42.91	1970.49
J-209	0	1928.06	32.87	1960.93
J-210	0	1928.17	55.29	1983.46
J-211	0	1930.24	40.26	1970.5
J-212	1	1930.29	40.27	1970.56
J-213	1	1931.85	51.61	1983.46
J-214	0	1932.26	29.35	1961.61
J-215	0	1932.84	37.69	1970.53
J-216	0	1932.88	50.58	1983.46
J-217	0	1944.88	25.75	1970.63
J-218	0	1957.35	13.28	1970.63
J-219	0	1961.24	9.39	1970.63
J-221	0	1856	128.57	1984.57
J-222	0	1856	126.56	1982.56
J-223	0	1876.77	106.65	1983.42
J-224	0	1878.13	101.94	1980.07
J-225	3	1878.32	106.54	1984.86

J-226	0	1879.72	95.64	1975.36
J-227	0	1880.75	102.66	1983.41
J-229	4	1883.33	73.03	1956.36
J-230	0	1888.2	95.2	1983.4
J-231	1	1888.66	93.45	1982.11
J-232	1	1901.39	81.73	1983.12
J-233	0	1913.25	68.39	1981.64
WP_5	2	1839.33	144.03	1983.36
J-235	0	1843.02	140.39	1983.41
J-236	1	1844.73	138.66	1983.39
J-237	1	1845.57	137.81	1983.38
J-238	0	1851.17	132.24	1983.41
J-239	0	1853.75	129.66	1983.41
J-240	0	1858.72	104.01	1962.73
J-241	0	1863.72	95.81	1959.53
J-242	1	1864.85	97.88	1962.73
J-243	0	1864.86	94.4	1959.26
J-244	0	1865.4	96.33	1961.73
J-245	1	1868.59	87.65	1956.24
J-246	0	1871.03	101.17	1972.2
J-247	0	1875.68	102.1	1977.78
J-248	1	1878.51	82.11	1960.62
J-249	1	1878.59	101.23	1979.82
J-250	0	1863.5	96.11	1959.61
J-251	0	1867	95.61	1962.61
J-252	0	1865	118.4	1983.4
J-253	0	1871	89.52	1960.52
J-254	0	1880.82	93.37	1974.19
J-255	0	1885.45	88.74	1974.19
J-256	0	1890.09	80.4	1970.49
J-257	1	1891.41	79.02	1970.43
J-258	0	1894.22	76.23	1970.45
J-259	0	1895.24	75.21	1970.45
J-260	0	1895.49	75.33	1970.82
J-261	1	1895.66	64.58	1960.24
J-262	0	1896.47	73.86	1970.33
J-263	1	1901.3	69.1	1970.4
J-264	0	1903.55	66.87	1970.42
J-265	0	1904.37	69.82	1974.19

J-266	1	1909.67	68.9	1978.57
J-267	0	1911.44	60.93	1972.37
J-268	1	1912.09	60.31	1972.4
J-269	0	1912.83	63.31	1976.14
J-270	0	1894.51	75.81	1970.32
J-271	0	1900.48	69.75	1970.23
J-272	1	1901.58	68.49	1970.07
J-273	0	1903.29	66.78	1970.07
J-274	2	1903.75	66.31	1970.06
J-275	0	1911.55	58.52	1970.07
J-276	0	1912.4	57.67	1970.07
J-277	0	1912.56	57.6	1970.16
J-278	1	1913.08	57.09	1970.17
J-279	0	1913.44	56.63	1970.07
J-280	0	1914.01	56.13	1970.14
J-281	0	1914.37	55.79	1970.16
J-282	0	1904.49	65.81	1970.3
J-283	1	1919.4	50.76	1970.16
J-284	0	1919.93	50.23	1970.16
J-285	0	1927.87	42.42	1970.29
J-286	0	1928.94	41.35	1970.29
J-287	0	1931.4	38.9	1970.3
J-288	0	1931.48	38.68	1970.16
J-289	0	1931.58	38.75	1970.33
J-290	0	1932.63	37.67	1970.3
J-291	0	1932.94	37.42	1970.36
J-292	0	1933.16	37.13	1970.29
J-293	0	1935.2	35.04	1970.24
J-294	0	1937.39	32.85	1970.24
J-295	1	1937.97	32.19	1970.16
J-296	0	1950.52	19.78	1970.3
J-297	1	1950.85	19.34	1970.19
J-298	1	1959.09	10.91	1970
J-299	0	1879.91	90.4	1970.31
J-300	0	1884.18	86.13	1970.31
J-301	0	1884.71	85.6	1970.31
J-302	0	1886.99	83.32	1970.31
J-303	0	1898.73	61.8	1960.53
J-304	1	1900.31	57.99	1958.3

J-305	0	1900.81	60.01	1960.82
J-306	0	1901.3	55.37	1956.67
J-307	0	1911.54	52.18	1963.72
J-308	1	1912.48	49.39	1961.87
J-309	0	1913.02	49.21	1962.23
J-310	1	1913.44	48.28	1961.72
J-311	1	1913.45	80.72	1994.17
J-312	1	1913.69	48.08	1961.77
J-314	1	1914.63	52.61	1967.24
J-315	2	1914.65	51.27	1965.92
J-316	0	1914.74	46.13	1960.87
J-317	1	1914.75	50.53	1965.28
J-318	1	1914.76	46.96	1961.72
J-319	2	1916.41	44.46	1960.87
J-320	0	1919.63	41.41	1961.04
J-321	1	1919.74	41.16	1960.9
J-322	1	1919.86	45.53	1965.39
J-323	0	1920.57	40.37	1960.94
J-324	0	1920.66	40.25	1960.91
J-325	1	1921.37	39.68	1961.05
J-326	1	1922.7	38.4	1961.1
J-327	0	1885.05	79.29	1964.34
J-328	1	1915.05	46.2	1961.25
J-329	0	1918.14	43.05	1961.19
J-330	0	1918.58	42.61	1961.19
J-331	0	1899.03	39.79	1938.82
J-332	1	1864.72	98.1	1962.82
J-333	0	1901.86	62.76	1964.62
J-334	2	1902.52	82.24	1984.76
J-335	1	1902.99	54.55	1957.54
J-336	0	1903.24	54.41	1957.65
J-337	0	1903.38	60.14	1963.52
J-338	1	1904.2	59.14	1963.34
J-339	1	1905.51	57.48	1962.99
J-340	0	1907.15	50.39	1957.54
J-341	0	1915.81	48.83	1964.64
J-342	0	1920.3	40.75	1961.05
J-343	0	1896.38	71.02	1967.4
J-344	1	1898.1	69.4	1967.5

J-345	1	1900.67	66.64	1967.31
J-346	3	1903.56	64.17	1967.73
J-347	0	1904.3	65.76	1970.06
J-348	0	1905.59	62.35	1967.94
J-349	1	1907.21	58.38	1965.59
J-350	0	1908.41	58.81	1967.22
J-351	1	1910.74	54.61	1965.35
J-352	0	1911	49.9	1960.9
J-353	1	1914.69	50.47	1965.16
J-354	1	1897.87	68.15	1966.02
J-355	2	1901.93	66.46	1968.39
J-356	0	1902.59	67.53	1970.12
J-357	0	1897.79	112.69	2010.48
J-358	0	1899.52	104.71	2004.23
J-359	1	1900.64	86.01	1986.65
J-360	1	1905.06	72.64	1977.7
J-361	0	1906.77	63.32	1970.09
J-362	0	1907.09	62.99	1970.08
J-363	0	1908.67	61.4	1970.07
J-364	0	1909.81	60.22	1970.03
J-365	0	1914.09	50.65	1964.74
J-366	0	1914.25	50.71	1964.96
J-367	0	1914.38	38.51	1952.89
J-368	0	1914.46	50.13	1964.59
J-369	0	1914.62	50.45	1965.07
J-370	1	1915.69	49.05	1964.74
J-372	0	1892.79	74.32	1967.11
J-373	0	1904.49	65.8	1970.29
J-374	0	1895.66	78.53	1974.19
J-375	1	1825	156.48	1981.48
J-376	1	1875	89.41	1964.41
J-377	2	1832	149.49	1981.49
J-378	0	1875	108.46	1983.46
J-379	0	1863	83.79	1946.79
J-380	0	1846	101.42	1947.42
J-381	0	1876	88.71	1964.71
J-382	0	1825	124.38	1949.38
J-383	1	1935.16	61.6	1996.76
J-384	1	1915.95	79.02	1994.97

J-385	0	1921	73.97	1994.97
J-386	0	1975	26.74	2001.74
J-387	0	1945	56.75	2001.75
J-388	0	1984	17.59	2001.59
J-389	0	1967	34.56	2001.56
J-390	0	1938.5	63.02	2001.52
J-391	0	1986	17.31	2003.31
J-392	0	1939.8	65.87	2005.67
J-393	0	1939.38	62.08	2001.46
J-394	0	1928.18	79.78	2007.96
J-395	0	1911.2	88.96	2000.16
J-396	1	1914	87.59	2001.59
J-397	0	1909.6	91.97	2001.57
J-398	1	1900	95.2	1995.2
J-399	1	1901	100.23	2001.23
J-400	0	1902	91.8	1993.8
J-401	1	1903	95.9	1998.9
J-402	1	1904	85.67	1989.67
J-403	1	1906	92.59	1998.59
J-404	1	1907	77.96	1984.96
J-405	1	1908	77.15	1985.15
J-406	2	1913	91.17	2004.17
J-407	1	1914	74.29	1988.29
J-408	0	1915	79.82	1994.82
J-409	1	1923	75.31	1998.31
J-410	0	1925	70.66	1995.66
J-411	1	1935	65.68	2000.68
J-412	2	1905	98.07	2003.07
J-413	1	1905	79.89	1984.89
J-414	2	1912	75.59	1987.59
J-415	0	1961.2	39.38	2000.58
J-416	1	1915	85.21	2000.21
J-417	0	1962	36.64	1998.64
J-418	1	1932	66.36	1998.36
J-419	1	1910	88.3	1998.3
J-420	1	1910	92.51	2002.51
J-421	1	1913.5	88.5	2002
J-422	1	1912	88.16	2000.16
J-423	0	1894.38	67.04	1961.42

J-424	2	1896.87	64.1	1960.97
J-425	0	1897.04	63.86	1960.9
J-426	0	1897.73	61.88	1959.61
J-427	0	1898.67	66.47	1965.14
J-428	0	1907.66	53.21	1960.87
J-429	3	1909.28	51.59	1960.87
J-430	0	1910.54	56.68	1967.22
J-431	0	1913.32	47.51	1960.83
J-432	2	1913.33	47.5	1960.83
J-433	0	1914.18	46.69	1960.87
J-434	0	1914.52	46.31	1960.83
J-435	1	1914.87	46	1960.87
J-436	0	1915.12	50.03	1965.15
J-437	0	1915.46	45.41	1960.87
J-438	0	1919.12	45.86	1964.98
J-439	0	1924.14	40.9	1965.04
J-440	0	1901.85	55.1	1956.95
J-441	0	1895.35	97.78	1993.13
J-442	0	1985.84	7.86	1993.7
J-443	0	1983	10.03	1993.03
J-444	0	1981	11.91	1992.91
J-445	1	1972	20.84	1992.84
J-446	1	1973	19.86	1992.86
J-447	0	1893.9	99.24	1993.14
J-448	5	1872	112.68	1984.68
J-449	4	1835	136.4	1971.4
J-450	0	1816.53	155.03	1971.56
J-451	0	1884.5	54.94	1939.44
J-452	0	1823	160.41	1983.41
J-453	2	1824	149.91	1973.91
J-454	0	1802	181.41	1983.41
J-455	0	1836	146.68	1982.68
J-456	0	1892	81.44	1973.44
J-457	2	1854	119.36	1973.36
J-458	0	1891	91.11	1982.11
J-459	0	1853	130.42	1983.42
J-460	1	1901.59	68.86	1970.45
J-461	0	1894.22	76.75	1970.97
J-462	0	1901.3	69.08	1970.38

J-463	0	1865	105.45	1970.45
J-464	0	1925.3	58.16	1983.46
J-465	0	1912	96.16	2008.16
J-466	0	1934.6	78.5	2013.1
J-467	0	1934	76.72	2010.72
J-468	1	1965.6	18.9	1984.5
J-469	2	1885	76.46	1961.46
J-470	0	1902	59.46	1961.46
WP_1	1	1862.56	115.61	1978.17
WP_2	1	1872	99.33	1971.33
WP_3	1	1880.2	107.02	1987.22
J-474	3	1877.6	108.19	1985.79
J-475	1	1863.5	96.05	1959.55
wp-4	1	1867.2	95.38	1962.58
J-477	1	1991	-8.33	1982.67
J-478	1	1885	94.8	1979.8
WP-6	1	1879.3	95.94	1975.24
WP-6	2	1894.5	77.97	1972.47
WP-7	1	1897.68	75.08	1972.76
J-482	1	1843	129.36	1972.36
WP18	1	1931.58	38.68	1970.26
WP-12	1	1950.3	19.87	1970.17
WP-16	0	1931.39	38.91	1970.3
J-486	1	1901.3	69.07	1970.37
WP-19	1	1897.2	73.25	1970.45
J-488	1	1932.94	37.41	1970.35
WP-10	1	1914.5	50.76	1965.26
J-490	1	1914.8	46.07	1960.87
J-491	1	1901.3	43.13	1944.43
WP-13	1	1959.6	10.4	1970
J-493	0	1897.16	87.8	1984.96
J-494	1	1904.64	79.81	1984.45
J-495	0	1917.91	66.73	1984.64
J-496	1	1919.74	67.59	1987.33
J-497	1	1922.37	64.93	1987.3
J-498	1	1923.66	74.85	1998.51
J-499	1	1932.12	64.84	1996.96
J-500	0	1937.15	52.52	1989.67
J-501	1	1942	59.34	2001.34

J-502	0	1945.14	54.54	1999.68
WP-11	1	1904	80.79	1984.79
J-504	0	1823	164.33	1987.33
J-505	1	1833	168.03	2001.03
J-506	0	1865.4	173.89	2039.29
J-507	0	1855	174.46	2029.46
J-508	0	1888.6	131.3	2019.9
WP-14	1	1842	123.05	1965.05
J-510	1	1895	62.53	1957.53
J-511	1	1921	35.23	1956.23
J-512	2	1870	100.4	1970.4
J-513	1	1967	26	1993
J-514	2	1963	29.49	1992.49

6.4 Existing Hydrant data

ID	Label	Elevation (m)	Hydraulic Grade (m)	Pressure (kPa)
1965	H-1	1,882.03	1,983.57	994
1968	H-4	1,876.61	1,984.02	1,051
1969	H-5	1,904.22	1,986.51	805
1970	H-6	1,965.00	1,988.94	234
1971	H-7	1,892.79	1,972.18	777
1972	H-8	1,887.09	1,970.65	818
1973	H-9	1,914.44	1,945.15	301
1974	H-10	1,889.64	1,970.71	793

6.5 Existing reservoir data

Label	Elevation (Base) (m)	Elevation (Minimum) (m)	Elevation (Initial) (m)	Elevation (Maximum) (m)	Diameter (m)	Hydraulic Grade (m)

T-7	1,933.08	1,933.58	1,938.16	1,938.41	16.3	1,938.16
T-6	1,955.00	1,955.50	1,960.18	1,960.43	16.3	1,960.18
T-5	1,965.55	1,967.05	1,970.63	1,970.88	10.5	1,970.63
T-4	1,996.65	1,997.00	2,001.58	2,001.83	10.5	2,001.58
T-3	1,988.65	1,989.15	1,993.73	1,993.98	16.3	1,993.73
T-2	1,996.50	1,997.00	2,001.58	2,001.83	10.5	2,001.58
T-1	1,965.55	1,967.05	1,970.63	1,970.88	16.3	1,970.63

6.6 BH elevation data

Label	Elevation (m)	Flow (Out net) (L/s)	Hydraulic Grade (m)
R-1	1,861.15	5	1,861.15
R-2	1,862.41	12	1,862.41
R-3	1,763.66	8	1,763.66
R-4	1,780.07	28	1,780.07
R-5	1,783.74	0	1,783.74
R-6	1,850.00	0	1,850.00
R-7	1,847.35	0	1,847.35
R-8	1,785.91	0	1,785.91
R-9	1,795.98	16	1,795.98
R-10	1,897.56	0	1,897.56
R-11	1,855.75	0	1,855.75
R-12	1,787.75	8	1,787.75
R-13	1,780.79	8	1,780.79
R-14	1,858.91	0	1,858.91
R-15	1,850.94	0	1,850.94
R-16	1,800.94	0	1,800.94
R-17	1,860.14	0	1,860.14
R-18	1,855.25	0	1,855.25
R-19	1,918.00	0	1,918.00

R-20	1,864.50	33	1,864.50
R-21	1,865.36	31	1,865.36
R-22	1,883.70	33	1,883.70
R-23	1,887.57	23	1,887.57
R-24	1,929.00	52	1,929.00

6.7 Existing pump functionality data

Label	Elevation (m)	Pump Definition	Pump Status	Hydraulic Grade (Suction) (m)	Hydraulic Grade (Discharge) (m)	Flow (Total) (L/s)	Pump Head (m)
PMP-9	1,785.91	PUMP_BH_8	Off	1,785.91	1,889.62	0	0
PMP-03	1,855.74	PUMP_BH_3	Off	1,855.75	1,993.33	0	0
PMP-11	1,855.25	PUMP_BH_11	Off	1,855.25	1,993.33	0	0
PMP-2	1,860.14	PUMP_BH_2	Off	1,860.14	1,993.33	0	0
Pump-5	1,850.94	PUMP_BH_5	Off	1,850.94	1,993.33	0	0
PMP-4	1,847.35	PUMP_BH_4	Off	1,847.35	1,993.33	0	0
PMP-07	1,783.74	PUMP_BH_7	Off	1,783.74	1,888.54	0	0
PMP-6	1,858.91	PUMP_BH_6	Off	1,858.91	1,993.33	0	0
PMP-18	1,918.00	PUMP_Bishoftu	Off	1,918.00	3,915.43	0	0
PMP-29	1,800.94	PUMP_CHELEKA_4	Off	1,800.94	1,954.20	0	0
PMP-17	1,780.07	PUMP_BABOGAYA	On	1,772.80	2,007.48	28	234.68
PMP-19	1,862.41	CHELEK_3	On	1,861.89	2,284.77	12	422.88
PMP-20	1,787.75	CHELEK_2	On	1,787.74	1,948.86	8	161.12
PMP-21	1,780.79	PUMP_DIB_1	On	1,780.61	2,120.33	8	339.71
PMP-23	1,865.36	Pump 1	On	1,857.06	2,042.74	31	185.67
PMP-24	1,887.57	Pump Definition - 2	On	1,886.66	2,087.46	23	200.8
PMP-27	1,864.50	PUMP_DIBAYU_BH3	On	1,855.10	2,270.81	33	415.72
PMP-28	1,883.70	Pump 1	On	1,882.99	2,023.27	33	140.28
PMP-31	1,795.98	pump_DIB_BH_2	On	1,795.93	1,976.01	16	180.08
PMP-32	1,763.66	CHELK_1	On	1,763.48	1,983.64	8	220.16

PMP-33	1,861.15	CHELEK_2	On	1,861.07	2,281.09	5	420.01
PMP-34	1,752.00	CHELELKA_BH5	On	1,928.53	2,012.35	52	83.82

6.8 PRV data

Label	Elevation (m)	Diameter (Valve) (mm)	Minor Loss Coefficient (Local)	Flow (L/s)	Hydraulic Grade (From) (m)	Hydraulic Grade (To) (m)	Head loss (m)
PRV-3	1,844.73	100	0.39	1	1,887.36	1,844.73	42.63
PRV-5	1,887.40	152.4	10	1	1,956.57	1,887.40	69.17
PRV-6	1,886.59	400	10	0	1,993.96	1,956.51	0
PRV-7	1,842.06	200	10	0	2,085.59	1,970.28	0
PRV-8	1,826.25	100	10	0	1,957.47	1,954.55	0
PRV-9	1,911.81	100	10	2	2,031.34	1,911.81	119.53
PRV-10	1,899.60	65	10	0	1,953.53	2,180.79	0
PRV-11	1,910.47	50	0	1	1,978.45	1,910.46	67.98
PRV-13	1,876.49	100	10	0	1,956.57	1,992.58	0
PRV-14	1,863.73	100	10	0	1,973.74	1,992.58	0
PRV-16	1,917.96	50	10	0	2,030.85	1,980.92	0

6.9 Pictures of field visit

Picture 2: Babogaya BH site (Source Author)

Picture 1: Field pressure measurement