TECHNICAL EVALUATION OF WATER DISTRIBUTION NETWORKS AND SUPPLY COVERAGE /CASE STUDY OF BODIT TOWN, DAMOT GALE WOREDA, WOLAITA ZONE, SOUTHERN ETHIOPIA REGION

MSc THESIS

BY

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A THESIS SUBMITTED TO DEPARTMENT OF WATER RESOURCE AND IRRIGATION ENGINEERING INSTITUTE OF TECHNOLOGY HAWASSA UNIVERSITY, HAWASSA ETHIOPIA.

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ADVISOR'S APPROVAL SHEET

This is to certify that the thesis entitled as **"Technical Evaluation of Water Distribution Networks and Supply Coverage/Case Study of Bodit Town, Damota Gale Woreda , Wolita Zone, Southern Ethiopian.**" has been approved by the Department of Water Resource and Irrigation Engineering for partial fulfillment of the degree of Master of Science with specialization in 'Water Resource Engineering and Management' and has been carried out by Lebenu Lema, under my/our supervision. Therefore, I/we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Lebenu Lema have read and evaluated his thesis entitled "Technical Evaluation of Water Distribution Networks and Supply Coverage/Case Study of Bodit Town, Damota Gale Woreda , Wolita Zone, Southern Ethiopian", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of master's science.

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DECLARATION

I declare that this thesis is my own original work and all sources of materials used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Lebenu Lema Signature....…………………….........

Place: Institute of Technology, Hawassa University.

Date of Submission ....:………………………………………...................

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LIST OF ACRONYMS & ABBREVIATIONS

AAWSSA	Addis Ababa Water supply and Sewerage Authority
AWWA	American Water Works Association
BH	Borehole
C	Hazzan William Roughness Coefficient
C^{o}	Degree Celsius
CAD	Computer Aided Design
CIWD	Commercial and Institutional Water demand
DWD	Domestic Water Demand
EPS	Extended period simulation
EPA	Environmental protection Agency
EPAN	Environmental Protection Agency Network
EPANET	Environmental Protection Agency Network Evaluation Tool
ETB	Ethiopia Birr
FTU	Formazan Turbidity Unit
HC	House Connection
HDPE	High Density Polyethylene
HHS	Households
HGL	Hydraulic Grade Line
JMP	Joint Monitoring Program
GEMS	Geospatial Engineering Modeling System
GI	Galvanized Iron Pipe
GIS	Geographic Information Systems
GPS	Geographic Position System
GTP-2	Growth and Transformations Program 2
IWA	International Water Association
L/c/d	Liter per capita per day
LULC	Land use Land cover

m.a.s.l	Meter above Sea Level
MNF	Minimum Night Flow
MDG	Millennium Development Goal
MoWIE	Ministry of Water, Irrigation, and Energy
MoWR	Ministry of Water Resource
ND	Nodal Demand
NRW	Non-Revenue Water
OD	Outside Diameter
OWWDSE	Oromia Water Works Design and Supervision Enterprise
PRV	Pressure Reducing Valve
R	Regression
RPS	Rural pipe system
RWS	Rural Water Supply
SNNPR	South Nation Nationality People Region
SSA	Sub-Saharan Africa
UARL	Unavoidable Annual Real Loss
UFW	Unaccounted-for Water
UN	United Nation
UNDP	United Nation Development Program
UNICEF	United Nations Children’s Fund
UWSS	Urban Water Supply System
uPVC	Un-Plastic Polyvinyl Chloride
UTM	Universal Transverse Mercator
UWSSP	Urban Water Supply Project
WDN	Water Distribution Net work
WDS	Water Distribution System
WHO	World Health Organization
YCO	Yard Connection Own
YCS	Yard Connection Shared

Abstract

Water is the primary need to sustain life every citizen in the country has the right to have access to potable water. The main objective of this study was to evaluate the technical analysis of water distribution systems of Bodit Town using WaterGEMSv8i software. Both secondary and primary data sources were used for this study. Moreover, to analyze existing water distribution system a model was developed by using WaterGEMSv8i software. Modeling results showed violation of minimum pressure and velocity criteria at different junctions and pipes. After optimizing the existing water distribution system service reservoir, 93% of the junctions are in the recommended pressure range and 74.29 % of the pipes are in the recommended velocity range. The water loss of the town was 34.28% from the total water production. The analysis showed that the current total domestic water demand in town was 3535.64 m3/day and average per capital domestic water consumption was 23.49 l/c/day. Hence, this result indicates there is a big gap between demand and supply. Generally, the result of the analysis showed that, the overall hydraulic performance of water distribution of the town was poor and, it is therefore significant to improve the water distribution system capacities, changing the diameter of the pipe to get the proper level of pressure and velocity. Therefore, providing more attention to water losses reduction policies and strategies are vital for remedial measures, and this also helps to get clean water at house hold level. Drilling additional borehole water sources, to narrow the gap between supply and demand in water supply system.

Keyword: *technical analysis, water losses, water quality, water supply and Water demand*

1. Introduction

1.1 Background

Water is one of the most essential commodities of every living being in the world. Globally, the population using piped drinking water supplies between 2000 and 2017 year is increased from 3.5 billion to 4.8 billion, this equates to an average of 85,000 people per day over a 17-year period. While over the same period, the population using non-piped drinking water supplies increased from 1.6 billion to 2.2 billion (WHO/UNICEF, 2017). According to WHO and UNICEF (2015) report, almost one-third of all deaths in developing nations and about 80 percent of the diseases are water-related, and each person spends nearly one-tenth of their productive time tending to water-related illnesses. Further, the data indicates that close to two billion people globally lack water services that are well managed, including 1.2 billion people who cannot access basic water services; 282 million with limited services, 367 million who use unimproved sources, and 122 million who drink surface water in 2020. The coverage of well-managed safe drinking water services was higher in urban areas (86%) than in rural areas (60%) per the data of 2020 estimates that 90% of the world's population has been using essential drinking water services, but only 65% of Sub-Saharan Africans have access to these services (WHO, 2021).

Safe drinking water, sanitation and good hygiene are fundamental to health, growth and development. However, these basic necessities are still a luxury for many poor people in many parts of the world. It is estimated that nearly 1.1 billion people, 16% of the world's populations, are still without some form of safe water. While 2.4 billion people, close to 40% of the global population, are living without adequate sanitation. Additionally, inadequate access to water and `sanitation is also unequally distributed between urban and rural areas, and across geographic regions (Mahdi, 2008).

The WHO/UNICEF Joint Monitoring Program (JMP) 2017 Update is the most comprehensive global assessment to date. It establishes country; regional and global baseline estimates for the new Sustainable Development Goal targets and indicators relating to of drinking water, sanitation and hygiene (WASH) and includes a wealth of new information on the types of facilities people use and the level of service they receive. The latest estimates show that some 3 in 10 people worldwide, or 2.1 billion, lack access to safe, readily available water at home.

The most common challenges in water distribution system include water quality degradation, capacity shortages, infrastructure aging and deterioration, demand increases, and their ever-increasing energy consumption coupled with the global energy crisis (CSA, 2007).

This is largely because most of the water utilities do not have enough attention and monitoring systems within water losses and its management, further, water theft, metering error and lack of effective data recording and handling system is the other problem of the water utilities in developing countries (EPA, 2010).

The provision of adequate supplies of potable water for use in urban areas in developing countries is crucial for the well-being of the people. The demand for such supplies in the developing countries has been on the increase over time as a result of rising standards of living that occur with economic progress and population increase resulting from natural growth, and rural urban migration and rising per capital income (Rewata and Sampath, 2000).this is therefore, this study is so paramount to deal the problem of the distribution systems.

1.2 Statement of Problem

Access to safe drinking water is a global concern, at present sub-Saharan countries and in general Ethiopia has low water supply coverage, at most its rural area has shortage of potable water coverage (MoWR, 2011).The scarcity and low coverage of water in urban area is the major problem in many developing countries. Due to increasing Urbanization, Population growth, aging infrastructure, and coupled with unsustainable conventional water management, water loss were facing huge challenge now a day.

Ethiopia has plenty of water resources but the available water is not distributed evenly across the country and the amount varies with seasons and years. The challenge in any situation is to maintain a year-round supply that is adequate to meet people's needs. To ensure that supply meets demand the source of the water must be carefully chosen, considering present and future demand for water (WASH, 2016).

The provision of adequate clean drinking water in the study area has been through challenging situations in the past years and even still has no enough potable water in Bodit TownIn addition to insufficient water supply coverage, high water loss issues due to aged pipe and villages in the town which are out of water supply area of distribution network and even if, villages with distribution network unavailability of water most of the time. Therefore, there is a need to perform analysis of the present status of water supply performance of the existing water distribution system and coverage of water supply of Bodit Town Wolaita Zone Damot Gale Woreda Southern Ethiopia.

1.3 Objectives

1.3.1 General Objective

The main objective of this research is to evaluate the technical analysis of water supply distribution systems of Bodit Town using *WaterGEMS8vi Software.*

1.3.2 Specific Objectives

1. To evaluate existing status of water supply in the Town.
2. To quantify the water loss and pinpointing the causes of water loss in the distribution network,
3. To evaluate technical performance of the water supply distribution network by using WaterGEMSv10i software,
4. To evaluate the water quality of existing water supply

1.4 Research Questions

1. What is the present status of water supply system of the town and does the present water supply system satisfying the current demand of the Town?
2. What is the quantity of water loss in the existing system of water supply?
3. How the technical performance of the existing water supply distribution network?
4. What is the current status of water quality of the water supply system?

1.5 Significance of Study

This study focused on technical analysis of water distribution system and coverage of water supply. This could have a significance on the improvement of evaluating the existing water distribution network, though, indicating the problems in relation to the operation, maintenance activities and hydraulic performance of the water distribution systems with possible mitigation measures. In addition, researchers can use the results of this study as a reference for further research study. Furthermore, this study also serve as a lesson for the future development of water supply distribution schemes in other areas of similar nature.

1.6 The Scope of the study

The scope of this study was limited to investigate only the technical analysis of Bodit Town water distribution system as per the above-stated objectives over the study area. This study was conducted in the distribution network from the borehole water source to the service reservoir and from the service reservoir to the distribution ends. The assessment identified the technical analysis of the existing water supply system and the factors for irregular supply, water loss, and leakage management of the town's water distribution. This was achieved with the application of hydraulic modeling (WaterGEMSv8isoftware) and through discussion with the town water utility personnel together relevant information in the subject area.

1.7 Limitation of the study

Inadequate documentation by the town's water utility office was an additional limitation for this study. It was difficult to get source documents in an organized manner. The study therefore relied on the broad field collected data and estimates. Because of the absence of in depth previous research on water supply of the town, it was not possible to see parameters thoroughly and to do a comparative study or deal with another side of the previous study.

2. Literature Review

2.1 Urban Water Supply and Coverage

Water supply coverage provides a picture of the water supply situation of one specific country or city and helps to compare one country with others and the inter and intra city distribution with in specific country. The percentages of population with or without piped water connection are a relevant indicator to compare the coverage of water supply in urban areas. Although the water supply coverage is better in urban areas while compared with the rural, the actual water supply coverage in cities of developing countries in general and African cities in particular is very low while compared to the demand. According to the Global Water Supply and Sanitation Assessment 2000 Report, the African capital cities are having 43% house connection or yard tap, 21% served by public tap while 31% of the population are un-served (WHO,2000).

In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Walling ford HR.2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use. Water demand management refers to any socially beneficial action that reduces average or peak water withdrawals or consumption form either surface or ground water, consistent with the protection or enhancement of water quality (Tate, 2000).

In developing countries; many water authorities are facing the challenges in providing adequate water supply to the rapidly growing populations. Thereby, most of the existing water supply systems are unable to meet the various demands of water. Besides this; infrastructural aging problem, poor management of the existing system components/assets and utility capacity shortages increased the level of water losses in the distribution system (Welday, 2005).

2.1.1 Water Demand

Water resources must be used effectively to meet the demand of the ever-growing population, considering the limited and dwindling water availability (Connor et al., 2017). Water demand is the amount of water required to fulfill the demand of consumers. It depends on the size of the city, lquality of water, metering system, pressure in the pipeline, etc. It is necessary to determine the quantity of water required daily before designing water supply schemes. In the context of water resource management, human and natural scale mismatches can impose substantial unanticipated costs to water utilities if demand is incorrectly estimated (Billings and Agthe, 1998). Water demand increases with time because of the fast population growth and urban expansion. Therefore, developing new sustainable water resources based on adjusted water demands is important to meet the increasing water demand at present and future times.

2.1.2 Types of Urban Water Demand

Urban water demand is classified into different categories: a) domestic water demand and b) non-domestic demand.

2.1.2.1 Domestic Water Demand

Domestic water demand is the quantity of water required in houses for drinking, bathing, cooking, toilet flushing, gardening, etc. Domestic water consumption varies according to the mode of service, climatic conditions, socio-economic conditions, and other related factors. The domestic water demand analysis for the town was made based on the urban water supply design criteria. Commonly, there are three categories of mode of service, namely yard connection, public tap connection, and house connection. But, according to (MWR 2006, p. 14), the mode of service is divided into four categories as shown below.

House connection (HC)

Own yard connection (YCO).

Yard connection share (YCS)

Public tap supplies (PT)

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

2.1.2.2 Non-Domestic Demand

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

Industrial Water Demand

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

Commercial and Institutional Water Demand

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

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

Fire Water Demand

For assuring public safety, the provision of adequate fire demand is quite important. However, unless there is a specific national and/or local regulation, water required for firefighting shall be met by stopping supply to customers for the required time of fire suppression due to economic reasons (OWWSE, 2010).

2.2 Water Loss and Leakage

According to Allan (2003), Leaks can be categorized in different ways like physical and administrative losses. Physical losses can be caused by leaks which may occur in any part of the system like transmission pipes, service reservoirs, pumps, distribution networks, and house connections. Whereas administrative losses can are related to illegal connections, faulty (under registering) or broken meters, inaccurate billing, etc.

2.2.1 Some Definitions of Unaccounted for Water (UFW)

There is no universally applied or accepted definition of unaccounted-for water. In general, Unaccounted-for water (UFW) is the difference between the water supplied to a distribution system and the water that leaves the system through its intended use (Richard G.et al.,2000) UFW may be defined as the percentage of the water produced from the raw water source which is not accounted for (MWAC, 1999). UFW is defined as the difference between water delivered to the distribution system and water sold (Yepes, 1999).

The term Unaccounted-for Water (UFW) refers to an accumulated range of losses that will be experienced by water Utility when comparing the system demand of a hydraulic water network with the quantity of water that is acknowledged as consumed by the water consumers residing within the network (UNEP, 2000).

Although the above definitions seem to have differences, all have in common that they took the water produced and distributed to the system as an input and the water consumed or exported from the distribution system as an output. From the local context, the UFW has been defined as the water loss calculated as the difference between the amount of treated water produced and supplied and the total amount of water billed and collected. The volume of water consumption due to the inaccuracy of the water meters as well as the lump-sum payments made by the customers when their meters cannot be repaired are also taken in to account for the determination of the UFW (AAWSA,1997). On the other hand because of the widely varying interpretation of the term 'Unaccounted-for UFW) worldwide, the IWA task forces do not recommend the use of these terms. If the term UFW is used at all, it should be defined and calculated in the same way as ‘non-revenue water’ (NRW) (Farley and Trow, 2003)

2.2.2 Methods of Measuring Water Losses

The unaccounted-for water (UFW) expressed as a percentage of the total consumption and the minimum night flow (MNF) per connection are the most commonly used methods of measuring losses. UFW is the measure of losses over a period as the difference between the amount of water put into a system and the metered or estimated quantity of water taken by consumers, while MNF is an indicator of the probable rate of losses at a given time. Unaccounted for water is a useful indicator of probable losses, but it may overestimate them because supply meters tend to under-record consumption. In the UK, figures for unaccounted for water tend to be unreliable because the un-metered consumptions have to be estimated and can be 10% in error. Attempts to compare the performance of different undertakings by measuring some uniform figure for domestic consumption can be misleading. Many factors influence unaccounted for water and differ from one undertaking to another, standards of housing, rates of occupancy, age of mains, length of mains per 1000 population served proportion of trade and bulk supplies, ground condition, etc. (Twort A.C.***et al***., 1994) The minimum night flow (MNF) per property connection is a better indicator of loss rates on part of a system. However, figures of this type are affected by the characteristics of an area; in dense urban areas there will be more blocks of flats with large storages which may fill at night. Nevertheless, the MNF is a good direct indicator of the state of parts of a system (Twort AC ***et al,*** 1994). On the other hand, Weimer referring to fully metered situations considers that the annual water balance can initially only be taken as a guide as the calculations are susceptible to errors, analyses show this uncertainty in the calculated annual losses to be +/-46% (Lambert and Wallace, 1993). Different countries use different methodologies to evaluate the losses like the U.K. leakage practitioners and planners consider leakage almost exclusively in terms of night flow rates, rather than as a calculation of annual losses as in West Germany. Each 13 method has its respective merits. 'Annual losses' are used for retrospective assessment of overall performance and long-term demand forecasting. 'Night flows' are used by practitioners responsible for leakage control and prioritization of leakage control activities. Any conceptual model, therefore, needs to be able to link night flows with annual losses in a consistent manner (Lambert and Wallace, 1993).

2.3 Water Supply Coverage

Service level refer to utility`s declared dedication to deliver service of specified level in water supply institutes. Service level can be regulatory/customer related (response times, information availability, complaints etc.) or performance related (asset performance drove by faults, equipment failure etc.)

The quality of service is assessed based on service indicators consisting of coverage of service zone, service hours, metering and billing and the degree of responsiveness of service providers to consumer`s complaints. All sources confirm that water supply coverage in Ethiopia is on a strong upward trajectory.

According to official government data, water supply coverage has risen in 1990 from (11 percent rural, 70 percent urban) to in 2009 (62 percent rural, 89 percent urban). Based on the official government data, Ethiopia has already met of 60 percent. Estimates of current coverage from the International Joint Monitoring Program (JMP) are significantly more cautious, due to a range of factors. Nevertheless, the JMP data still portray a remarkable increase in coverage of over 1 million people per year (1990–2008), (AMCOW, 2015).

A municipal water supply system has the objective of providing an adequate and reliable water supply to meet the following demands:

- Residential occupancy water consumption;
- Commercial occupancy water consumption;
- Industrial occupancy consumption;
- Municipal and educational building use; etc.
- Needed Fire Flows (NFFs) that are available from a planned location of fire hydrants throughout the municipality; and
- Water for special community needs that include parks and recreation, street cleaning, decorative water fountains, sale of water to contractors through metered water from fire hydrants, etc. (Harry, 2008) .

The problem of inadequate access to water supply exists in both rural and urban areas, but the problem is particularly pressing in cities. With internal migration and the “urbanization of poverty,” cities are where an increasing proportion of the poor live. In the last three decades, growth in urban populations in developing countries exceeded that of rural areas three times more.

According to Ethiopian water sector (strategy, 2015) "As per the GTP-2 water supply service level standard, it is required to provide safe water in minimum 25 l/c/day within a distance of 1km for rural areas while in urban areas it is required to provide safe water in minimum 100 l/c/day for category 1 towns/cities (towns/cities with a population more than 1 million), 80 l/c/day for category 2 towns/cities (towns/cities with a population in the range of 100,000- 1million), 60 l/c/day for category 3 towns/cities (towns/cities with a population in the range of 50,000 -100,000), 50 l/c/day for category 4 towns/cities (towns/cities with a population in the range of 20,000-50,000) up to the premises, and 40 l/c/day for category-5 towns/cities (towns/cities with a population less than 20,000) within a distance of 250m".

2.4 Water Supply Distribution System

In water distribution system, the reliability of water with a constant flow rate should be available to customers throughout the design time. If water is not available in sufficient quantities it should be pumped for a short period of time and at high flow rate, to meet the various demand of customers. Accordingly, service reservoir/storage tanks usually provided in order to store water when the pumping rate is higher than the demand at low/night times. But, this can be also used in the case that the pumping rate is below the needed demand, since to equalize the pressure in the network (Zyoud, 2003).

In developing countries; many water authorities are facing the challenges in providing adequate water supply to the rapidly growing populations. There by, most of the existing water supply systems are unable to meet the various demands of water. Beside to this; infrastructural aging problem, poor management of the existing system components/assets and utilities capacity shortages were increasing the level of water losses in the distribution system (Welday, 2005; Jalal, 2008). Water utilities are facing the high level of water loss in their distribution networks. 'For many utilities, reducing loss should be the first option to pursue when addressing low service coverage levels and increased demand for piped water supply. But, expanding water distribution networks without addressing water losses will only lead to a cycle of waste and inefficiency' (Frauendorfer & Liemberger, 2010). However, there is no simple solution to reduce water losses in the distribution system especially in the developing world, it should be involving improvements not only regard to the water system, but also required a change in attitudes (WUAM, 2013).

In addition, understanding how leakage are currently performing and collecting relevant data, and turning it into useful information for planning and good information systems are essential to water loss reduction polices (Farley, et al., 2008). In general, using a computer model; assessing the hydraulic behaviors and evaluating the performance of existing towns' water distribution network are advantageous. Therefore, making hydraulic simulation software, especially from hydraulic point view using engineering approach is one of the methods used for discussion and decision measure on the system, either is the system within level of service based on pressure consideration or not (Zyoud , 2003).

2.4.1 Importance of Water Distribution System

In the design of water supply distribution system, its being recognized that consumption varies with the season, month, day, and hours. As far as design of distribution system is concerned it is the hourly variation in consumption that matters the fluctuations in consumption is accounted for by considering the peak rate of consumption. The variation in the demand will be more pronounced in the case of smaller population and will gradually even out with the increasing population this is so because increase in large population different habits and customs of several groups tends to minimize the variation in the demand pattern. The product, delivered to the point of consumption, is called potable water if it meets the water quality standards required for human consumption. The water in the supply network is maintained at positive pressure to ensure that water reaches all parts of the network, that a sufficient flow is available at every take-off point and to ensure that untreated water in the ground cannot enter the network. The water is typically pressurized by pumps that pump water into storage tanks constructed at the highest local point in the network. One network may have several such service reservoirs. In small domestic systems, the water may be pressurized by a pressure vessel or even by an underground cistern (the latter however does need additional pressurizing). This eliminates the need of a water-tower or any other heightened water reserve to supply the water pressure. These systems are usually owned and maintained by local governments, such as cities, or other public entities, but are occasionally operated by a commercial. Water supply networks are part of the master planning of communities, counties, and municipalities. As water passes through the distribution system, the water quality can degrade by chemical reactions and biological processes.

2.4.2 Types of Water Supply Distribution System

According to (Tomas, et al., 2003), the water distribution networks can classify as explained below.

Branched System

This network is also called a tree system. The water has only one possible path from the source to a customer. Thereby, these are applicable for small-capacity water suppliers, and are common in most developing countries. The advantage of these system is the most economical because of its low cost, but it has some disadvantages as presented below;

- Low reliability, affects all users especially located downstream of any breakdown in the system. So that, their water services were interrupted until the repairs are finished.
- Fluctuating in water demand, producing rather large pressure variations in the system.
- When there is a need for developing the network, new branches follow that development and new dead ends will be constructed.
- It also danger of contamination during the network without water.

Looped System

As the name suggests, in looped systems it serves different paths that water can follow to get from the source to a particular customer. The systems are generally more desirable than branched systems because it coupled with sufficient valves and accessories, and can provide reliability in the water distribution. In these system because of more than one path for water, the system capacity is greater and it improves the hydraulics of the distribution system. In the looped system, that break can be isolated and repaired with little impact on outside of that immediate area. While, the effect of water service interruption is more significant to branched system. (source: Advanced water distribution modeling and management: Haestad Methods)

2.4.3 Components of Distribution Network

Transmission and Distribution Mains

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

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

Distribution Mains: Distribution mains are an intermediate pipeline used to delivering water from transmission main to customers.

The mains are smaller in diameter than transmission mains, and typically follow Pipe Break Customers without Services Customers without Services the general topology and alignment of the town streets. Different fittings such as elbows, tees, reducers, crosses and numerous other accessories are used in the main to connect pipes. While, other maintenance and operational appurtenances, such as fire hydrants and valves are also connected directly to the distribution mains. Further, services also called service line were laid and transmit water from the distribution mains to end customers.

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

Pump

Stations: Pumps are used for convey energy to the water in order to boost water at higher elevations. Most pumps used in the water supply systems are centrifugal in nature, and are installed to improve the water distribution, if gravity is insufficient to supply water at an adequate pressure. So that, to control the operational condition of pumps switch-board were provided in the station.

2.5 Hydraulic Analysis and Design of WDN

The computation of the flows and pressures in networks of pipes has been of great value and interest for those involved with the design, construction and maintenance of public water distribution system and with the advent of computer network components of WDS as well as to investigate more complex issues associated with their design and operation (Ormsbee, 2006). In a water distribution system, the steady state analysis is an important component of assessing the adequacy of a network. The hydraulic problem in connection with pipe networks consists of solving for the distribution of flow and head loss in the individual elements for a given total discharge or for a total given total head loss. The supply may be from reservoirs, storage tanks or pumps or specified as in flow or outflows at some points in the network and from the known flow rates the pressure or head losses through the system is computed. Alternatively, the solution may be initially for the heads at each junction of the network and these can be used to compute the flow rates in each pipe of the distribution system. Within the formulation individual energy equations for every pipe are combined with individual nodal equations for every junction node to provide for a simultaneous solution for both nodal heads and individual pipe flow (Ormsbee, 2006). The method can directly solve both looped and branched network is numerically stable when the system becomes disconnected by checked valves, pressure regulating valves, or modeler’s error and the structure of the extremely fast and reliable sparse matrix solves (Haestad Method, et al., 2003).

2.5.1 Basic Principles of Hydraulic Modeling

The hydraulic simulation model of distribution network is taken into account to be one within which all elements are connected to every other, every element is influenced by its neighbors and every element is consistent with the condition of all other elements. These conditions are mainly controlled by two laws; law of conservation of mass and law of conservation of energy. Thus, the total mass of water living within the system should be equal to the total mass of water leaving in the system and also the sum of the flows at any given node should be equal to zero. The principle of conservation of energy is principally dictated by the Bernoulli's equation, which states that the difference in the energy between any two points should be the same regardless of the path taken (Haestad Method, et al., 2003). A typical network in hydraulic model consists of the following components; these are pipes, storage tanks, pumps, valves and reservoirs.

The junctions are representing points having particular base demands. Reservoirs are those points in model, which can have a specific storage capacity that varies with time. Reservoirs in hydraulic model are assumed to be an infinite source of water (Haestad Method, et al., 2003). Pumps are energy devices which provide pressure and head to the water distribution system. Generally, there are three parameters that define the pump operation; shut off head, the design point and the maximum point. The pump should be able to overcome the elevations differences, which is dependent on the topography of the system. The head added on the pump to overcome these differences is called the static head. Friction and minor losses also affect the discharge from beginning to end of the pump.

2.5.2 Hydraulic Model Selection Criteria

Due to the rise of advanced computing techniques and applications. There are various computer software's developed for the purpose of design and analysis of models for a water distribution networks like EPANET, Water CAD, Water GEMS, etc. Among this application software's Bentley Water GEMS/CAD at the current time is a well-known throughout the world due to its availability, functionality, user interference, compatibility, etc. The advantages of Water GEMS V8i over other software's its tools for a simplified model building with geospatial modules like water quality modeling, fire flow analysis, optimization and scenario management, etc. Water GEMS V8i is thus easy to use as a multipurpose water distribution schemes as well as quality modeling. In addition, the main advantage of Water GEMS application is its various tools like Darwin designer for analyzing cost of pipes and pipe catalogue tools which are found to be very effective for modeling, design and optimization of water distribution network with respect to strong data management and integration along with AutoCAD, ArcGIS and other related software packages (Bentley Systems, Incorporated, 2014). Moreover, the choice of software's for modeling distribution network is based on the overall cost of project, data required by software's, specificity of the software related to types of distribution networks it can handle as well as its computational requirements.

2.5.2.1 Bentley WaterGEMSv8iCONNECT Edition Update 2

WaterGEMSv8iCONNECT Edition Update 2 is a powerful tool for hydraulic Modeling software package with the advancements in highly competent and active Modeling software, which provides wide management of investigation and resolutions for fire-flow analysis, water quality Modeling. Many of the features and functions are common in Water CAD V8i and WaterGEMSv8i CONNECT Edition Update 2, which modernizes the model building, integrated with the GIS and AutoCAD functionalities, and optimized model calibration, scenario management, design, and its operations (Rudolf, & Liemberger, 2010). The best part of the Water GEMSCONNECT Edition Update 2 is the presentation of obtaining results which is very attractive and appealing and can be presented with a variety of graphical tools include Arc Map conception, thematic charting, contouring, outlining with color coding and symbology. WaterGEMSv8iCONNECT Edition Update 2 is selected due to the ease of model building and operation and is greater programming competencies as compared to water CAD V8i.

The software finds the lowest allowable diameter for each pipe segment that will allow the system to function, or more specifically, to meet the minimum pressure requirements at all junctions (Shinde, et al., 2018).

2.5.2.2 Input data for assembling the model.

Brown (2007) has recognized as a water distribution system model is created using a link node formulation that is governed by two conservation laws, namely mass balance at nodes and energy management round hydraulic nodes. The node is an idea where water drinking is allocated and defined as demand which treated as the nodal hydraulic head can be solved. This design is valid only if the hydraulic pressure at all nodes is acceptable so that the demand is autonomous of pressure. All the nodes are connected by the pipes. In practice, pipe networks consist not only of pipes but composed of various fittings, services, storage tanks and reservoirs, meters, regulating valves, pumps, and electronic and mechanical controls. For modeling purposes, these system elements were organized into the following categories (Hussni, & Zyoud, 2003a).

Table 2 1*: Input parameters and the primary purpose of water GEMS tools*

Label	Type	Primary Modeling purpose	Input data
Reservoir	Node	Provides water to the system	Hydraulic Grade Line, water surface elevation
Pump	Node/Link	Provides energy to the system and raise the water pressure to overcome elevation deference and friction loss	Elevation, pump definition (characteristics of max, operation and design discharge, head efficiency)
Tank	Node/link	Store execs water within the system and release that water at the time of high usage	Base elevation, maximum elevation, minimum elevation and Diameter
Valve	Node / Link	Controls flow or pressure through a pipe and results in losses of energy in the system	Elevation, diameter, valve type
Pipe	Link	Transport water from one node to another node	Diameter, material, Pipe length and roughness coefficient
Junction	Node	Discharge the demand required or recharge the inflow water from/to the system	Elevation

(Source: Hussni & Zyoud, 2003a)

2.5.3 Water GEMS Simulation

Simulation refers to the process of imitating the behavior of one system through the functions another. In our case, the term simulation refers to the process of using a mathematical representation or real system, called a model (Bentley Water CAD/GEMs, 2008). Simulation can be used to predict system responses to under a wide range of conditions without disrupting the actual system, and solutions can be evaluated before time, money, and materials are invested in a real-world project. There are two most basic types of simulations that a model may perform, depending on what the modeler is trying to observe or predict. These are:

- Steady state simulation.
- Extended period simulation (EPS)

Steady State Simulation

It computes the state of the system (flows, pressures, pump operating attributes, valve position, and so on) assuming that hydraulic demands and boundary conditions do not change with respect to time. A steady-state simulation provides information regarding the equilibrium flows, Pressures and other variables defining the state of the network for a unique set of Hydraulic demands and boundary conditions. Steady-state models are generally used to analyze specific worst-case conditions such as peak demand times, fire protection usage, and system component failures in which the effects of time are not particularly significant.

Extended Period: Simulation Extended period simulation tracks a system over time, and it is a serious of linked steady state run. The need to run extended period simulation is because the system operations change over time.

- Demands vary over the course of the day
- Pumps and wells go on and off
- Valves open and close
- Tanks fill and draw

Simulation Duration: An extended-period simulation can be run for any length of time, depending on the purpose of the analysis. The most common simulation duration is typically a multiple of 24 hours, because the most recognizable pattern for demands and operations is a daily one.

Hydraulic Time Step: An important decision when running an extended-period simulation is the selection of the hydraulic time step. The time step is the length of time for one steady-state portion of an EPS, and it should be selected such that changes in system hydraulics from one increment to the next are gradual. A time step, too large May cause abrupt hydraulic changes to occur, making it difficult for the model to give good results. Using an EPS model, we can simulate based on the peak, minimum and average day demands.

Pressure Head and Velocity

Water distribution networks must maintain adequate water pressure throughout the network to ensure continuity in service and for fire suppression. Low water pressure can result in flow reductions and high-water pressure can cause leaks and damage to system components.

The main problems related to the water supply distribution network of the cities were the high-water loss (actual water loss) mainly due to increased pressure above the recommended limits and insufficient water due to low pressure at nodes. Practical and short-term measures should be applied to minimize these challenges. High pressure and low pressure at nodes are a reason for reducing the hydraulic performance of the water distribution network. High pressure above recommended values (70 m) is a cause for pipe burst that leads to water loss and pipe failure (Dual, 2020). The low pressure at a demand node decreases the amount of water delivered to the consumer. Installing pressure regulating values (PRV) at critical points is a cost-effective and short-term measure that significantly minimizes and regulates the high-pressure problem at nodes, considerably reducing physical water loss in the system.

Lower pressure (water deficit) at the nodes is resolved by introducing an overhead tank near the affected area to increase the head at nodes responsible for the low water flow at maximum hourly demand. Further, low velocity in the pipes is resolved by redesigning the system and changing some old pipelines in a problematic area with the recommended diameter size. Other water loss problems in WSS can be minimized by active leakage control, pressure management, infrastructure management, and repair speed. Monitoring and controlling the entire Water distribution system using advanced and computerized systems is crucial to operating components properly (Beker, B.A., Kansal, M.L. 2023).

Water velocities shall be maintained at less than 2 m/sec, except in short sections (see also paragraph 5.2 for pumps). Velocities in small diameter pipes (<DN100) may need even lower limiting velocities. A minimum velocity of 0.6 m/sec can be taken, but for looped systems there will be pipelines with sections of zero velocity.

Head loss is related to velocity and pipe roughness. The maximum head loss with therefore be governed by the maximum velocity criterion (MoWR, 2006)

Head Loss

A continuous resistance is exerted by the pipe walls during water flow. This resistance depends on the flow rate, pipe dimensions and internal roughness of the pipe material as well as from the fluid viscosity, and results in linear head degradation along the pipeline. A head-loss (energy) for a specified length is commonly referred to as friction loss. There are several formulae for calculation of head losses. The most frequently used in the design of water supply system are Darcy-Weisbach and Hazen Williams formulae (OWWSE, 2010).

2.6 Water Quality

Water quality issues are critical, just like the water supply problem in urban Ethiopia; hence, the supplied water should be safe and potable for consumers. The water quality may deteriorate because of travel in space and time and natural or artificial accidents. Ensuring appropriate water quality for the consumer is one of the primary responsibilities of water utilities. The safety of water supplies can be judged based on the health risk posed to the users (Beker, B.A., Kansal, M.L. (2023).

According to WHO (2008), the basic requirements for domestic water use are: free from pathogenic organisms, no compounds that have adverse effects on human health, fairly clear, not saline, no offensive taste and smell, not causing corrosion or incrustation of the supply system.
To provide safe water there is a need to ensure that the quality of drinking water is assessed and monitored (UNEP, 2008). Quality is defined by certain physical, chemical and biological characteristics. Even a personal preference such as taste is a simple evaluation of acceptability. Drinking water quality is assessed by comparisons of water samples to drinking water quality guidelines or standards. These guidelines and standards provide for the protection of human health, by ensuring that clean and safe water is available for human consumption (WHO, 2008).

2.6.1 Physical Indicators

Physical indictors of water include Turbidity, Color, Odor, Temperature, Electrical conductivity WHO, 2008).

Table 2 2 *: Physical parameter (WHO, 2011 and ES, 2013)*

S.No	Description	Unit	WHO Standard	Ethiopian Standard
1	Turbidity	FTU	5	5
2	Color			
3	Odor		Un objectionable	Un objectionable
4	Temperature	C^o		
5	Electrical Conductivity	μs/cm	2500	2500

2.6.2 Chemical Parameters

Chemical parameters of drinking water quality give an indication of water acceptability for human consumption, which can be domestic use, agricultural use and industrial use (Chatwell, 1989). The chemical parameters must be taken into consideration in the assessment of water quality, such as source protection, treatment efficiency and reliability and protection of the distribution network (WHO, 1996). Chemical water quality parameters in Ethiopia are Iron, Hardness, pH, Nitrate, Fluoride, Manganese, and Chloride (Mengistayehu Birhanu, 2007).

Table 2 3*: Chemical Parameters (WHO, 2011 and ES, 2013)*

S.No	Description	Unit	WHO Standard	Ethiopian Standard
1	PH		6.5-8.5	6.5-8.5
2	TDS	Mg/l	1000	1000
3	Total chlorine	Mg/l	5	5
4	Total hardness	Mg/l	300	300
5	Calcium hardness	Mg/l	300	300
6	Magnesium hardness	Mg/l	300	300
7	Total Alkalinity	Mg/1	500	500
8	Bicarbonate alkalinity	Mg/l	500	500

9	Dissolved Ammonia (NH3)	Mg/l	1.5	1.5
10	Ammonium ($NH4^{+}$)	Mg/l	1.5	1,5
11	Sodium (Na^{+})	Mg/l	200	200
12	Potassium (K)	Mg/l	1.5	1.5
13	Calcium (Ca^{+})	Mg/l	100	100
14	Magnesium (Mg^{+})	Mg/l	30	30
15	Iron (Fe^{+})	Mg/l	0.3	0.3
16	Copper (Cu^{+2})	Mg/l	2	2
17	Manganese (Mn^{+2})	Mg/l	0.5	0.5
18	Chromium (Cr^{6+})	Mg/l	0.05	0.05
19	Fluoride (F^{-})	Mg/l	1.5	1.5
20	Chloride (CL^{-})	Mg/l	250	250
21	Nitrite (No_2^{-})	Mg/l	3	3
22	Nitrate (No_3)	Mg/l	50	50
23	Sulfate ($So4^{2-}$)	Mg/l	250	250
24	Phosphate ($Po4^{3-}$)	Mg/l	0.1	0.1
25	Bicarbonate (Hco_3^{-}	Mg/l	500	500 -
26	Carbonate ($Co3^{2-}$)	Mg/l	-	-

2.6.3 Bacteriological Parameters

Microbiological quality is the most important aspect of drinking water in relation to waterborne diseases. Detection of bacterial indicators in drinking water means the presence of pathogenic organisms that are the source of waterborne diseases. Such diseases could be fatal. (Macler., et al 2000).

The most common and widespread health risk associated with drinking water is contamination, either directly or indirectly, by human or animal excreta, and with the micro-organisms contained in faeces. Monitoring of specific bacterial, viral and protozoan pathogens is usually complex, expensive, and time consuming, and may fail to detect their presence. In monitoring for microbiological quality, reliance is therefore placed on relatively rapid and simple tests for the presence of indicator organisms. The common organisms used as microbial indicators are total coliforms (TC) and Escherichia coli (*E. coli)* (US EPA, 1999; WHO, 2008).

Table 2 4 *:* Bacteriological Parameters (WHO, 2011 and ES, 2013)

S.No	Description	Unit	WHO Standard	Ethiopian Standard	Incubation temperature
1	Total coliform	(CFU/100ml)	0	0	
2	*E*.Coli (fecal coliform)	(CFU/100ml)	0	0	

3. Material and Methods

3.1 Description of Study Area

Bodit town situated in Southern Central Ethiopia at a road distance of 147km Southwest of Hawassa town, 370km South of Addis Ababa and 18kms from Wolaita Zone capital, Sodo town. The town is accessed through asphalt road running from Addis Ababa to Arba Minch via Shashamane town and or Addis Ababa to Shashamane-Hawassa via Butajira-Hosaina-Sodo towns. The town is bounded with geographical coordinates between UTM/ WGS84 37º50'0"E to 37º53'0"E longitude and 6º56'30"N to 6º58'0"N latitude in Zone 37N.

The study area characterized by sub-humid climatic nature experiencing low to moderate temperature, medium to high rainfall and low to moderate evapotranspiration. The mean annual temperature is estimated at about 20.15ºC. The hottest month is February while the relatively coldest one, being said, is December. The mean annual rainfall in the project area is estimated to be about 1200.6mm. From town administration Office total population of the town is 85,407 of this male 41,849 and female 43,558 for the year 2023.

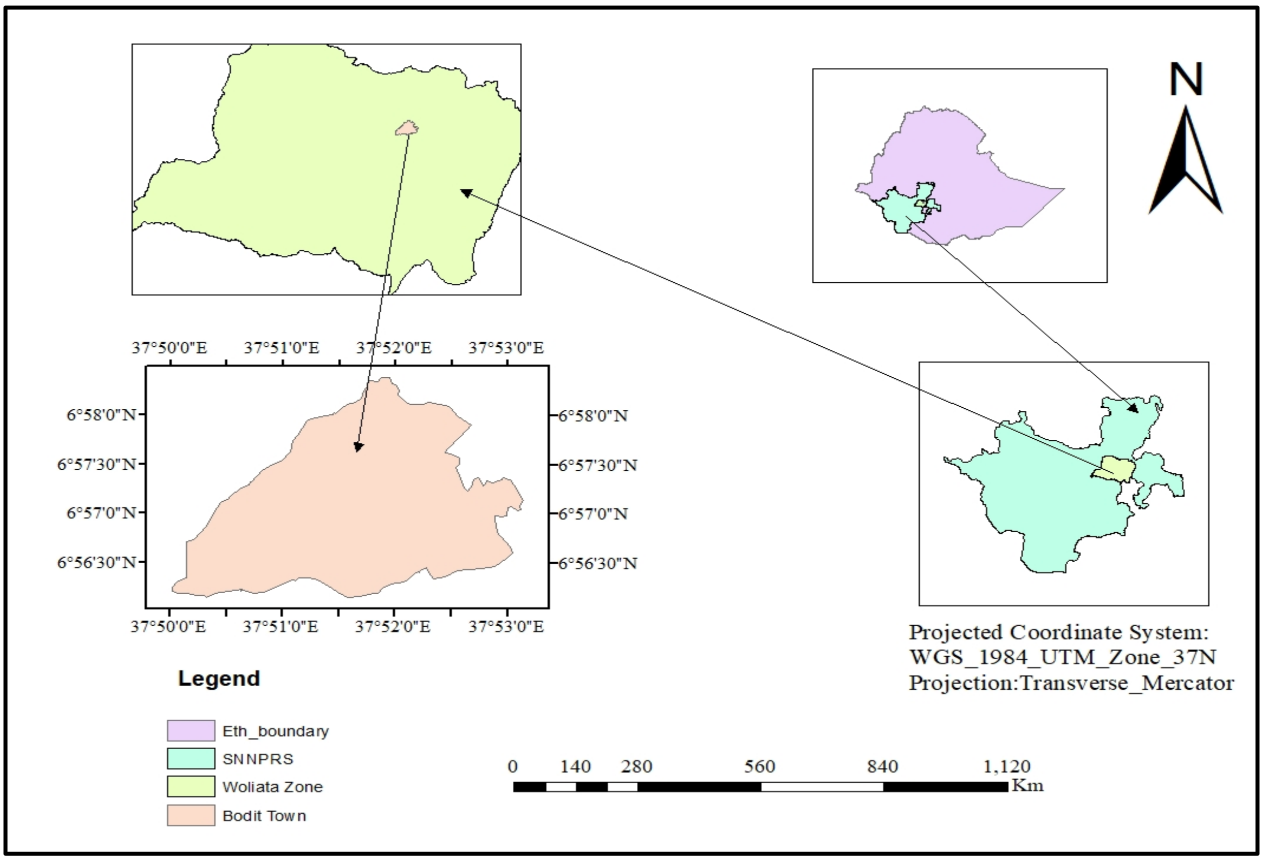

Figure 3 1: ***Location Map of Bodit Town.***

3.2. Materials

For this research work, the following equipment and materials were used for data collection, processing and evaluation.

- WaterGEMSv8ihydraulic model: to determine velocity, nodal pressure and other parameter
- Arc GIS 10.3: for delineation of the study area,
- GPS: to check coordinates points of reservoir and sources of water supply
- Global Mapper: to check the elevation of the network,
- Pressure gage: to measure the pressure at the nodes and pump outlet
- DEM, AutoCAD 2018 and Google Earth Pro.

3.3 Methods

3.3.1. Data Collection

Prior to the fieldwork, all necessary information prepared by the Regional Water Irrigation Mines Development Bureau and Wolaita Zone Water Irrigation and Mines Department use as a base for the study area. The secondary data were collected from the city administrative municipality office, Regional Water Irrigation Mines Development Bureau and Wolaita Zone Water Irrigation and Mines Department, Town water supply and sewerage service and the other relevant sector of the city. Supportive qualitative information were gathered through discussion with experts of the Regional Water Irrigation Mines Development Bureau and Wolaita Zone Water Irrigation and Mines Department and Town Water Supply and Sewerage Service direct concerned different technical staff and departments.

3.3.2. Existing water supply sources of the town

Currently Bodit Town is getting its water supply from ground water sources. Seven boreholes were drilled at different locations, by different organizations. The sources of water supply system of the town, which are functioning currently located at Ade koisha kebele, Bodit Agaza , Bodit Korkie and Chawakare. The following boreholes found in the aforementioned kebeles respectively. BH 1, BH 3, BH 5 and Chawakare Borehole. The potential yield of BH1, BH 3, BH 5 and Chawakare are 20l/s, 20l/s, 25l/s and 8.9 l/s respectively. The total yield is 73.9 l/s .BH 1, BH 3, BH 5 and Chawakare borehole is located 5.612km, 3.915km, 1.487km and 2.976km from service reservoir respectively. Summary of existing water sources in and around the Bodit town are shown in table 3.1 below.

Table 3 1: The existing water sources of Bodit Town

Label	X (m)	Y (m)	Elev. (m)	Q (l/s)
BH-01	376219	773220	1903	20
BH-02	375684	772549	1918	19
BH-03	374807	771636	1914	20
BH-04	374313	770624	1923	18
BH-05	372055	768756	1986	25
Chawakare	375135	768002	1929	8.9
Melese metasebia	373542	770219	1959	10
Total				120.9

Though seven boreholes were drilled by the governmental organization in surrounding areas of Bodit town to serve the town and rural Kebeles. The current status of the Boreholes indicated that only four boreholes are functional. The status of the bore holes their respective year of construction indicated below in table 3.2.

Table 3 2: The Status of Existing Water Supply Source

S/No	Name of Boreholes	Yield (l/s)	Remark	Construction Year
1	Melese Metasebya	10	Non functional	2015
2	BH 02	19	Non functional	2019
3	BH 04	18	Non functional	2019
4	BH 01	20	Functional	2022
5	BH 03	20	Functional	2022
6	BH 05	25	Functional	2023
7	Chawakare	8.9	Functional	2015
	Total	120.9		

Source: Bodit Town Sewerage and Water Utility Enterprise 2023

3.3.2.1 Water Production

The water production has been evaluated as total annual water supplied to the water distribution system (WDS). The production of water depends on supply system, which administrated by Bodit town water service Enterprise.

In Bodit water supply system, there is big discrepancy between the demand and production of water. As result of this water is distributed intermittently and even some compartment of the town does not receive water for long period. The daily production of water from the boreholes is 6384.96 m^3 assuming that the pumps working for 24 hours per day. However, significant proportion of water produced is lost in the system. But we considered the actual production (4375 m^3) for waterGem analysis as shown in the table 3.3.

Table 3 3: Daily Production and Year of Construction of Existing Boreholes

Name of Source	Constructed by	Year of construction, EC	Design Yield (l/s)	Daily production (m3)	Actual Pumping hour	Actual daily production m^3
BH 01	SNNPR WMEDB	2022	20	1728	**16**	**1152**
BH 03		2022	20	1728	**18**	**1296**
BH 05		2023	25	2160	**15**	**1350**
Chawakare BH		2015	8.9	768.96	**18**	**577**
	Total		73.9	6384.96		**4375**

Source: (Data Collected from Field and BTWSSE data 2023)

3.3.3. Water distribution system of the town

The water distribution system is started from the source of supply, in this case from the boreholes. The water is pumped using different diameters of ordinary HDPE, DCI and GI transmission pipe from the existing borehole to the different service reservoir systematically scattered on the chained train to Bodit Town. There is no continuous supply of water in the distribution system. Almost half part of the community of the town could not get ample water supply pressure problem. As a result, currently the water production from ground water sources is not sufficient.

Table 3 4: The Existing Pipes in Transmission main line of Bodit Town

Material type	Pipe diameter(inch)	Length(m)
DCI	6	3284
DCI	6	1585
DCI	8	1105
GI	4	1751
DCI	12	1225
DCI	8	1487
DCI	12	4834

(Source: Bodit Town Water and Sewerage Service Enterprise, 2023)

3.3.4. Existing balancing reservoir of the town

The existing water distribution systems of the town are both pump and gravity system. The water from the four sources are taken to $2000m^3$ reservoir by pumping which give service to the Town and from this reservoir busted to another 800 m^3 reservoir to give service to upper part of the town of which cannot get water from $2000m^3$ reservoir.

Figure 3 2: The existing $800m^3$ reservoir in the Town

Figure 3 3: The existing 2000m3 reservoirs in the town

3.3.5. Water production and Consumption of the town

In order to evaluate the water loss of distribution system of the town, water production and billed water consumption data was collected. There were more than 5225 numbers of customers in Bodit water supply system. These customers within the entire area have been considered to estimate domestic water supply coverage, water loss and demand gap analysis. The total annual water production and consumption data the town from was shown in table 3.3 below.

Table 3 5: Annual Water Production and Consumption of Bodit Town

Year (G.C)	Production (m^3/year)	Consumption (m^3/year)
2019	898,982	565,913
2020	621,465	450,872
2021	621,465	460,359
2022	1,353,447	936,359
2023	1,596,910	1,076,813

3.3.6. Operation & Maintenance Information of the Town

The system was operated by the town utility operator. A progressive mode of tariff was set by the town water board (TWB) and collection of water revenues are being carried out by the utility operator and utilizes it for operation and maintenance of the town water supply system. As reported by the utility operator all customer connections are metered except the Public Taps. The utility operator has operation & maintenance manual, 'as built' drawing, technical data sheet for electro-mechanical equipment, pipes, fittings and accessories. But they are not updated and revised. The utility operator is being trying to update them by this time but technical support is required.

3.4. Water Supply Coverage

The water supply coverage of study area was evaluated based on the average per capital consumption by using yearly domestic consumption with the current population and level of connection per family by using the total domestic connection as per average family size. The whole system water supply coverage has been evaluated by considering domestic as well as non-domestic user by using Design guide line of MoWR (2006). For this study the average family size of 6 was used.

$$\text{Per Capital Consumption (l/person/day)} = \frac{\text{Annual Consumption(m3)} * 1000\ \text{l/m3}}{\text{Population number} * 365\ \text{day}} \ldots\ldots\ldots (3.1)$$

$$\text{Connection per family} = \frac{\text{Total number of connection}}{(\text{number of population of the town/Average family size})} \ldots\ldots\ldots.. (3.2)$$

3.4.1 Analysis of Water Demand Coverage of Bodit Town

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

A. **Domestic Water Demand**

Estimation of water demand per mode of service and estimation of population by mode of service was used to calculate the average per capita water demand. The average per capita domestic water demand for each year was computed by combining water demand by mode of service and population percentage distribution by mode of service for the year 2019-2023.

There are three modes of services identified for domestic water consumption of town such as, house connection user, yard connection user, and public tap user. The per capital water demand for various categories of the town was adopted by taking into account the different development factors and standards used by the Ministry of Water Resources (MoWR, 2006).

i. Population percentage distribution by mode of service

The mode of service is an important element to assess the level of water coverage of the town. Based on the available data obtained from the Water Supply Service during the field visit in 2023; three major modes of service were identified for domestic water consumers. These are house tap users (HTU), yard connections users (YCU), and public tap users (PTU). The distribution of population for each mode of services was determined by considering socio-economic situation and living standard of the town (MoWR, 2006).

ii. Per-capita domestic demand by mode of service

The per-capita domestic water demand for various demand categories varies depending on the size of the town and the level of development, the type of water supply scheme, the socio-economic conditions of the towns and the climatic condition of the area. The per capita water demand for adequate supply level has to be determined based on the basic human water requirements for various activities of demand category (MoWR, 2006).

Adjustment to climate

In addition to per-capita water demand and mode of services which influence the quantity of water consumption, the climate also affected the water consumption and the per-capita domestic demand was adjusted by a factor which is given in table 3.5.

Table 3 6 : Climate Adjustment factor (MoWR, 2006)

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

Adjustment for socio-economic activity

The domestic water demand also depends on the socio-economic situation of the area. Thus per-capita domestic water demand was modified using appropriate factor. The demand adjustment factors in socioeconomic situations were given in table 3.7.

Table 3 7 : Demand adjustment factor for socioeconomic situation

Group	Description	Factor
A	Towns enjoying living standard and with very high potential development	1.10
B	Towns having a very high potential for development, but lower living standard at present	1.05
C	Towns under normal Ethiopia condition	1.00

B. **Non-Domestic Water Demand**

i. Institutional Water and Commercial Demand

The water required for schools, hospitals, health centre, government offices and services, religious institutions and other public facilities is classified as institutional water demand whereas the water required for restaurants, shopping centres, local drinks, and other commercial purposes, is classified as commercial water demand. Both water demands are termed as public water demand. This type of demand is recommended 10% of the domestic demand.

ii. Industrial Water Demand

Water required under this head depends mainly on the type of industry in the town or area. The water required by factories, paper mill, textile mills, breweries, sugar mill, etc. comes under industrial uses. This demand accounts 5-10% of the total domestic water demands. In Bodit Town there is no huge industries, so for this study industrial demand was taken as 10% of domestic demand.

iii. Fire Demand

Fire demand is the quantity of water required for fighting a fire that may break out at commercial center, stores, etc. in the town. Fire demand can be expressed as a function of population and it is estimated by using empirical formula. But, in Ethiopia, the demand is generally taken care of by increasing the size of service reservoirs by 10 % (MoWR, 2006)

iv. Unaccounted water demand

This includes the quantity of water due to wastage, losses, etc. from water supply systems vary considerably according to diverse factors. System losses are a function of the quality of construction, the type and age of pipes in the distribution network and pressure within the system (MoWR, 2002). For urban schemes, unaccounted water equivalent to 25% of the total domestic, commercial and institutional, and industrial water demand was assumed. Note that the total water demand is the sum of domestic demand, unaccounted for water and non-domestic demand.

Variation of Water Use

The maximum daily water demand and peak hour demand coefficients and factor respectively figured out in table as the guidelines.

Table 3 8: ***Maximum daily coefficient and peak hour factor***

Maximum daily coefficient	Town population	Peak hour factor
2.00	0-50,000	2
1.55	50,001-100,000	1.8
1.45	>100,000	1.6

(Source: MoWR, 2006)

In demand analysis knowing maximum daily demand and peak hour demand are very crucial. The maximum daily demand is based on the average daily water required and peak hour demand is greatly influenced by population size.

3.5. Water Loss Analysis

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

3.5.1. Quantifying Total Water Loss

In order to evaluate the total loss of water in the town, the total volume of water input to the network distribution system was compared with the actual water consumption. In this case, the data on consumption were collected to the entire town level. The total annual water produced and distributed to the system and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water loss for the town.

All the water consumptions in the town were metered as the authorized non-metered consumption is insignificant while compared with the total water production, the unaccounted-for water (UFW) has been used as a similar of the total water loss in this study.

Certain level of water losses could not be avoided from a technical point of view and considered as acceptable from an economic point of view. According to AWWA leak detection and accountability committee (1996) recommended 10% as a benchmark for UFW (Sharma, 2008).

3.5.1.1. Water Loss by Mathematical Calculation

Water loss expressed as a percentage can be an appropriate means to show the extent of the loss within a given town, but it is not a good indicator for comparing the losses from one area to another. Water loss as % of net water production was used to quantify losses as it could be expressed by Equation 3.4 (EPA, Slums of the World: the faces of urban poverty in the new millennium, 2010).

$$\text{UFW (\%)} = \frac{\text{Total water produced} - \text{Total water billed}}{\text{Total water produced}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4)}$$

UFW levels less than 10% is acceptable and no need for monitoring action whereas UFW levels 10-25% is intermediate and could be reduced. UFW levels above 25% are very acute and it requires immediate action for water loss management.

3.5.1.2. Water Loss by Water Balance Method

The AWWA Water Balance diagram shown in table 3.7 describes all component volumes of water supplied, delivered to customers, or lost during the course of a reporting year. Each box represents an annual volume of water, and each column totals to the same amount of water. Thus, all columns "balance" as water moves across the system, and all water is accounted for. Accordingly, there is no "unaccounted-for" water, and AWWA recommends against use of the term "unaccounted-for water." Instead, AWWA recommends use of the term NRW. The water balance diagram provides accountability for water utilities by defining a clear path to quantify the loss volumes and demonstrate how those losses affect utility operations.

Table 3 9: Classification of water balanced method

<table>
<tr><td rowspan="8">System input volume
A1</td><td rowspan="4">Authorized Consumption
A2= A4 + A5</td><td rowspan="2">Billed Authorized Consumption
A4= A8 + A9</td><td>Billed Metered Consumption
A8</td><td rowspan="2">Revenue Water
A18 =A8+A9</td></tr>
<tr><td>Billed Unmetered Consumption
A9</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption
A5= A10 + A11</td><td>Unbilled Metered Consumption
A10</td><td rowspan="6">Non-Revenue Water (NRW)
A19 = A1-A18</td></tr>
<tr><td>Unbilled Un metered Consumption
A11</td></tr>
<tr><td rowspan="4">Water Loss
A3= A1-A2</td><td rowspan="3">Apparent Losses (Commercial Losses) **A6 = A12 + A13 + A14**</td><td>Unauthorized consumption
A12</td></tr>
<tr><td>Customer meter inaccuracies
A13</td></tr>
<tr><td>Systematic data handling Errors
A14</td></tr>
<tr><td>Real Losses</td><td>Leakage in Transmission and</td></tr>
</table>

		(Physical Losses) **A7 = A15 +A16 +A17**	Distribution Mains **A15**	
			Storage Leaks and Overflows from water storage Tanks **A16**	
			Service Connection leaks up to the meter **A17**	

3.5.2. Unavoidable annual real losses (UARL)

The annual volumes lost through all types of leaks, bursts, and overflows on mains, service reservoirs and service connections up to the point of customer metering is real losses.

UARL represents the allowable volume of real losses from the system, which estimated a volume of leak that are undetectable or would be uneconomical to repair during the year. This could help to evaluate the feasibility of real loss minimization (provides better understanding of real loss component). The total length of main pipes, number of service connections and the average pressure from the result of WaterGEMSv8iwas used in the calculation of UARL. Based on the analysis, unavoidable annual real losses of town were determined as (Farley M. &., 2003):

UARL= (18*Lm+0.8*Nc+ 25*Lp) *P………………………………………………… (3.5)

Where, UARL = unavoidable annual real losses (l/d)

Lm = length of main pipes (km)

Nc = number of service connections (main to meter)

Lp = Total length of private pipe property line to customer meter (km) or length of unmetered underground pipe from street edge to customer meter (km)

P=average operating pressure (m)

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

$$NRW = system\ input\ volume - Billed\ authorized\ consumpition \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

Apparent Losses consist of components that seem like losses to the municipality, but are actually consumed. Apparent losses are mainly made up by unauthorized consumption (theft or illegal use) and Metering inaccuracies, but can also include administrative errors.

The total amounts of apparent losses in the system were determined from the Bodit Town water balance

$$\text{Apparent loss } = \text{Total NRW} - \text{UARL} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

3.6. Data Analysis

To analyze the data which was collected from different sources, both qualitative and quantitative methods were used. From the quantitative methods, the descriptive statistical methods like percentage, graphs and cross tabulation were used in order to come up with the appropriate result. The computer software application water GEMS model and excel were used to analyze the data obtained from office and field survey. The field survey data for distribution system was evaluated by using the software *Water GEMS connect edition 10, Global Mapper and GIS.* The method of analysis was based on nodal pressure and velocity parameters. During data analysis, the nodal pressure and pipe link velocity were determined to identify higher or lower pressure zone of the area. The standard value of nodal pressure and velocity were determined. The value which was under normal value taken as acceptable and below and above the standard values taken as unacceptable compared with urban design criteria (MoWR, 2006).

3.6.1. Technical Analysis of Distribution Network of the Town

The entire water supply network of the town, including their attribute like pipe length, diameter and material type, pipe material, pump stations and reservoir were collected from town water supply and sewerage enterprise. Hydraulic simulation was determine the hydraulic parameters such as velocity, pressure, head loss, flow etc.by using water software water GEMS.

Bentley Water GEMS

It is a multi-platform hydraulic and water quality modeling solution for water distribution systems with advanced interoperability, geospatial model-building, optimization, and asset management tools (Ramesh et al., 2012).

The calculation software algorithm which is based on Hydraulic Gradient method, allows the hydraulic analysis of water networks determining the pressures at various points in the system, as well as the flow rates, velocities, losses the lines that make the water network, and many other operating parameters derived from the elements present in the system as pumps, control valves, tanks, etc. from the physical characteristics of the system and demand conditions previously established. Water GEMS also allows extend its capabilities to issues of long-term management of supply systems including: vulnerability analysis fire protection analysis, cost estimating energy, hydraulic calibration, optimization, etc. This additional program to conventional tools for analysis and modelling of pressurized networks has productivity tools in data management processes, building models from external files, elevation extraction, mapping techniques demands from spatial analysis, preparation and management of scenarios, additional hydraulic calculations, operational management and preparation of reports and plans. In addition, the software provides several options for displaying results as tabular reports, profiles, time-varying graphs, notes and color coding, etc. (Ramesh et al, 2012).

Developing the Distribution Network

The network was developed by using data entry dialogue boxes to enter data from field surveys, offices, and other sources, such as nodes (elevation, geometry, and base demand), pipes (pipe diameters, pipe lengths, material types, pipe roughness), tank (base, initial, minimum, and maximum elevation, and diameters of the tank), pumps (elevation, pump head, and yields), and Hazen–Williams pipe coefficient pipes values, and other necessary values by flex table of the software. The data analysis was simulated by developing water distribution network scenarios to evaluate the performance of the hydraulic parameters in terms of pressure, velocity, flow, head loss, and other. There are various types of simulation that a model may perform, depending on what the modeler trying to observe or predict.

Nodal Demand Allocation

To allocate the base nodal demand for water distribution network, the following steps were followed: the town shape file obtained from the town administration was displayed on ArcGIS in a given area was calculated by dividing their respective area. The Theisen polygon was used to design the nodal influence area around each demand node on the town water distribution network using the Water GEMS software, and it could be converted to shapefile format. The Theisen polygon was used to form a polygon around the junction influenced area on the Water GEMS software and saved in shape file format. The town shape file, which was filled with relevant data in ArcGIS, was loaded into Water GEMS using the Load builder toolbar of the software.

The demand for each junction was assigned within the load builder toolbar on Water GEMS within the load estimation by area methods.

Steady State Period Simulation

Steady state analyses determine the operating behavior of the system at a specific point in time or under steady-state conditions (flow rates and hydraulic grades remain constant over time). This type of analysis can be useful for determining pressures and flow rates under minimum, average, peak. For this type of analysis, the network equations are determined and solved with tanks being treated as fixed grade boundaries. The results that are obtained from this type of analysis are instantaneous values and may or may not be representative of the values of the system a few hours, or even a few minutes, later in time.

Extended Period Simulation

This illustrate how to model a water distribution system over time using the extended period simulation (EPS) calculation engine and by adding demand patterns to junctions. An EPS could be conducted for any duration you specify. System conditions are computed over the given duration at a specified time increment. Some of the types of system behaviors that could be analyzed using an EPS model include how tank levels fluctuate, when pumps are running, whether valves are open or closed and how demands change throughout the day.

Scenario Management

One of the many hydraulic model tools in Bentley Water GEMS is Scenario Management. Scenarios allow you to calculate multiple "What If?" situations in a single file. You may wish to try several designs and compare the results, or analyze an existing system using several different demand alternatives and compare the resulting system pressures. A scenario is a set of alternatives, while alternatives are groups of actual model data. Scenarios and alternatives are based on a parent/child relationship where a child scenario or alternative inherits data from the parent scenario or alternative.

Head Loss Calculation

The Hazen-Williams formula is the most commonly used head loss formula for the hydraulic head lost by water flowing in a pipe due to friction with the pipe walls, is being used for the present study (Bentley System Incorporated, 2012). Darcy-Weisbach equation is viewed by many engineers as the most accurate method for modeling friction losses. However, the Hazen Williams formula is widely used for manual design and analysis of a pipe line system for its less complexity than Darcy Weisbach. In any case, the end result of any design is to select and quantify appropriate and economical pressure pipes and fittings that could deliver the required quantity of water and pressure to consumers provided that all other design criteria are met (Oromia WWDSE,2010).

Reporting Results

An important feature in all water distribution modeling software is the ability to present results clearly. It outlines several of Bentley Water GEMS reporting features, including

- Element Tables (Flex Tables), for viewing, editing, and presentation of selected data and elements in a tabular format.
- Profiles, to graphically show, in a profile view, how a selected attribute, such as hydraulic grade, varies along an interconnected series of pipes.
- Contouring, to show how a selected attribute, such as pressure, varies throughout the distribution system.

- Element Annotation, for dynamic presentation of the values of user-selected variables in the plan view.
- Color Coding, which assigns colors based on ranges of values to elements in the plan view. Color coding is useful in performing quick diagnostics on the network.
- Reports, which display and print information on any or all elements in the system

Flex Table

When data must be entered for a large number of elements, clicking each element and entering the data can be time consuming. Flex Table fields can be changed using the global edit tool, or filtered to display only the desired elements. Values that are entered into the table will be automatically updated in the model. The tables can also be customized to contain only the desired data. Columns can be added or removed, and the order in which they appear can be rearranged. Flex Tables are dynamic tables of input values and calculated results.

Pressure

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

Table 3.10: Operating pressure in distribution network (MoWR,2006)

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

Velocity

Water velocities should be maintained at less than 2 m/sec, except in short sections. Velocities in small diameter pipes (<DN100) may need even lower limiting velocities. A minimum velocity of 0.6 m/sec can be taken, but for looped systems there will be pipelines with sections of zero velocity (MoWR, 2006).

3.7. Evaluation of Existing Water Supply Coverage

Water supply coverage is usually evaluated based on the quantity, quality, paying capacity of the people, distance, etc., the quantity of supply and level of connection that are related to the imbalance between supply and consumption of water to the city. The number of domestic connections per family and the average daily per capita consumption is used to analyze the domestic water supply coverage for the entire study area. Access to water supply may be evaluated using the amount of water consumed and the level of connection. For evaluating the amount of water consumption, the annual water consumption is converted to average daily per capita consumption using the population data of the city.

$$\text{Per capital consumption (l/person/day)} = \frac{\text{Anual consumption in (m3)} \times 1000\text{l/m3}}{\text{Number of population of the city} \times 365 \text{ days}} \quad \text{Eq. 3.4}$$

3.7.1. Base population

The 2007 CSA survey did not address the town of Boditi with the currently proposed town coverage encompassing the rural kebeles. Thus, the base population figure obtained from the town municipality office is considered for future population projection. As per the data collected from the municipality and town water supply and sewerage service for 2023 the estimated total population of the town with expected expansion areas encompassing the rural kebeles to the current town administration is about 85,407 population.

3.7.2. Water Demand

3.7.2.1. Domestic Water Demand

The domestic water demand is the portion of that municipal water supply, which is used in home and largest portion of total demand for most water system (DOH, 2009). It includes toilet flash, cooking, drinking, washing, bathing, and other uses.

Mode of Services

It indicates the consumer's category in urban water supply system and it is directly related with the ability to pay and the living standard of the population. Four major types of mode of services have been considered as; house connection, yard connection (owned), yard connection (shared) and public tap users. The percentage of mode of service of any community changes over times as the living condition of the user's changes (SNNPRS WIMDB, 2022).

Per Capita Mode of Service

The per-capita water demand is the sum of the water requirement for different uses which is related to specific conditions of the project area, living standard of the people and availability of water supply facilities, etc. The water requirement for different domestic use could also vary based on the mode of service to be used and the closeness to water supply facilities. The per capita demand depends on the service level mix; the proportion of population served through house connections, yard connection (owned & shared) and public fountains (SNNPRS WIMDB, 2022).

Table 3 11: Mode of service per capita water demand MoWR, 2006

Modes of Service	Stage I (L/cap/day	Stage II (L/cap/day)
House connection (HC)	50	70
Yard Connection Owned (YCO)	25	30
Yard Connection shared (YCS)	30	40
Public Tap (PT)	20	25

Provide urban water supply access with GTP-2 minimum service level of 100 l/c/day for category-1 towns/cities, 80 l/c/day for category-2 towns/cities, 60 l/c/day for category-3 towns/cities, 50 l/c/day for category-4 towns/cities, up to the premises and 40 l/c/day for category-5 towns/cities within a distance of 250m with piped system for 75% of the urban population (GTP-II, 2015). Therefore, the per capita water demand was setted according to MoWR, 2006 and GTP-II plan base. The total domestic demand is then found by multiplying the per-capita per day demand with population served by each mode of service, adding the amount of water demand calculated for each mode of service.

Adjustment Socio-Economic Factors

Water used by a person depends on the climatic and socioeconomic conditions of the area. This means water is more used at hot area than cold ones. In addition, reach people consume more water than poor ones. These are adjusted by multiplying the adjustment factors with total domestic demand. Climatic and Socio- economic Condition Adjustment Factors are presented in the following two tables respectively:

Table 3.12: Climatic Adjustment Factor Oromia WWDSE, 2010

Mean annual Temp.(°C)	Description	Altitude	Factor
<10	Cool	>3300	0.8
10--15	Cool Temperate	2300--3300	0.9
15--20	Temperate	1500--2300	1
20--25	Warm Temperate	500--1500	1.3
25 and above	Hot	<500	1.5

Table 3 103: Socioeconomic Adjustment Factor MoWR, 2006

Group	Description	Factor
A	Towns Enjoying high living standards and with very high potential for development	1.1
B	Towns having a very high potential for development but lower living standards at present	1.05
C	Towns under normal Ethiopian conditions	1
D	Advanced Rural Towns	0.9

The total domestic water demand is computed after applying the socio-economic level of town and climate adjustment factors on total domestic water demand stated so far is called adjusted domestic water demand. It is also highly recommended to check the total water demand as whether it satisfies the nation's development plan or not.

Total Adjusted Domestic Water Demand (TADWD) = CAF*SAF*DWD

3.7.2.2. Non-Domestic Water Demand

Commercial and Public Water Demands: Commercial demand includes water requirement for restaurants, Cinema houses railways, bus stations, hoping centers, Local drinks (Teji, Areqe, Xela) etc. whereas institutional/public demand includes water required by schools, hospitals, public offices, military camps, public parks, dispensaries, day-care centers and so on. In case where exhaustive estimation of the public and commercial institutions are not possible it is recommended to take 20 to 40% of the domestic water demand, depending on the size of population (Oromia WWDSE,2010).

Industrial Water Demand (IWD): This demand category includes demands for small to medium scale industries which are intended to be supplied from the public water sources. For larger scale industries, it is recommended to develop their own sources. Since heavy industries will impose large stress on town water supply systems, it is recommendable to have their own sources. Industrial demand always covers two categories as; water for human needs (for workers) and water for industrial processes. The amount of water needed for industrial use depend on type of industry and technological processes (Oromia WWDSE, 2010). Small-scale industrial enterprises will not be categorized separately but should be included in the allowance for institutional and commercial demand (MoWR, 2006).

Unaccounted Water or Non-Revenue Water Demand (UWD): Unaccounted-for water (UFW) is expressed as a percentage of the total water produced for the system. 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).

Firefighting Water Demand

Water demand for firefighting purposes shall be assessed on a town-by-town basis, depending on the existence of equipment and the capacity of any firefighting service. Fire hydrants shall be installed at public and municipality interest such as schools, shops, hospitals, fuel stations and at salient points of distribution network. This demand is taken by increasing the volume of the storage tanks by 10 % (MoWR, 2006).

Average Daily Water Demand

This is obtained by simply summing up the domestic and non-domestic demands as well as unaccounted for water (UFW) (Oromia WWDSE, 2010).

Average Daily Water Demand (TWD)= DWD+CIWD+IWD+UWD

Maximum Day demand

It is the highest demand of any one 24-hour period over any specified year. It represents the changes in demand with season and some special events happening in any specified year. The maximum day demand is obtained by multiplying the average day demand with the maximum day peak factor.

Peak Hour Demand

It is the highest demand of any one-hour over the maximum day. It represents the diurnal variations in water demand resulting from the behavioral patterns of the local population. The peak hour demand is obtained by multiplying the maximum day demand with the peak hour factor**.**

Demand Variations

Seasonal Peak

Towns in Ethiopia are characterized by widely varying climatic conditions and so the variations in consumption during the year, reflected by a peak seasonal factor, will similarly vary. Some consultants have adopted a seasonal peak factor of 1.1. The seasonal peak factor adopted for any particular scheme shall be selected according to the particular climatic conditions and existing consumption records (if reliable and unsuppressed).

It is expected that seasonal peak factors will vary between 1.0 and 1.2, representing the relative increase in the average daily demand during the dry and/or hot season months compared with the average annual demand (MoWR, 2006).

Peak Day Factor

Many communities exhibit a demand cycle that is higher in one day of the week than in others. This situation shall be considered by the use of a peak day factor. Some consultants have used peak day demand factors of between 1.0 and 1.3. The value adopted for the design of each individual scheme shall be selected according to judicious observance of the habits of consumers and the knowledge of the community and system operators. It is expected that any value selected for the peak day factor would not fall outside the above range (MoWR, 2006).

Peak Hour factor

Water demand varies greatly during the day. The distribution system must be designed to cope with the peak demand, which is considered by the use of a peak hour factor. This peak hour factor is expressed as a multiple of the annual average daily demand and applied additionally to the seasonal and peak day factors. The peak hour factor varies inversely with the size of the consumer base (MoWR, 2006).

Table 3 114: Peak Hour Factor According to MoWR, 2006

Population range	Peak hour factor
<20,000	2
20,000-50,000	1.9
50,000-100,000	1.8
>100,000	1.6

3.8 Water Quality

The key to increase human productivity and long life is good quality of water. The provision of good quality drinking water is often regarded as an important means of improving health (Chan et al., 2007). The analytical results from laboratory analysis compared with the WHO, 2011 water quality guide line standards. The physicochemical parameters included electrical conductivity (EC), pH, Total Dissolved Solids (TDS), Turbidity (TUR), Nitrate ($NO3^{-}$), Hardness, Iron (Fe), Manganese (Mn), and residual Chlorine (Cl).

3.8.1. Physicochemical Parameter

Turbidity: Formazin turbidity measure the intensity of light scattered by the suspended particles. The result is a measurement of turbidity in Formazin Turbidity Units (FTU). A simple test to measure the turbidity is to use a 2 L clear plastic bottle filled with the sample water. Place this on top of large print. If you can see this logo looking down through the top of the bottle, the water probably has a turbidity of less than 5 FTU.

Color: In general, color of a water sample is evaluated by simple visual observation. It can also be measured by visual comparison with a series of standard solutions.

Odor: Odor and taste are evaluated by observation. When smelling a water sample from an unknown source, do not breathe the odor in directly. Use your hand to gently waft the vapors towards your nose. Never drink a sample from an unknown source.

Temperature A thermometer is used to measure the temperature of water. Temperature does not carry any significance in terms of contamination. However, we generally prefer cool water over warm water. High water temperature (20-30°C) can also enhance the growth of microorganisms and may lead to taste, odor, color and corrosion problems. The most desirable temperature for drinking water is between 4^oC to 10^oC ($39-50^oF$) and temperatures above 25^oC (77^oF) are usually objectionable.

Electro conductivity: The electro conductivity measured in laboratory by the electro conductivity probe instrument. The instrument inserted into the sampled water and then read the electro conductivity content.

pH: pH is one of the most important parameters of water quality. It is defined as the negative logarithm of the hydrogen ion concentration (Spellman FR,2017 and Edzwald JK, 2010) It is a dimensionless number indicating the strength of an acidic or a basic solution. Actually, pH of water is a measure of how acidic/basic water is. Acidic water contains extra hydrogen ions (H^+) and basic water contains extra hydroxyl (OH^-) ions. As shown in Figure 2, pH ranges from 0 to 14, with 7 being neutral. pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base solution. Pure water is neutral, with a pH close to 7.0 at 25°C. Normal rainfall has a pH of approximately 5.6 (slightly acidic) owing to atmospheric carbon dioxide gas. Safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and living organisms need [WHO; 2011]

Total Dissolved Solids (TDS): The palatability of water with a total dissolved solids (TDS) level of less than about 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l.

The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances (WHO, 2011).

Nitrate (NO_3): A high concentration of nitrate in surface water can stimulate the rapid growth of the algae which degrades the water quality. Nitrates can enter the groundwater from chemical fertilizers used in the agricultural areas. Excessive nitrate concentration (more than 10 mg/L) in drinking water causes an immediate and severe health threat to infants. The nitrate ions react with blood hemoglobin, thereby reducing the blood's ability to hold oxygen which leads to a disease called blue baby or methemoglobinemia (Tchobanoglous G. et al, 2003)

Hardness: Hardness is a term used to express the properties of highly mineralized waters (APHA, 2005). The dissolved minerals in water cause problems such as scale deposits in hot water pipes and difficulty in producing lather with soap (Davis ML, 2010). Calcium (Ca2+) and magnesium (Mg2+) ions cause the greatest portion of hardness in naturally occurring waters [9]. They enter water mainly from contact with soil and rock, particularly limestone deposits. These ions are present as bicarbonates, sulfates, and sometimes as chlorides and nitrates (APHA, 2005). Generally, groundwater is harder than surface water. There are two types of hardness:

- Temporary hardness which is due to carbonates and bicarbonates can be removed by boiling, and
- Permanent hardness which is remaining after boiling is caused mainly by sulfates and chlorides (APHA, 2005). Water with more than 300 mg/L of hardness is generally considered to be hard, and more than 150 mg/L of hardness is noticed by most people, and water with less than 75 mg/L is considered to be soft. From health viewpoint, hardness up to 500 mg/L is safe, but more than that may cause a laxative effect [10]. Hardness is normally determined by titration with ethylene diamine tetra acidic acid or (EDTA) and Eriochrome Black and Blue indicators. It is usually expressed in terms of mg/L of CaCO3 (APHA, 2005 and Tchobanoglous G. et al, 2003)

Iron (Fe) and Manganese (Mn)

Although iron (Fe) and manganese (Mn) do not cause health problems, they impart a noticeable bitter taste to drinking water even at very low concentration (APHA, 2005). These metals usually occur in groundwater in solution as ferrous (Fe2+) and manganous (Mn2+) ions. When these ions are exposed to air, they form the insoluble ferric (Fe3+) and manganic (Mn3+) forms making the water turbid and unacceptable to most people (APHA, 2005). These ions can also cause black or brown stains on laundry and plumbing fixtures (Chatterjee, 2001). They are measured by many instrumental methods such as atomic absorption spectrometry, flame atomic absorption spectrometry, cold vapor atomic absorption spectrometry, electrothermal atomic absorption spectrometry, and inductively coupled plasma (ICP) (APHA, 2005).

Residual Chlorine (Cl): Chlorine (Cl_2) does not occur naturally in water but is added to water and wastewater for disinfection (APHA, 2005). While chlorine itself is a toxic gas, in dilute aqueous solution, it is not harmful to human health. In drinking water, a residual of about 0.2 mg/L is optimal. The residual concentration which is maintained in the water distribution system ensures good sanitary quality of water (Davis ML, 2010). Chlorine can react with organics in water forming toxic compounds called trihalomethanes or THMs, which are carcinogens such as chloroform CHCl3. Chlorine residual is normally measured by a color comparator test kit or spectrophotometer (APHA, 2005).

3.8.2. Bacteriological parameters

The three common organisms used as microbial indicators are Total coliforms (TC), thermotolerant coliforms (TTC) and Escherichia coli (*E. coli)* will be examined.

To analyze the quality (WHO, 2008) states that the samples must be taken from location that representative of the water resource, treatment plant, storage facilities, distribution network, point at the water delivered to consumer, the point of use. Therefore, based on these criteria the samples are taken from the source and water point (Bono) that near to the consumer samples will be collected analyzed in SNNPR Water Resource Bureau Laboratory and checked with WHO guideline standards. Total coliform, Thermotolerant and Escherichia (E. coli) will be also analyze onsite filter method which reads the result after 24 hours. WHO (2006) advise that the bacteriological results will be taken with 6 hours after collection to avoid the growth death of microorganisms in the sample.

4. Results and Discussion

4.1 Water Supply Coverage Analysis

4.1.1 Existing Water Supply Coverage in the Town

The coverage of the water supply of the Town has been evaluated based on the average per capita consumption and by mode of service. The average per capita consumption has been derived from the yearly consumption that was collected from the individual domestic water meters. The analysis of average domestic water supply consumption of the town is found to be only 23.49 %. According to Ministry of Water Resources, according to GTP-II (Ethiopian Water Sector Strategy, 2015); the per capita consumption standard set for category-3 town like Bodit is 60l/d within a distance of 250 m, so the water supply coverage of the town is below the standard.

4.1.2 Water Production and Consumption

The water production capacity of the borehole in the area was (1,596,910 m3/year). The water production of the town shows a variable trend year after year and the lowest production rate was recorded in 2020/21 due to the ceasing of Melese Metasebia BH service as shown in (Table 4.1).

Table 4 1: ***Water Production and Consumption of Bodit Town (2019-2023)***

Year	Production m^3/year	Consumption m^3/year
2019	898,982	565,913
2020	621,465	450,872
2021	621,465	460,359
2022	1,353,447	936,359
2023	1,596,910	1,076,813

4.1.3 Average Per capita Water Consumption

The water supply coverage of the town was evaluated based on the average per capita consumption. Evaluating the domestic water supply coverage using volume of consumption may not allow realizing the distribution comparison among the town. For this reason, the annual consumption data has been converted to average daily per capital consumption using population the number. The average water consumption per capita was derived from the town's annual consumption, which was aggregated from the individual water meter and the public tap as shown in (Table 4.2)

Table 4 2: ***Annual Water Consumption Trends in the Town (BTWSSE, 2023)***

Description	Unit	Year				
		2019	2020	2021	2022	2023
Population number	No	71,427.00	74,692.00	78,105.00	81,674.00	85,407.00
Total Domestic consumption	m3/year	424,435	306,593	313,044	636,724	732,233
Average per capita water for Domestic consumption	l/c/day	16.28	11.25	10.98	21.36	23.49
GTP-II minimum service level	l/c/day	60	60	60	60	60

The result of the analysis as indicated above in Table 4.2, the average domestic water consumption of the town in year 2023 is found as 23.49 l/c/day. According to WHO (2008), the minimum quantity of domestic water required in urban areas of developing country is taken as 20 l/c/day. From this value, the domestic water supply of Bodit Town is below from the standard value.

Furthermore, according to GTP-II (Ethiopian Water Sector Strategy, 2015); the per capita consumption standard set for category-3 town like Bodit is 60 l/c/day within a distance of 250 m. But the current water supply of the Town is 23.49 l/c/d which is far below from the standard.

Finally, according to GTP-II (Ethiopian Water Sector Strategy, 2015); the per capita consumption standard set for category-3 town like Bodit is 60 l/c/day. From this side also water supply coverage is only satisfying almost 39.15 % of the demand.

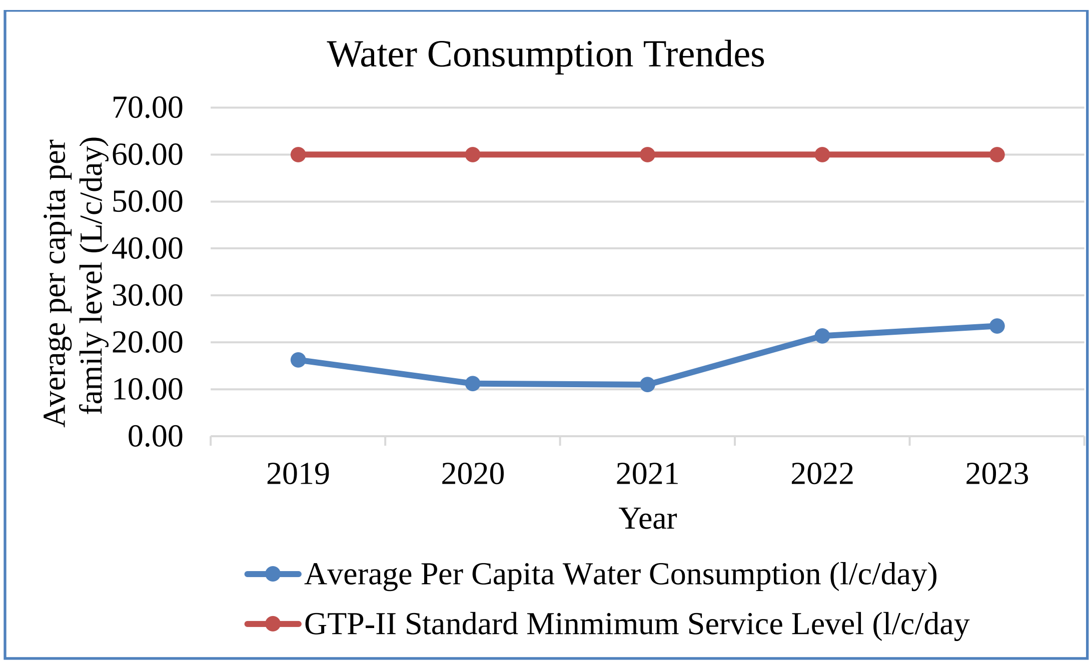

Figure 4 1: Water per water consumption Trends from 2019 to 2023.

4.2 Water Loss Analysis

Globally, water demand was increasing while the recourses were diminishing. Water loss from water distribution systems has long been a feature of the Water distribution system operations management. Water loss occurs in all water supply distribution, only the quantity of loss varies and depends on the physical characteristics of the pipe network, operating factors and parameters, and the level of technology and expertise applied to control this loss.

Reducing and controlling water loss was becoming very important issue in this age of rapidly growing demand and relative abundance to one of relative scarcity of the water resource, and climate changes that bring droughts to many locations over the world (Hossam, 2011). The water resources were subjected to the fluctuations of the nature and were therefore largely beyond the human control. In order to preserve valuable water resources, many wat0er utilities have been developing new strategies to minimize losses to an economic and acceptable level.

Residential, commercial, industrial, public water use, and unaccounted system loss and leakage constitute the overall water demand. While all components create revenue to the water utility, the unaccounted system loss and leakage were not associated with total cost revenues, and are a source of wasted production costs. With today's high-water production, treatment and transmitted costs and rates, the expense of detecting and reducing the unaccounted-for water and leakage was an attractive solution for minimizing operating expenditures.

The total water loss for the town was calculated using the total annual water produced and distributed to the distribution system, as well as the water billed from individual customer meter readings. The water loss is usually expressed in terms of percentage unaccounted for water (UFW), and loss per properties or number of connections. The total water loss has been evaluated based on the three measurement approaches as explained here below.

4.2.1 Percentage of Water Loss (UFW)

The total annual water produced and distributed to the system within the specified year of 2023 G.C is 1,596,910 cubic meters and the annual total water loss is 520,097cubic meters that accounts for 32.57 % of the total water production.

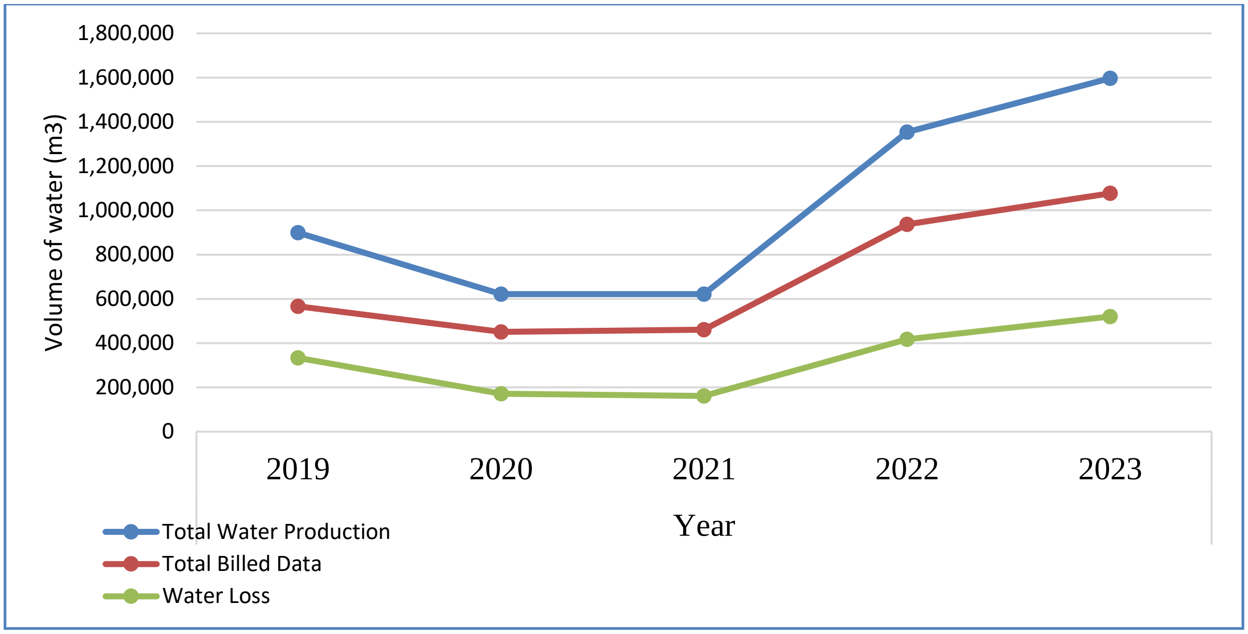

Figure 4 2: ***Total Water Production, Billed Data and Loss Trends***

As illustrated in figure 4.2 above the total water production, total consumption and the water loss have shown decreasing trends since 2019 to 2021. These was happen due to the fact that the system was served by two boreholes Melese Metasebia and Chawakare. But Melese Metatebia stop the service at the end of year 2019 then the system served by only Chawakare boreholes as to BTWSSE. The total production, the consumption and the water loss have also shown increasing trends since 2021/22 this was due to new boreholes (BH01, BH03 and BH 05) added year by year. Though new boreholes were added, the result of the analysis indicated that the Bodit town water demand not satisfied. The total annual water loss of the water supply system is 37.05% in 2019, 27.45% in 2020, 25.92% in 2021, 30.82% in 2022 and 32.57% in 2023 G.C. As it is shown in table 4.3 below, non-revenue water from the system is varied from year to year due to the aging of pipe that leads to leakage, pipe bursting, installation (extension of network in new area) and illegal connection.

Table 4 3 : Annul Water Production and Billed of Data Bodit Town Water Supply System

Description	Unit	Year				
		2019	2020	2021	2022	2023
Total Water Production	m3/year	898,982	621,465	621,465	1,353,447	1,596,910
Total Billed Data	m3/year	565,913	450,872	460,359	936,359	1,076,813
Water Loss	m3/year	333,069	170,593	161,106	417,088	520,097

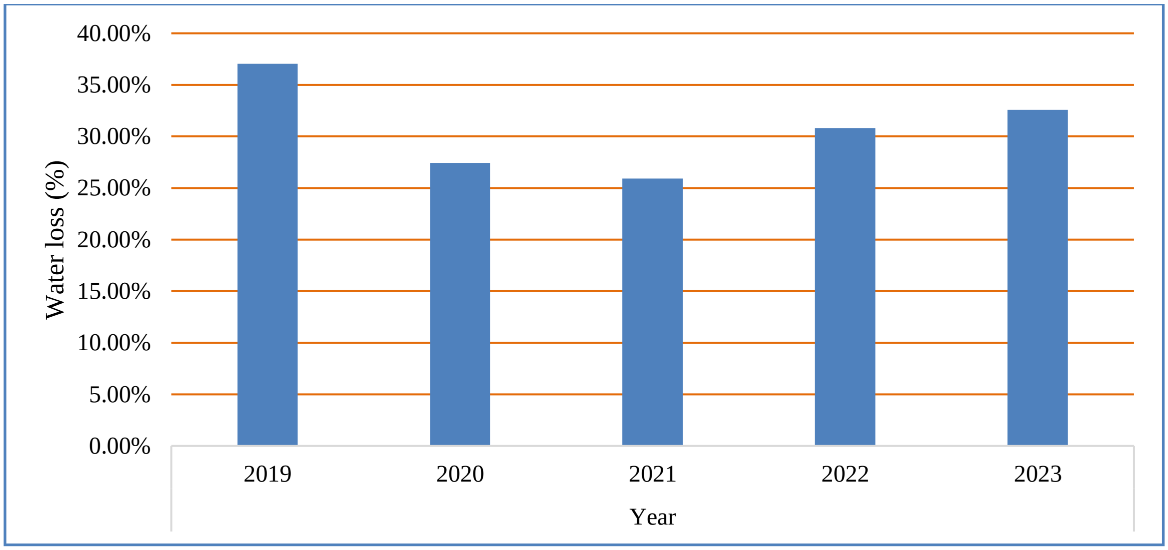

Figure 4 3: Percentage of Water Loss Trends

The water loss trend of the town showing that loss was fluctuated from year to year. This could be due to breakage of pipes in the town was occurred, and this maximized water loss. Water loss was increases in 2023 comparing with 2022 because many pipes aged. It is a compromise between the cost of reducing water loss and maintenance of distribution system and the cost of water saved. Saroj (2008) gives classification and descriptions of UFW as acceptable, which could be monitored and controlled, when the loss is < 10%, as intermediate, which could be control when the loss is 10-25% and as a matter of concern that reduces the water supply when the loss is > 25%. According to this study, water loss in Bodit town was 32.57% in the year 2023, showing that the loss in the town was as a matter of concern that reduces the water supply, according to the description given by Saroj (2008). Thus, the loss it can lead high deficit of water in the town and the aged pipes must be replaced.

4.2.2 Water Loss as Per Family Connection

Water loss expressed as a percentage could be an appropriate means to show the extent of the loss within a given environment, but it is not a good indicator for comparing the losses from one area to another. According to some literature comparison of water loss between different areas is recommended to be done using the water loss per service connection per day. Taking the total number of connections in as 5,225 the water loss per connection for the similar duration was estimated as 272.71 liter/connection/day.

4.2.3 Water loss expressed as pipe length

One of the best indicators of water loss in the distribution network system was determining loss as per length of the main pipe. According to the Town water utility report, the total length of water supply system was estimated around 59.642 km of this 44.371km length distribution pipe and 15.271km transmission pipe length. The water loss per kilometer length of main pipe was determined as (520,097m3/yea÷(59.642km×365days))x1000 is 23,891 liters/km/day. According to Farley et al. (2008), the performance indicator of physical loss target matrix describes as a good condition system if water loss per length of main pipe 18,000liters/km/day. In line of this, the town water loss per length of main pipe was 23,891 liters/km/day, which shown as above the condition.

4.2.4 Factors Contributing to Water Loss in Town

Age of pipe network

Pipe age is one of the factors that affects the magnitude of the loss specially that of physical loss. Aged pipes are more likely having more water loss through leakage than newly installed pipes. The main duties which made more than half a month is checking of each customer (door to door water connection) by sounding rod. In this time get so many invisible & visible leakages both on the private connection & also on the main line. These lines are including DCI (Ductile cast iron), HDPE pipes. The aged pipe is especially in the central part of the town and in densely population areas. All these materials suffer from degradation over time due to operational measures, environmental conditions and general wear and tear result in increased leakage in the network. It is therefore necessary to replace older mains so that less leakage occurs.

Illegal Connection

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

4.3 Current Water Demand Estimation

4.3.1 Population Number

The 2007 CSA survey didnot address the town of Boditi with the currently proposed town coverage encompassing the rural kebeles. Thus, the base population figure obtained from the town municipality office is considered for future population projection. As per the data collected from the municipality and town water supply and sewerage service for 2023 the estimated total population of the town with expected expansion areas encompassing the rural kebeles to the current town administration was about 85,407 population.

4.3.2 Domestic Water demand

Domestic water demand is a water demand at a household level needed for drinking, food preparation, washing, cleaning, bathing and other miscellaneous domestic purposes. The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service and affordability of the users.

Mode of Service

Domestic water demand is the daily water requirement for use by human being for different domestic purposes like drinking, cooking, bathing, gardening, etc. the domestic water demand required by human being can be supplied or obtained through different modes of services depending on the economic level and facilities owned by the individual. The use of water for domestic purposes may be sub divided in various categories drinking, food preparation and cooking, cleaning, washing and personal hygiene, vegetable garden watering and other uses including waste disposal.

Generally, for Bodit town piped system, the models and levels can be categorized as Public Tap (PT), Yard connection Own (YCO) and House Connection (HC). From the town population data sector offices such as plan commission average household size of was 6 persons. The mode of services connected 604 house connections, 4621 use yard connections. The existing detail of mode of services and population served per mode of service is tabulated here under.

Table 4 4: Existing Percentage Mode of Services and Population Served Bodit Town

Category Mode of service	Percentage	Population Served
HC	4.24%	3,624
YCO	32.46 %	27,726
PTU	63.29 %	54,057
Total	100.00 %	85,407

As shown in the table 4.4 above the demand analysis identified the households who have access to safe water supply by mode of services. The demand analysis indicates that, the majority of the residents of the town 63.29% get their water from a tap outside their compound (i.e. from public fountains and vendors). About 32.46 % have a private yard connection and 4.24 % has house connection.

Per capital mode of services

The per-capita water demand for various demand categories varies depending on the size of the town and the level of development, the type of the water supply scheme, the socio-economic conditions of the town and the climatic condition of the project areas. The per-capita water demand is the sum of the water requirement for different uses, which are related to specific conditions of each area, living standard of the residents and availability of water supply facilities of the specific town, etc. The water requirement for different domestic uses could also vary based on the mode of service to be used and the closeness of the residents to water supply facilities.

Table 4 5 : Per Capita Demand by Mode of Services MoWR and Adjusted as per GTP-II

Modes of Service Category	Unit	MoWR 2006	GTP_II Adjusted Per capita mode of Services
HC	l/c/d	70	102
YCO	l/c/d	30	44
YCS	l/c/d	40	58
PTU	l/c/d	25	36
Average	l/c/d	41.5	60

After the percentage share of the different mode of services and the corresponding adjusted per-capita demands is determined, the total domestic water demand have been calculated for the town. The average domestic demand for the town in 2023 was described the following table 4.6.

Table 4 6: Domestic Water Demand by Mode of Services

Mode of Services	Unit	Demand by mode of Service
HC	m3/day	368.99
YCO	m3/day	1,219.94
YCS	m3/day	-
PT	m3/day	1,946.05
Total Domestic Demand	m3/day	3,535.64
	l/s	35.36

The most common means estimating current domestic water demand of estimating current per capita water consumption and multiplying it by population figure. Thus, the total domestic average water demand for Bodit town calculated was 3,535.64 m3/day or 40.92 l/s.

4.3.3 Factors Affecting Domestic Water Demand

The water used by a person depends on the climatic and socio-economic conditions of the project area. This means water is more used at hot area than cold ones. In same way rich people consume more water than poor ones.

Climate Condition

Climatic condition of this area is varying from season to season, due to this reason most of time very hot. During this time more, amounts of water is required for all persons The Climate of project area has an impact on quantities of water consumptions. To account for changes of average per capital domestic demand, the water demand is multiplied by climatic factors recommended. Thus, as per, the study area has altitude ranges from ranging from 1,880m to 2,090m with fallen in temperate zone as describe in table 4.7 and climatic factor of 1.

Table 4 7: Climatic Adjustment Factor Oromia WWDSE, 2010

Mean annual Temp.(°C)	Description	Altitude	Factor
<10	Cool	>3300	0.8
10—15	Cool Temperate	2300--3300	0.9
15—20	Temperate	1500--2300	1
20—25	Warm Temperate	500--1500	1.3
25 and above	Hot	<500	1.5

Socioeconomic Condition

Economic status of most of living population are very poor, because this town are developing town and also country is developing country, due to this reason most people are not use house connected and yard connected mode of service but to most of town community public fountain system. Though, for the estimation the socio-economic factor of study town is selected to be group C, with factor 1 as the town has Towns under normal Ethiopian conditions as describe in table 4.8.

Table 4 8 : Mode of service per capita water demand MoWR, 2006

Group	Description	Factor
A	Towns Enjoying high living standards and with very high potential for development	1.1
B	Towns having a very high potential for development but lower living standards at present	1.05
C	Towns under normal Ethiopian conditions	1
D	Advanced Rural Towns	0.9

4.3.4 Adjusted Domestic Water Demand

The domestic water demand found after applying the socio-economic and climate adjustment factors on the total domestic water demand stated so far is called adjusted domestic water demand and calculated as =TADD*Adjustment factor. Thus, adjusted domestic water demand is =3,535.64m3/day*1*1=**3,535.64 m3/day**.

4.3.5 Non-Domestic Water Demand

Commercial Institutional and Public Water Demand

Water demands of institutions, public areas and commercial centers generally, estimated as a percentage of the domestic demand. It is considered usually to be in the range of 20 to 40% of the domestic demand (Oromia WWDSE, 2010). Thus upper 35% of the range limit adopted and obtained as 3,535.64m3/day*0.35=**1,237.47m3/day**.

Industrial Water Demand

It is used for different types of industry, especially for small industries like, mining industry, small scale farming, soft drinking factory, food processing factory, metal factory, paper factory and etc. But large industry is not used water demand from town water supply system, because they are required high amounts of water demands, then it use its own sources of water separately. In this town there is not large industry due to this reason assumed 5% (3,535.64m3/day*0.05 = **176.78m3/day**) of total domestic demand is enough for all industries, which existing at current time.

Unaccounted for Water Demand (UFW)

Water losses in the water supply distribution system, illegal connections, overflow from reservoirs, improper metering, etc. are referred to as non-revenue water. There are no properly set water production and consumption records to estimate the probable water loss in the water supply system of Bodit town. It is very crucial to estimate this quantity as it usually a figure of 15% is generally regarded as good, and uneconomical to try and reduce (MoWR, 2006). However, from town utility report the current water loss from billed data about 32.57%. Even if this figure high compared to Ministry of Water Resource guide line standard, it recommended to take the value because it shows actual trends. Therefore, the UFW was estimated as 32.57% of domestic and non-domestic water demand. Therefore, it was a figure of (4,949.89m3/day*0.3257=**1,612.18m3/day**) adopted.

4.3.6 Average Daily Water Demand

The average water demand can be determined by adding the three categories of water demands: namely domestic and non-domestic water. The average water demand represents the daily demand of the town averaged current time. Therefore, it was estimated as a figure of 6,562.07m3/day.

Table 4 9: Summary of Average Water Demand

Demand Category	Estimated Amount (m3/day)
Domestic Water Demand	
Domestic Water Demand	3,535.64
Sub Total	**3,535.64**
Non-Domestic Water Demand	
Commercial Institutional and Public Water Demand	1,237.47
Industrial Water Demand	176.78
Unaccounted for Water Demand (UFW)	1,612.18
Sub Total	**3,026.43**

	Total	6,562.07

4.3.7 Maximum Day Water Demand

The maximum day water demand is the highest demand of any one-day in a specified year. If there is sufficient water and enough daily consumption records, it is possible to calculate the actual maximizing factor. However, since there is no any daily-recorded water consumption data at the study town, the maximizing coefficients are taken from the design guideline that has been developed according ministry of water resources between 1.0 and 1.3 (MoWR,2006).

Hence, a maximum day factor of 1.2 was adopted for assessing the maximum day water demand applied it corresponding to the total average day demand of a particular year 2023. Therefore, the maximum day demand estimated as 7,874.48m3/day or 91.13l/s.

Summary of Demand Estimation

Peak Hour Demand

The peak hour demand is the highest demand in any one hour over the year. It represents the diurnal variation in water demand resulting from behavioral patterns of the local population. Peak hourly demand is used to design distribution system of water supply schemes of study town.

Table 4 10: Hourly Peak Factors According (MoWR, 2006)

Population Size	Peak Hour Factor
<20,000	2
20,000-50,000	1.9
50,000-100,000	1.8
>100,000	1.6

The population number of at the town at the current year 2023 is 85,407, then this number is ranges of 50,001 to 100,000, therefore the factors of peak hourly demand is 1.8 respectively. As total calculation of water demand assessments of study town is shown below table 4.11.

Table 4 11 : Summary of Current Demand Estimation in Bodit Town

Year	Unit	2023
Population Number	No	85,407
Total Domestic Demand	m^3/d	3,535.64
Socio- Economic Factor		1
Climatic Factor		1
Adjusted Domestic Water Demand (ADD)	m^3/d	3,535.64

Non-Domestic Water Demand		
Commercial & Public Water Demand with (35% of ADD)	m^3/d	1,237.47
Industrial Water Demand with (5% of ADD)	m^3/d	176.78
Total Demands	m^3/d	**4,949.89**
Unaccounted for Water (UFW) or Non-Revenue-Water	m^3/d	1,612.18
Average Day Water Demand	m^3/d	6,562.07
Max Day Factor		1.2
Max Day Demand	m^3/d	7,874.48
	l/s.	91.13
Peak Hour Factor		1.8
Peak Hour Demand	m^3/d	14,174.07
	l/s	164.05

From above maximum daily demand and peak hourly demand is 7,874.48m3 /day and 14,174.07 m3 /d respectively. As generally water demands of existing system is very less compare to with the current water demands of study town, this cause major problem on town communities' day to day activities in said house and outside their house.

Table 4 12 : Estimated water Demand and Existing Water Production

Total Existing Production (m3/day)	Estimated Maximum Demand (m^3/day)	Deficit (m^3/day)
4,375.10	7,874.48	3,499.38

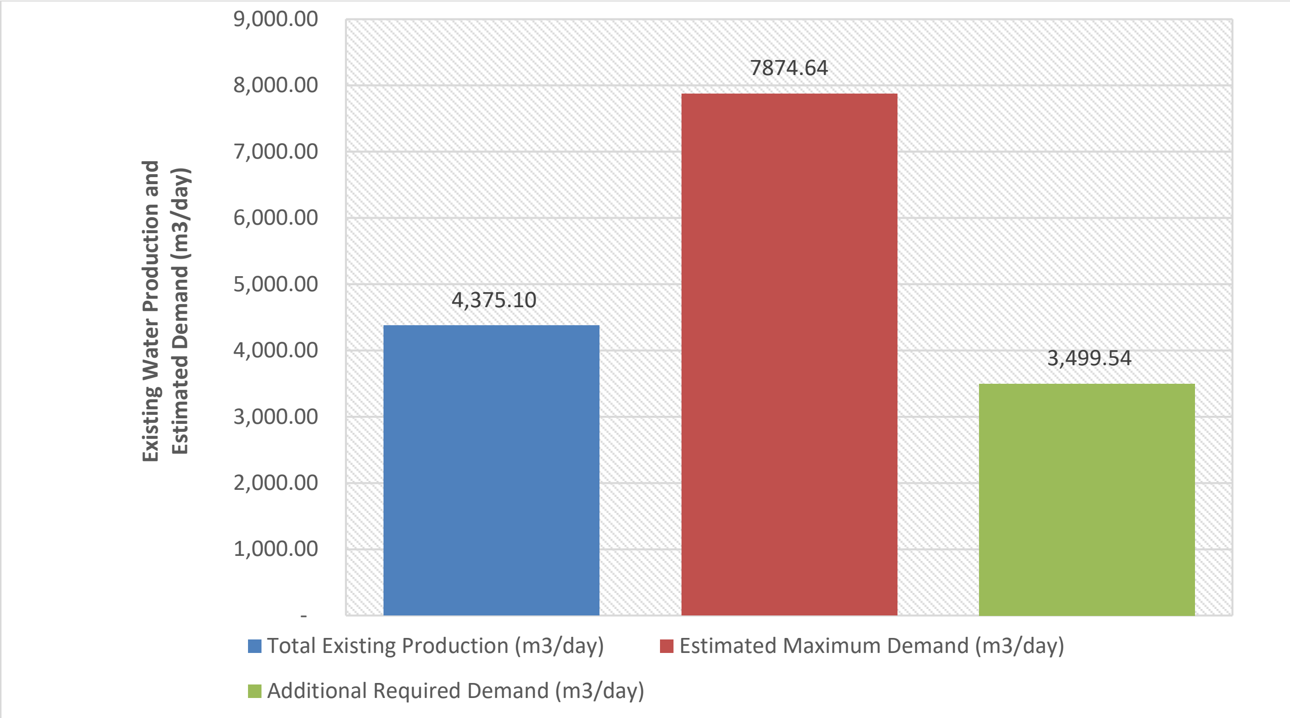

Figure 4 4: Estimated Water Demand, Existing production and Deficit

4.4 Hydraulic Analysis of Existing Water Supply Distribution Network

In the modern water supply system, clear water shall be delivered to the service reservoirs directly through the transmission main and which is completely isolated from the distribution system. The existing water distribution system has been evaluated based on the existing maximum and minimum operating pressure and velocity criteria proposed by Ministry Water Resource in the pipe network of urban water supply system as described in the below.

The existing water distribution system of the town is both pump and gravity system. The water from the four sources was taken to 2000m^3 reservoir by pump which services to most part of the town and from this reservoir boosted to another 800m^3 reservoir to give service to upper part of higher elevation that could not get water from the 2000m^3 reservoir. The 800m^3 reservoir also connected to town distribution system that gets water from 2000m^3 reservoir.

The minimum pressure at peak hour consumption hour: it appropriate to assist the maximum water supply idea of the system classify main, the nodal pressure not less than 10m would be prescribed based on MoWR, 2006 to efficiently make water available to each demand categories including during high withdrawal period. The maximum pressure at low consumption hour: The maximum pressure in the main is considered not to exceed 70m to limit the leakage volume and the stress on the pipe in water system during minimum consumption in day (MoWR, 2006).

4.4.1 Layout Schematization

In constructing a distribution network concerned with assigning labels to pipes and nodes, Tanks and pumps Bentley Water GEMS Connection Edition 10 was assign labels automatically. The water distribution network map was obtained from the Bodit town water supply and sewerage enterprise which was prepared from study and design document report of the town water supply distribution network. When creating a schematic drawing, pipe lengths are entered manually. In a scaled drawing, pipe lengths are automatically calculated from the position of the pipes' bends and start and stop nodes on the drawing pane. In this network, the modeling of a reservoir connected to service line and simulates a connection to the main water distribution system. Simplifying the network in this way can approximate the pressures supplied to the system at the connection under a range of demands.

Table 4 13: Distribution Network Pipe diameter and Corresponding Lengths with Their Coverage (BTWSSE, 2023)

Diameter (mm)	Pipe Material	Length (HDPE) (m)	Coverage
40	HDPE	246	0.55%
50	HDPE	2,599	5.86%
63	HDPE	4,519	10.18%
75	HDPE	13,652	30.77%
90	HDPE	4,454	10.04%
100	HDPE	14,828	33.42%
140	HDPE	522	1.18%
180	HDPE	815	1.84%
250	HDPE	2,736	6.17%
Total pipe length (m)		44,371	100.00%

4.4.2 Network System Data Files

The other point of consideration during the design work is managing network data files, which define the system in terms of pipes, nodes and system operational parameters. The investigated network data include physical characteristics of pipes such as length, diameter and the node data which describe elevation and water demand or water supply. Operational parameters which indicate the actual value of system facilities such as flow rates, overflow and bottom elevations of reservoirs are the main points of interest during the detail design of distribution network of the town. System data files are the most important inputs for the design of distribution systems and they have a direct impact on the out puts of the analysis. Model in the water supply distribution network consists, input data of the distribution system are elevations of node, base demand of the node, locations junctions/nodes, pipe length & its diameter and section and elevations of service reservoir. Water GEMS Connect Edition 10 could show pressure, demand and hydraulic grade in different nodes as well as flows, velocities, head-loss gradient and head loss in different pipes throughout the distribution system. The results of model were generally displayed in tabular and graphic forms by the different scenarios.

4.4.3 Distribution Network Simulation Results

Extended Period Simulation

Demand pattern is one of critical component at the system, from which is identified how much capitals consume to describe in graph. As far as distribution of water is concerned, the property of hydraulic parameters in distribution network allowable limit was known. The driving forces of hydraulic parameters are demand of water consumptions. The distribution pipe network was the adequacy of the system to meet the water demands town has been performed to optimize the system for extended period of 24-hourly time step simulations by considering the peak hourly water consumption pattern. The model is simulated for every one-hour time setup in the twenty-four-hour duration. However, for the analysis the peak and minimum hour demand are simulated to identify the current problems of the system and to locate the critical points in existing water supply distribution network. The peak hour demand analysis is conducted considering the maximum day demand and peak hour factor of 1.8 whereas the minimum demand analysis is carried out considering flow factor 0.25 of leakage and a maximum daily demand of the system.

However, the peak hour demands are used for sizing of the distribution pipelines that can deliver the required maximum flow at minimum established pressure at all consumers tap while the minimum water demand is used to analyze the maximum pressure in the system so as to select the pipe material and also to manage excessive pressure in the system. The critical scenarios have been identified during low and high-water consumption time period. During low consumption, velocity in a pipe was be lower and nodal pressure is high while during peak hour consumption velocity is relatively high and nodal pressure is becoming lower. Demand patterns used in simulating extended period simulation is presented in (Appendix A)

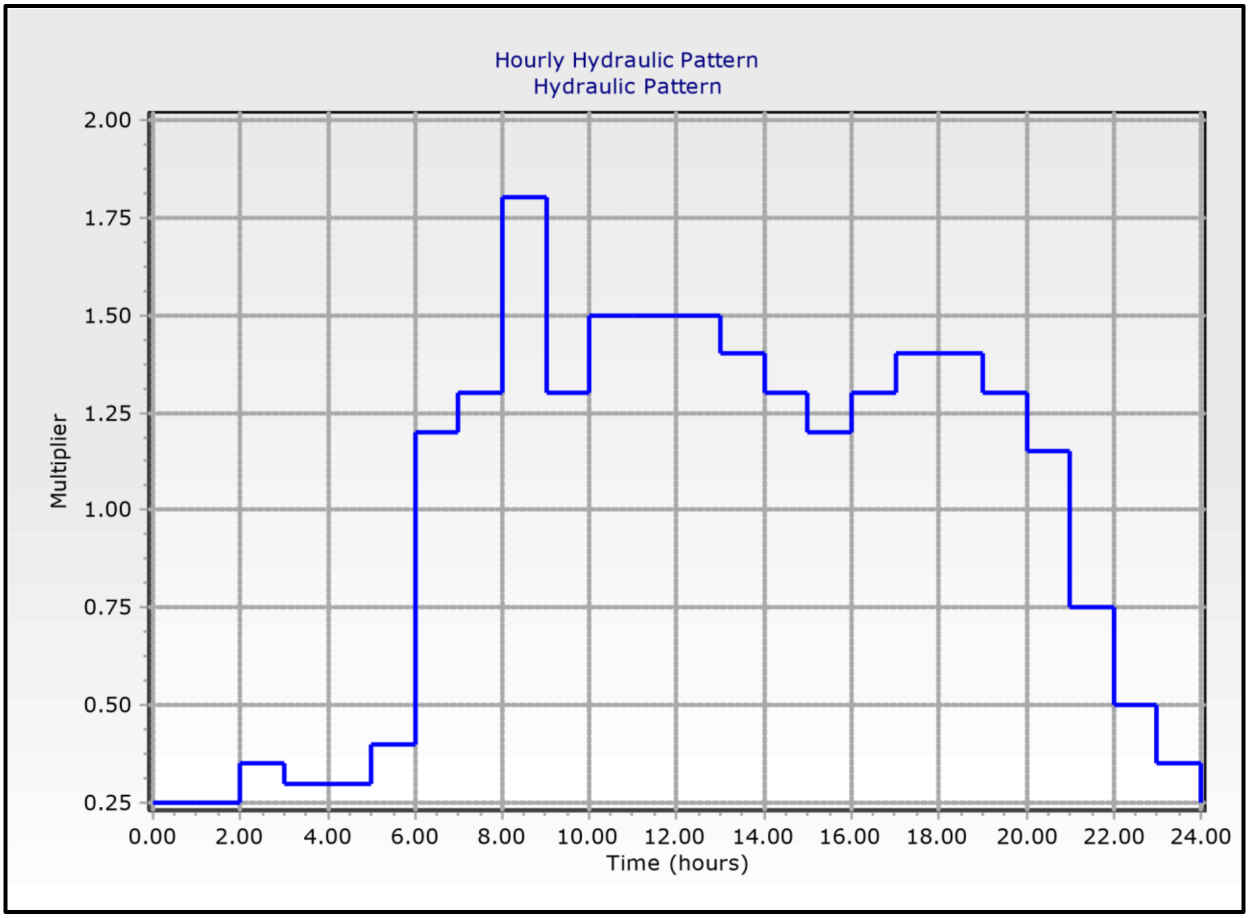

Figure 4 5: ***Demand pattern***

Pressure Adequacy

The model run from the input of existing data a total node of 48 was reported from the project inventory dialog box. The minimum pressure adopted for this study was 10m of water head. From the result about 21 out of 48 nodes are below the minimum adopted system pressure. This indicates that the pressure within the distribution system was 43.75% of nodes are below the minimum desirable pressures during peak hour (8:00hr) demand and these nodes was not capable of supplying the necessary demand to consumers. While 56.25% of nodes are within the permissible pressure ranges of minimum 10m and maximum 70m pressure head. At this peak hour level, the water consumption demand expected to more over all the hour demands. There were some reasons that are why the negative pressure was occurring in the water supply distribution system is as a result of the following: elevations difference, high demands, pipes of inadequate capacity and high lead loss. Low pressure can cause reduction of quantities of water supplied to the consumer and entry of a contaminant or self-deterioration of water quality within the network itself a severe damage to public health.

Table 4 14: Pressure distribution during at peak hour consumption

Pressure (m H2O)	Nodes number	Percentage
<10	21	43.75%
10--20	5	10.42%
20---30	4	8.33%
30---40	5	10.42%
40---50	6	12.50%
50---60	6	12.50%
60---70	1	2.08%
>70	0	0.00%
Total	48	100.00%

As described in figure 4.5 below the area highlighted by yellow color is indicate lower pressure (negative pressure, the area highlighted by blue color is indicate permissible pressure range between 10m to 70m water head.

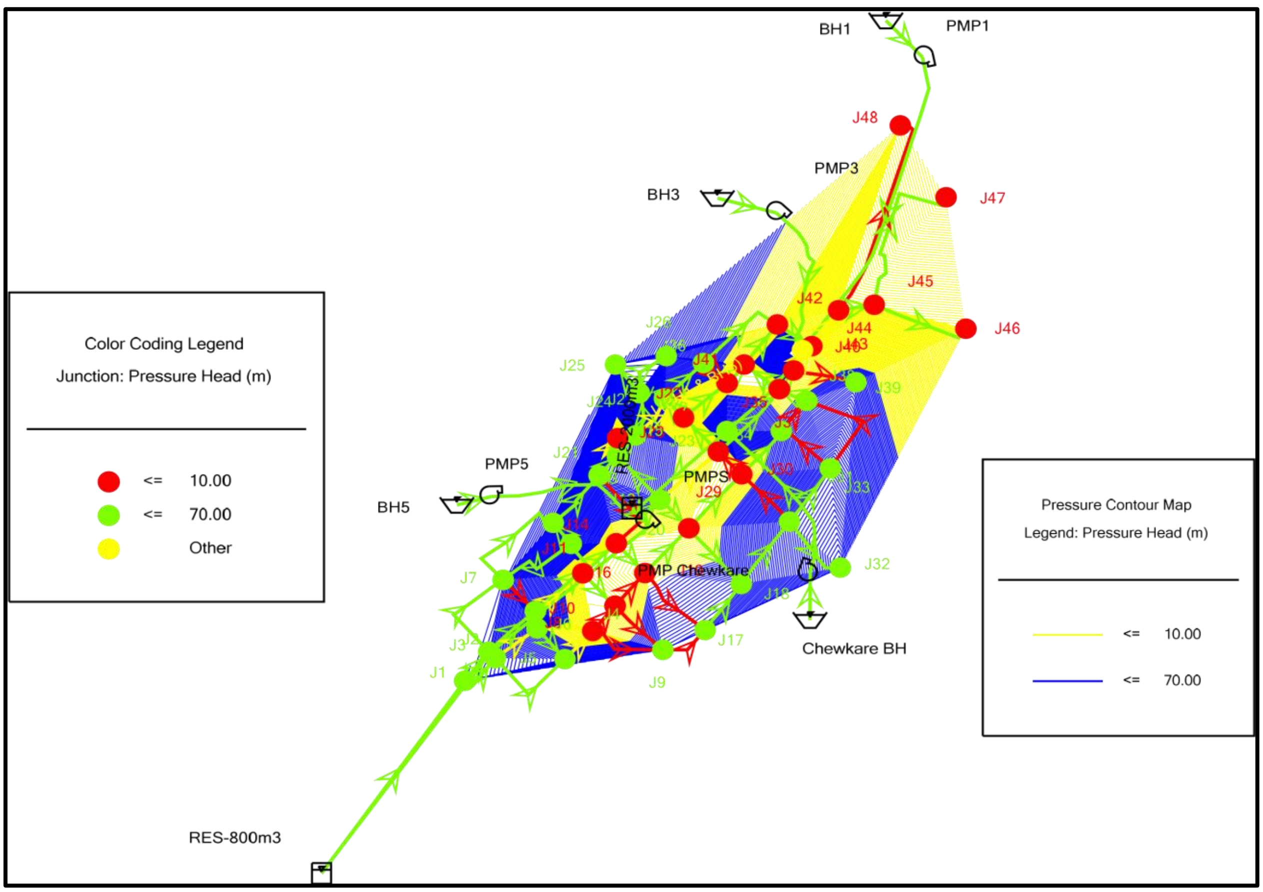

***Figure 4 6:** Pressure contour map during at high consumption*

On the other hand, red and green color highlighted shows the nodes pressure results during the high consumption or peak at 8:00 hr. morning day time. The pressure head simulation result shown that some nodes have low pressure as indicated in table 4.15 and full pressure simulation result presented in (Appendix B).

Table 4 15: Nodal pressure below MoWR, 2006 standard @ peak hour

Label	X (m)	Y (m)	Elevation (m)	Hydraulic Grade (m)	Pressure (m H2O)
J8	373,035.06	767,391.61	2,058.52	2,048.80	-10
J10	373,251.24	767,647.45	2,057.60	2,048.67	-9
J11	372,939.88	767,977.80	2,062.65	2,054.47	-8
J14	373,262.12	768,282.04	2,055.10	2,050.57	-5
J16	373,538.56	767,980.20	2,041.80	2,047.80	6
J19	373,963.69	768,434.67	2,045.20	2,037.00	-8
J22	373,275.28	769,349.65	1,990.77	1,984.91	-6
J28	373,912.15	769,558.05	2,015.00	2,000.56	-14
J29	374,248.30	769,213.71	2,031.00	2,019.78	-11
J30	374,474.03	768,982.69	2,022.00	2,020.47	-2
J35	374,332.47	769,910.09	1,994.62	1,994.05	-1
J37	374,837.40	769,847.90	2,003.10	2,003.01	0
J40	374,974.30	770,037.40	1,994.70	1,989.56	-5
J41	374,496.65	770,096.34	1,995.70	1,991.52	-4
J42	374,818.35	770,503.59	1,984.90	1,976.28	-9
J43	375,151.02	770,284.10	1,984.20	1,964.43	-20
J44	375,409.40	770,648.50	1,975.70	1,920.26	-55
J45	375,753.51	770,703.64	1,961.00	1,909.96	-51
J46	376,639.80	770,460.46	1,947.00	1,889.23	-58
J47	376,448.15	771,795.62	1,880.00	1,872.84	-7
J48	376,005.95	772,524.42	1,932.84	1,916.55	-16

Table 4 16*: Kebeles Nodal Pressure below the Guide at Peak hour*

S. No	Kebele Name	Number of Nodes	Names of Nodes
1	Hagaza Doge	6	J8, J10. J11, J14 J16 and J19
2	Gido Bodit	4	J22, J28, J29 and J30
3	Chacha	6	J35, J37, J40, J41, J42 and J43
4	Fate	3	J44, J45 and J46
5	Sibaye Korke	2	J47 and J48

Pressure Distribution during Minimum Consumption Period

Pressure during low demand periods fully approaches to static pressure: typically, at night should be as low as practicable to minimize leakage. Generally low water consumption period determines pipe thickness or pressure bar. The nodal pressure ranged with respect to the nodes indicated below in table 4.17.

Table 4 17: ***Pressure Distribution at Low Consumption***

Pressure (mH2O)	Node Number	Percentage
≤ 60	13	27.08%
61- 80	12	25.00%
81-100	12	25.00%
101-125	7	14.58%
126-160	3	6.25%
161-200	1	2.08%
	48	100.00%

Velocity of water in the existing distribution system

The velocity of water in the existing distribution system was shown in figure 4.7 by color coding from the model results to analyze the system's performance within the recommended standard limit. The results were as follows: the velocity below 0.6 m/s was about 22.86 % between 0.6–2 m/s is 67.14 % and above 2 m/s is 10 %, as shown in figure 4.7. According to these findings, many number of pipe velocity of the water supply network distribution system was less than the minimum and higher than above recommended value of 0.6 m/s and 2m/s respectively, indicating that the distributed amount of water in the system was minimal as a result of less supplied water and a low flow rate and an improper design of the pipe diameter. The low velocity in the distribution system, which could further reduce the water quality due to increased water age and deposited contaminants in the water distribution network. In the reverse , higher velocity, not more than 2.0 m/s in distribution system and transmission system respectively to prevent erosion and high head losses.

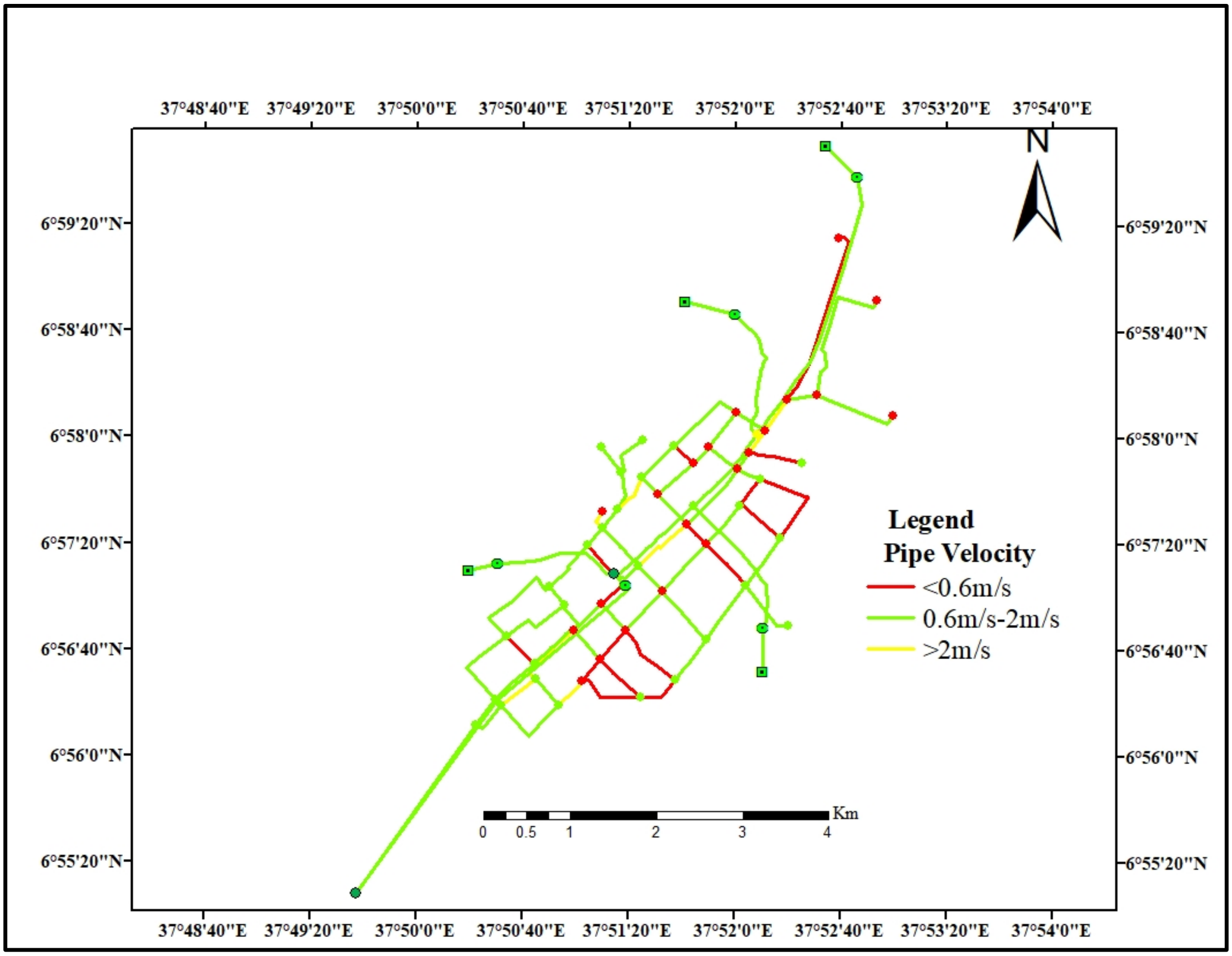

Figure 4 7: Velocity Distribution during High Consumption

Velocity distribution is also varying with demand pattern changes. At the peak hour demand the values were different as compare to minimum consumption hour. The water supply system network velocity during peak hour demand was summarized in the table 4.18 below.

Table 4 18: Velocity Distribution at High Consumption Before Optimization

Velocity (m/s)	Pipes Number	Percentage
< 0.6	16	22.86%
0.6-2.00	47	67.14.%
> 2	7	10 %
Total	70	100.00%

Analysis of Network Profile

The software has the potential to give a variety of information, including hydraulic profile, velocity profile, and pressure gradient at any point in the network to the user. One of the town s distribution main line is shown in figure with respectively

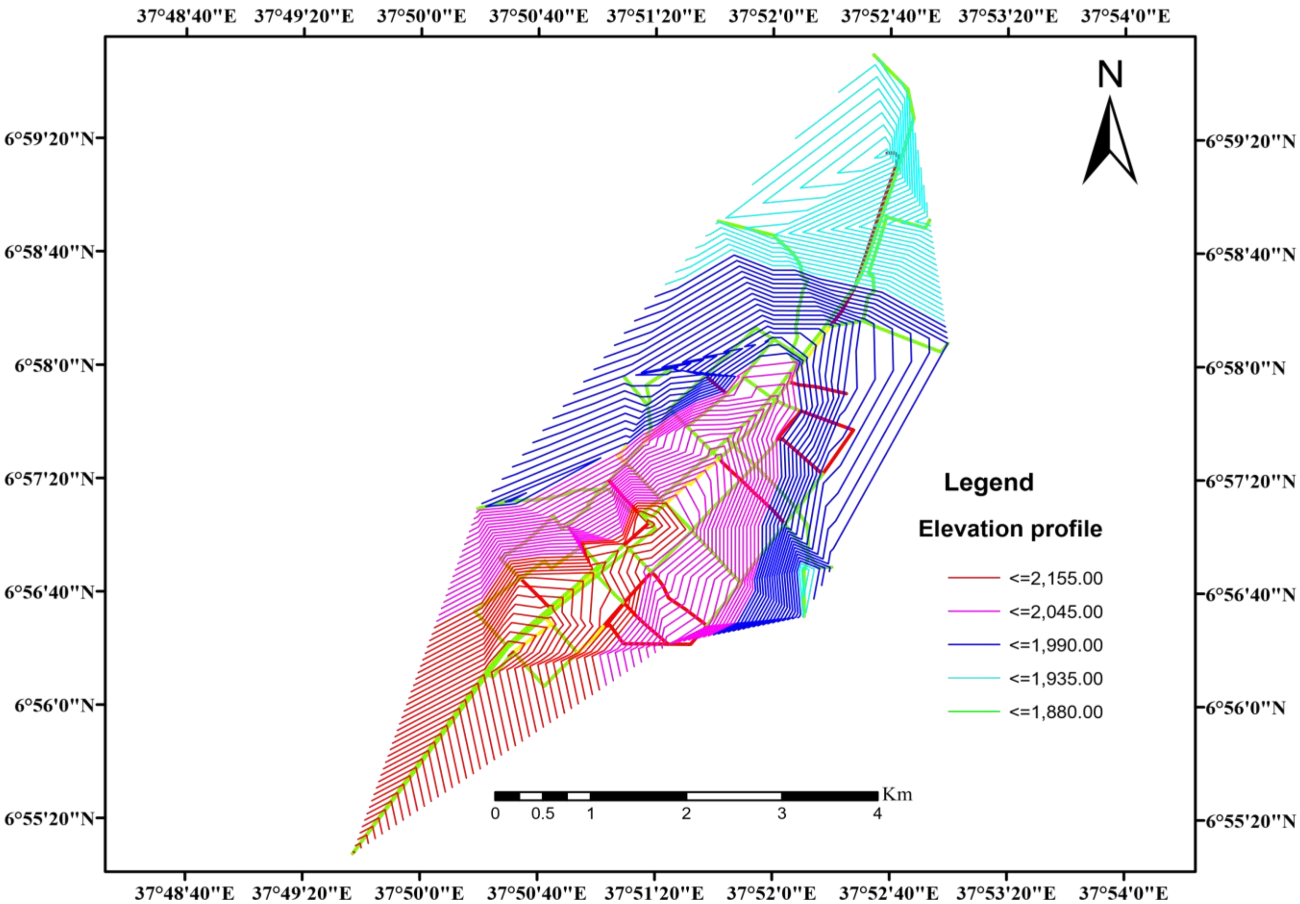

Figure 4 8: ***Elevation profile from 800 m^3 tanker to downstream end users***

In the distribution main lines of the study area the locations of nodes in the water distribution line were in close proximity to each other. The maximum and minimum water pressure at peak consumption period (8:00) in the distribution system was -58m and 69m from the reservoir head to the ends of costumer services pipe. According to the design criteria of the FDRE; Minster of water resources, the maximum and minimum water pressure in the distribution system is 70m and 10m, respectively. This was because of; water was delivered to the distribution main by gravity means and the system were served beyond its design life. Nodes having low values of pressure, extended simulation period (-58<=P<=6m) and No nodes having the pressure greater than 70m. The hydraulic grade line and base elevation starting from tank to the distribution system were plot as shown in figure 4.8.

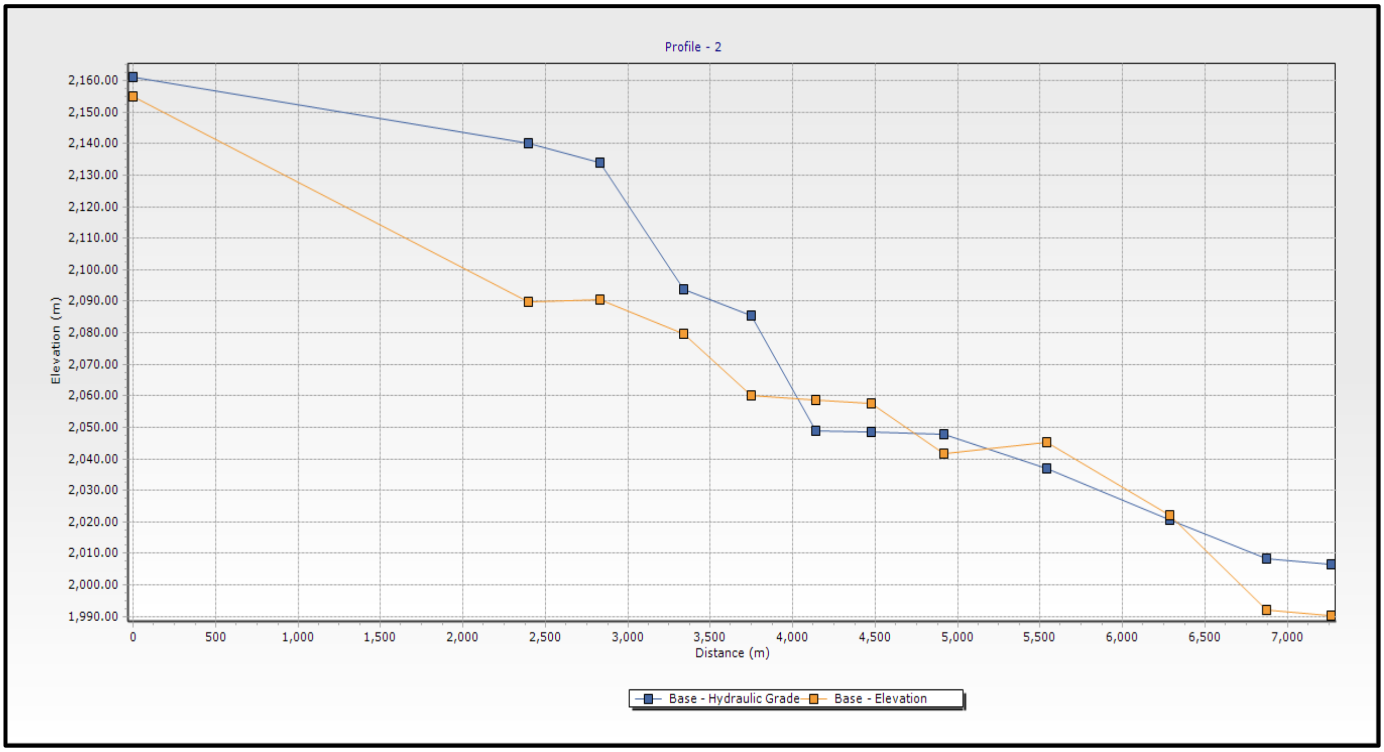

Figure 4 9 : Hydraulic grade line versus base Elevation from 800m^3 tank and distribution system of existing distribution system.

Optimized Pipe Diameter

The optimization of the pipe diameter of the water supply distribution was carried out based on commercially available pipe sizes. The pipe diameter before and after optimization schematized in figure 4.10 and 4.11 respectively which pipe optimization is undertaken during the high consumption time (8:00 AM) at the nodes due to the reason once satisfied the required demands in the distribution systems means then the other water demands are fulfilled.

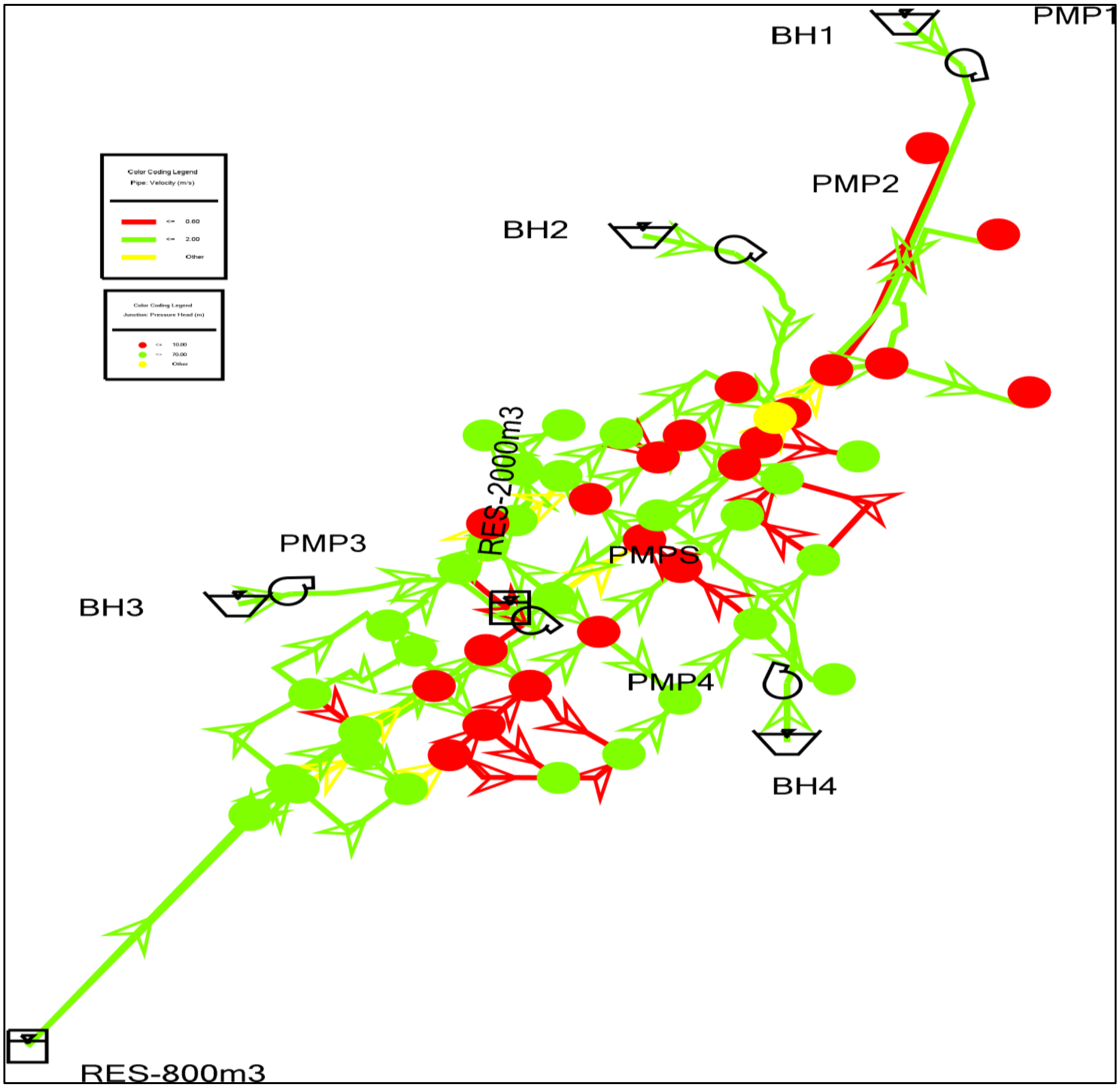

Figure 4 10: ***Existing Distribution Network Before Optimization***

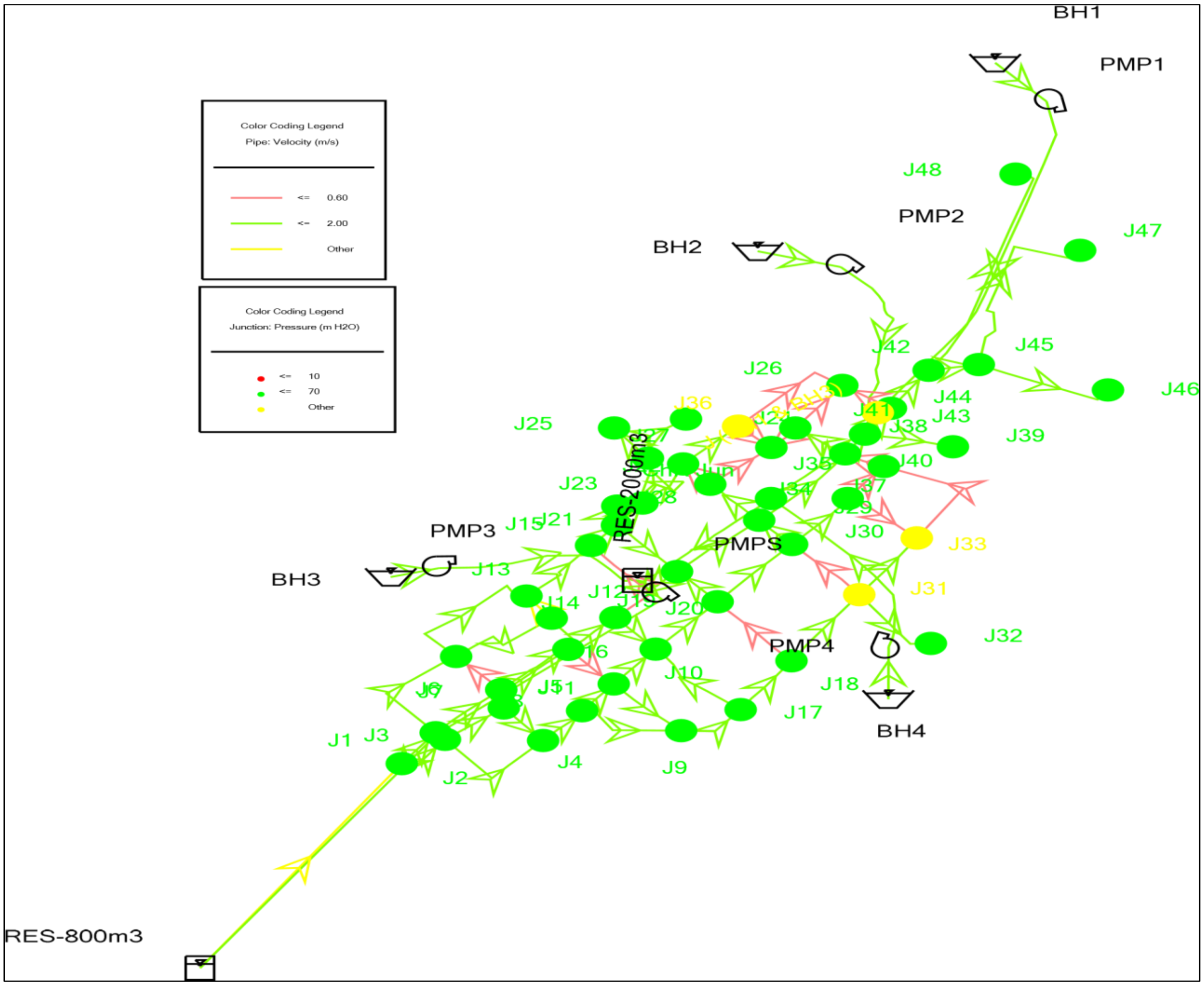

Figure 4 11: ***Existing Distribution Network After Optimization.***

Thus, the optimized pressures are increasing the pressures post-optimization than before and after optimization compare. In fact, some junctions have less pressure in the optimization pipe compared to the existing pressure at nodes. However, almost all pips above 93% in the optimization networks were fulfilled the required pressure at the junctions as per Ethiopian design standard guide line. The Water GEMS model result outputs for pressure before and after optimization within the 24 hours.

Table 4 19: Existing Distribution Network pressure before and after optimization

Label	Pressure head (m H2O) before optimization	Pressure head (m H2O) after optimization
J8	-10	35
J10	-9	28
J11	-8	24
J14	-5	22
J16	6	28
J19	-8	22
J22	-6	61

J28	-14	36
J29	-11	28
J30	-2	41
J35	-1	48
J37	0	50
J40	-5	51
J41	-4	47
J42	-9	58
J43	-20	59
J44	-55	51
J45	-51	55
J46	-58	21
J47	-7	49
J48	-16	67

The above table shows that the pressure of the post-optimization of nodes is higher than that of the pre-optimization. According to the Ethiopian standard MoWR (2006) the pressure at any hour demand must be 10m to 70m of water. Unfortunately, the analysis revealed that the pressure in the pipes in Bodit town is too low. After optimization, the pressure is sufficient flow to customer water demand and the problem of shortage of supply is resolved.

Table 4 20: ***Velocity Distribution at High Consumption After Optimization***

Velocity Range	No. of Pipes	%age
< 0.6 m/s	16	22.86
0.6 -2 m/s	52	74.29
> 2m/s	2	2.86
Total	70	100

After optimization, most pipe velocity fall within the MoWR, 2006 guideline (0.6-2m/s) which is about 74.29%. About 22.86% is below the minimum (0.6m/s) and 2.89% is above the maximum limit (2m/s). After optimization almost 52 pipes were fulfill the required velocity range within the Ethiopian design guideline standard which is about 74.29 %. And also the number of pipe where their velocity above the maximum limit reduced to 2, which is about 2.86%.

Pump curve

The pump characteristic is normally described graphically by the manufacturer as the pump performance curve. The pump performance curve describes the relation between the flow rate and the head for the actual pump. An efficiency curve determines pump efficiency in vertical percent as a function of pump flow rate in horizontal flow. Pump head is the head gain imparted to the water by the pump and plotted on the vertical of the curve in meter. Flow rate is plotted on the horizontal in litter per second. A valid pump curve must have decreasing head with increasing flow. An efficiency curve determines pump efficiency in vertical percent as a function of pump flow rate in horizontal flow. In figure 4.12 shows as the blue line the head increases the amount of discharge pushed by the pump decreases. When the head decreases the pump can push high amount of discharge to a lower elevation so that pump curve indicates decreasing head with increasing flow illustrate by red line.

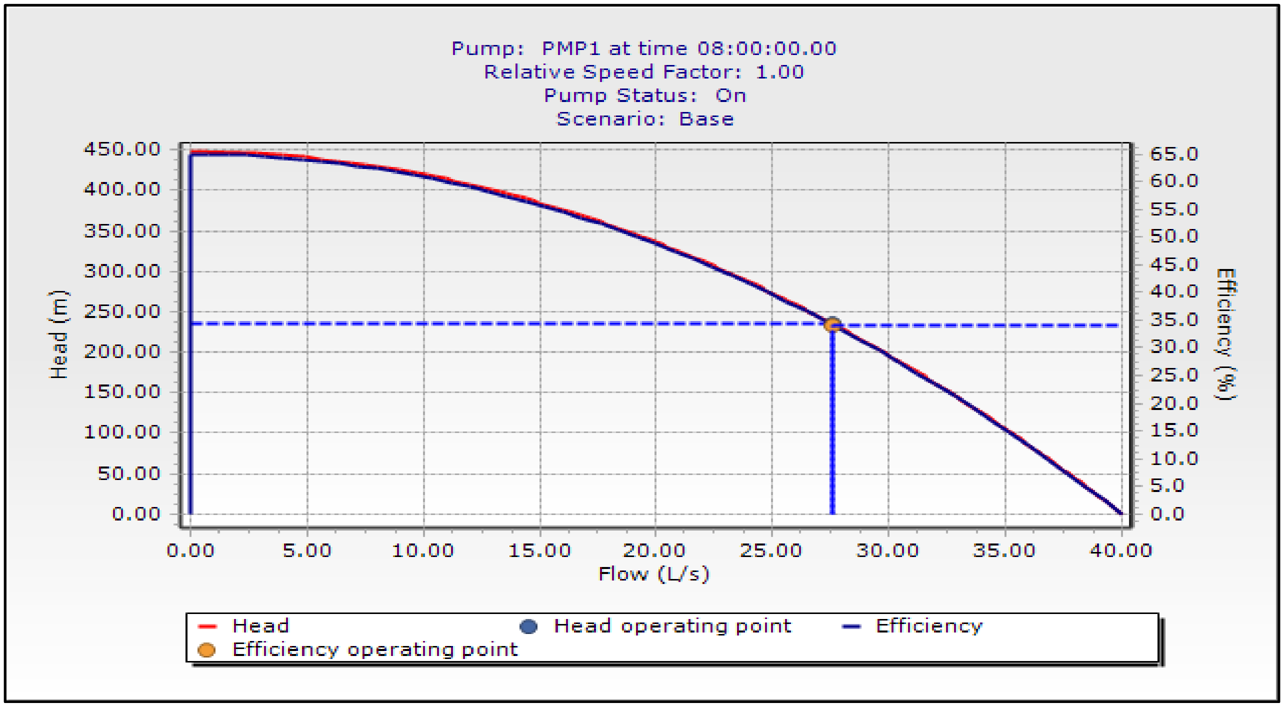

Figure 4 12: ***Pump curve***

Tank

Two reservoirs constructed in the town one is 800m^3 and the 2000m^3. The first one 800m^3 located at south boarder side of the town Bodit -Sodo to near asphalt exit road and second at the located the center of the town near town water utility. The service reservoir (storage tank) is provided to balance (constant) supply rate from the water source or treatment plant with the fluctuating water demand in distribution area. The extended period simulation result shows the fluctuating storage volume with time increments during high and low consumption. The time varying simulation indicates that storage tank 800m^3 starts to gradually increases the volume from mid night to morning day time that means the is tank is full.

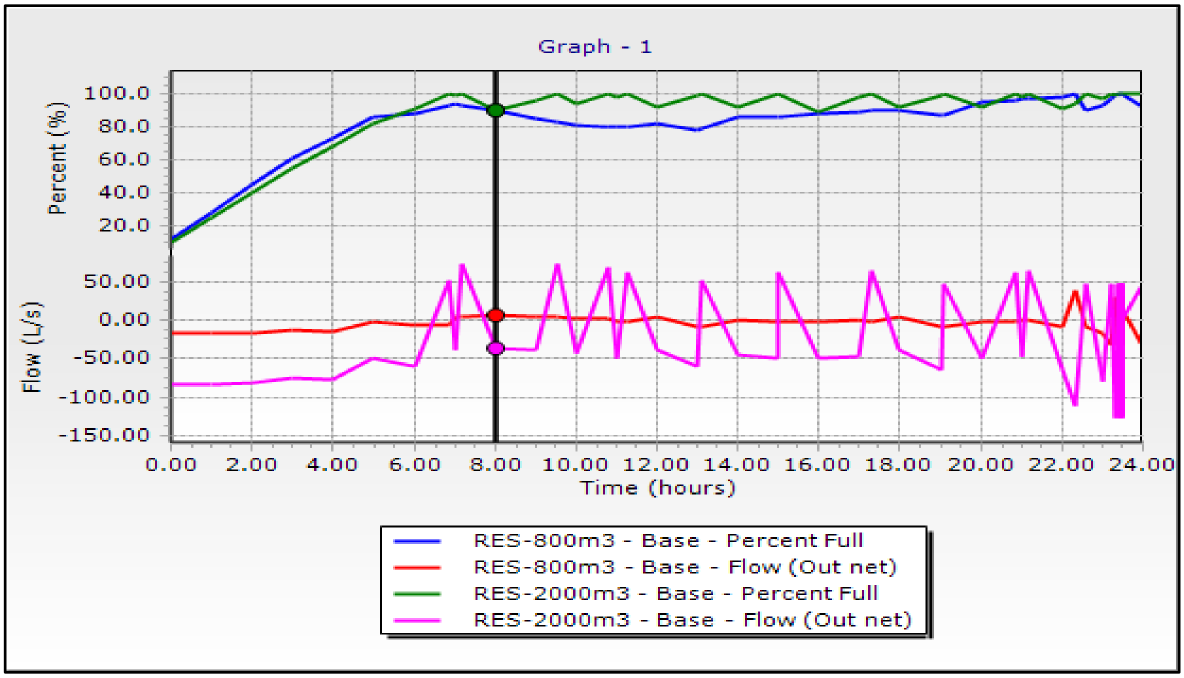

Figure 4 13: ***Tank verses flow outlet over 24 hours***

The above figure 4.13 shows that during the extended period simulation the storage level of the tank fluctuate for 24-hour period which shows the change in percent of full in different time interval.

Calibration and Validation Pressure Head Analysis

Calibration is a process or action that compares the measurement values of a measuring device or equipment against a reference standard and certifies the measurement accuracy. On the other hand, validation is a detailed documented process of confirming that the equipment or machine is installed correctly, operating effectively, and performing without any error. The degree of accuracy varies depending on the size of the system and the amount of field data and testing available to the modeler. Bentley (2008), states that the average difference of ±1.5m to a maximum of ± 5.0m for a good data set. Fifteen sample data were selected from field observation and simulated results for calibrating the nodes as show table 4.21 below.

Table 4 21: The comparison of simulated and field measured

Label	Simulated (m H2O)	Field measured (mH2O)	Pressure Difference Error
J1	50.10	51.82	-1.72
J3	47.22	46.22	1.00
J5	14.01	15.44	-1.43
J6	39.46	37.92	1.54
J7	48.79	49.63	-0.84
J12	35.73	34.01	1.72
J13	58.78	62.00	-3.22
J18	24.68	25.66	-0.98
J20	15.89	14.90	0.99
J21	40.81	41.99	-1.18
J25	51.53	49.76	1.77
J26	50.49	52.00	-1.51
J31	49.34	51.43	-2.09
J34	16.34	17.88	-1.54
J38	16.21	15.87	0.34
J39	24.58	26.04	-1.46
		Average	-0.54

As shown in table 4.21 above, compared values of observed and simulated pressure within an average error of 0.54m. Therefore, the model was acceptable calibrated which was satisfied the setting pressure calibration and validation criteria as per the acceptable limit average ±1.5m to the maximum ±5m. The comparison between the observed field data and the model result graphically sketched to show the overall relationship in between the two data sets as follows

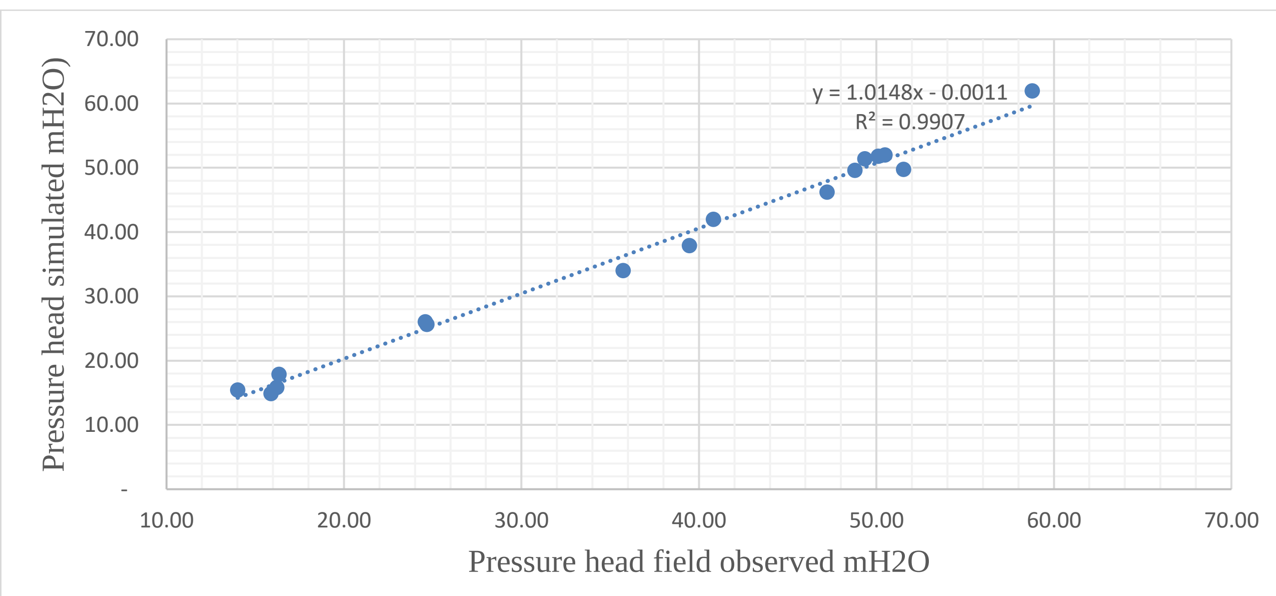

Figure 4 14: ***Correlated plot of Observed versus Computed Pressure during Validation***

R^2 is the square of the correlation between the constructed predictor and the response variable. The above figure 4.12 shows that the statistical correlations plot of observed versus computed pressure during calibration process. The results show that value of R^2 99.07%. This implies that the computed pressures were within the acceptable limit recommended by 0 to 1.

4.5. Water Quality

Groundwater resources are affected in principle by major activities such as excessive use of fertilizers and pesticides in agricultural areas, untreated/partially treated wastewater to the environment and excessive pumping. Also, the improper management of aquifers results in excessive water depletion in an area. Another important aspect is solid waste disposal in open un engineered landfill is the one of the factors that cause groundwater pollution due to lack of pollution control interventions such as waterproof layer, leachate treatment pond and monitoring wells.

4.5.1. Water Quality Evaluation by Using Analytical Method

The collected field water sample from Bodit Town water supply schemes and end user households Physico-chemical analysis were conducted at SNNPR state Water Mine and Energy Bureau Water quality laboratory located at regional Town, Hawassa. The of analyses were tested using DR5000 UV-Vis spectrophotometer (using HACH reagents), Total Hardness, Total Alkalinity and chloride were measured by titration. The other physic-chemical parameters including pH, electrical conductivity and total dissolved solids were measured by sensION portable pH/ISE Meter.

Physical properties: The important physical characteristics of any water sample are total suspended solids, turbidity and color, total dissolved solids (T.D.S), taste, odor and temperature. Factors such as color, odor & test may relate to both chemical and biological factors. Some disagreeable test and color often caused by microscopic organisms that decay organic matters, and color is because of certain dissolved salts.

Chemical properties: Practically true that pure water, two parts of hydrogen and one part of Oxygen does not exist in nature because water is able to dissolve many substances that come in contact with it. Therefore, any ground water contains considerable amount of dissolved minerals and salts. It also has dissolved gases, such as carbon dioxide and oxygen. Then it can be generalized that both surface and ground waters are a solution of many substances. Any water sources specially it intended for public uses can be decided by doing physic-chemical analysis tests to determine the concentration level of the constituents exists.

This study was carried out at Bodit Town water supply schemes sources and households. It has aimed to identify & view the main factors which could affect the quality of drinking water from the point of source to the end users. The test results of Physical and Chemical Parameters which are summarized in table 4.22 below. By comparing the quality result with WHO and National drinking water standard in table 2.3

Table 4.22: Physico-Chemical Water Quality Test of Water Samples

	Parameters																					
Sample Taken	**T.D.S**	**Turbidity**	**Conductivity**	**pH**	**Na**	**NH_4**	**K**	**Ca**	**Mg**	**Fe**	**Cu**	**Mn**	**Cr**	**Cl^-**	**F^-**	**HCO_3^-**	**NO_3^-**	**NO_2^-**	**$SO4^{-2}$**	**$PO4^{-3}$**	**T. Hardness**	**T. Alkalinity**
	mg/l	**NTU**	**(μs/c)**	**mg/l**																	**mg/l as $CaCO_3$**	
Samples from Boreholes																						
BH 01	127	4	347	6.9	25.4	0.22	11	32	3.4	0.15	0.25	0.10	0.02	10	2.0	268	4	0.01	2	0.46	160	220
BH 03	127	3	253	6.8	13.7	0.33	9	28	19.4	0.12	0.33	0.3	0.03	10	1.96	220	6	0.02	2	0.25	150	180
BH 05	139	1	277	6.4	61.6	0.47	7.5	100	19.4	0.01	0.04	0.1	0.01	10	1.76	187	10.1	0.03	2	20.1	54	153
Chawakare BH	94	6	187	6.2	40.4	1.1	7	20	30	0.01	0.07	0.1	0.01	10	1.3	151	16.7	0.08	2	5.8	68	124
WHO	**1000**	**5**	**2500**	**6.5-8.5**	**200**	**1.5**	**1.5**	**100**	**30**	**03**	**2**	**0.5**	**0.05**	**250**	**1.5**	**500**	**50**	**3**	**250**	**0.1**	**300**	**500**
Samples from Reservoirs and water point																						
Reservoir 2000m³	141	4	282	6.7	53.9	1.1	8	18	4.4	0.1	0.04	0.10	0.01	10	2.02	183	3.5	0.03	2	23.5	65	150
Reservoir 800m³	68	5	135	6.0	40.8	0.15	8.6	32	4.9	0.26	0.56	0.5	0.05	10	2.02	244	44	0.08	8	0.72	140	200
Water point	145	6	280	6.8	15.2	1.42	4	18.8	14.9	0.01	0.02	0.10	0.01	10	2.03	195	11	0.04	2	27.2	75	160
WHO	1000	5	2500	6.5-8.5	200	1.5	1.5	100	30	0.3	2	0.5	0.05	250	1.5	500	50	3	250	0.1	300	500

4.5.1.1. Physical parameters

Turbidity

Turbidity is the cloudiness of water. It is a measure of the ability of light to pass through water. It is caused by suspended material such as clay, silt, organic material, plankton, and other particulate materials in water. Turbidity in drinking water is esthetically unacceptable, which makes the water look unappetizing. The impact of turbidity can be summarized in the following points: -

- It can increase the cost of water treatment for various uses.
- The particulates can provide hiding places for harmful microorganisms and thereby shield them from the disinfection process.
- Suspended particles provide adsorption media for heavy metals such as mercury, chromium, lead, cadmium, and many hazardous organic pollutants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and many pesticides.
- The amount of available food is reduced because higher turbidity raises water temperatures in light of the fact that suspended particles absorb more sun heat.

Consequently, the concentration of the dissolved oxygen (DO) can be decreased since warm water carries less dissolved oxygen than cold water. Turbidity is measured by an instrument called Formazin Turbidity Unit , which expresses turbidity in terms of FTU is equivalent to 1 mg/L of silica in suspension.Turbidity more than 5 FTU can be visible to the average person while turbidity in muddy water, it exceeds 100 FTU. Ground water normally has very low turbidity because of the natural filtration that occurs as the water penetrates through the soil. All the samples collected from the BH01, BH03, BH05, reservoir-2000m^3 and reservoir-800m^3 and other water points before it reaches to end users, are in acceptable value range 4 FTU, 4 FTU,4 FTU, 3FTU, 5FTU and 6 FTU respectively. But the water sample collected from water point after reservoir shown that higher value than the standard value (6 FTU). This was beyond the WHO standards.

Temperature

Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature. Thereby, the sedimentation and chlorination processes and biological oxygen demand (BOD) are temperature dependent. It also affects the bio sorption process of the dissolved heavy metals in water. Most people find water at temperatures of 10–15°C most palatable. With this respect all the samples are in good temperature.

Solids

Solids occur in water either in solution or in suspension. These two types of solids can be identified by using a glass fiber filter that the water sample passes through. By definition, the suspended solids are retained on the top of the filter and the dissolved solids pass through the filter with the water. If the filtered portion of the water sample is placed in a small dish and then evaporated, the solids as a residue. This material is usually called total dissolved solids or TDS.

Water can be classified by the amount of TDS per liter as follows: freshwater: <1500 mg/L TDS, brackish water: 1500–5000 mg/L TDS and saline water: >5000 mg/L TDS. All the samples, collected at different BHs , reservoirs and water points , the result of the analysis shown in table 4.19 that they were categorized as fresh water since <1500mg/l.

Electrical conductivity (EC)

The electrical conductivity (EC) of water is a measure of the ability of a solution to carry or conduct an electrical current. Since the electrical current is carried by ions in solution, the conductivity increases as the concentration of ions increases. Therefore, it is one of the main parameters used to determine the suitability of water for drinking and irrigation as well. The result revealed that all the samples are under WHO drinking water values range as indicated in table 4.19.

4.5.1.2. Chemical parameters

Type of chemical Parameters analyzed in these water samples are pH, Alkalinity, Chloride, sulfate, Nitrogen, Fluoride, Copper, Hardness, Manganese, Calcium, Sodium, Iron, Magnesium, Phosphate, Nitrite, Nitrate, bicarbonate and Carbonate.

PH-is one of the most important parameters of water quality. It is a dimensionless number indicating the strength of an acidic or a basic solution. Acidic water contains extra hydrogen ions (H+) and basic water contains extra hydroxyl (OH^-) ions. Safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and living organisms need. The measured values of pH for almost all samples are within the range of 6.5 - 6.9 and which are fitted to the standard but reservoir 2000m^3 and Chawakare under the standard values as indicated in table 4.22 above.

Alkalinity- The alkalinity of water is its acid-neutralizing capacity comprised of the total of all titratable bases. Alkalinity of water is mainly caused by the presence of hydroxide ions (OH^-), bicarbonate ions (HCO_3^-), and carbonate ions (CO_3^{2-}), or a mixture of two of these ions in water. The high levels of either acidity or alkalinity in water may be an indication of industrial or chemical pollution. Alkalinity or acidity can also occur from natural sources such as volcanoes.

The samples collected from different points (boreholes, reservoirs and other water points) have shown value less than 200mg/l as $CaCo_3$ in the results of the analysis. Which is on the safe range.

The result of analysis revealed that the two parameters particularly the Fluoride (F^-) and Phosphate PO_4^{-3}) higher than the standard value as indicated in the above table 4.19. High geogenic fluoride concentration in groundwater (>1.5mg/l) are associated with a variety of geological and climate conditions. Such as granite basement aquifer, aird climates and alkaline volcanic rocks are conditions highly associated with fluoride. Phosphate indicator of anthropogenic contamination, over all regarding to the above two parameters the Bodit town water supply service enterprise needed to have treatment intervention.

As per the standard, set by WHO for drinking water, Bodit Town water supply sourced from deep borehole is not exposed foremost prevalent forms of groundwater pollutions like salt and nitrate contamination followed by pesticide and industrial contaminations as well. Similarly, the water sample from reservoir water quality result indicates that all parameter results are within ranges of WHO standards.

5. Conclusion and Recommendation

5.1 Conclusion

From the analysis of the result the average water supply consumption of Bodit town is found to be 23.49 liter/person/day. According to GTP-II (Ethiopian Water Sector Strategy, 2015); the per capita consumption standard set for category-3 town like Bodit is 60l/d with traveling distance is 250m so the value is below from GTP-II standard.

On the other hand, the Bodit town family connection of 0.36 which is far from the average and it is the worst, based on the standards mention here ,the average number of connection per family of the entire town is found to be 0.4. This shows that averages of two households or ten individuals are unable to share one connection or water tap.

High levels of water losses have a serious impact on Bodit Town water service as well as on available water resources in water scarce environments. The total annual water loss of the water supply system is 37.05% in 2019, 27.45% in 2020, 25.92% in 2021, 30.82% in 2022 and 32.57% in 2023 G.C. The non-revenue water from the system is varied from year to year due to the aging of pipe that leads to leakage, installation (extension of network in new area) and illegal connection.

During hydraulic modeling of water pressure of the Bodit Town has 48 nodes were identified. During calibration the model is acceptable calibrated which is satisfied the criteria pressure calibration under average level (average±1.5m to maximum±5m). There was a good correlation between fields measured pressure and simulated pressure since value of R^2 approaches 1 for scenarios. At peak hour consumption, 43.75 % of the nodes are under desirable minimum pressure, 0%of the nodes are exceeding maximum allowable pressure, 21 junctions were negative pressure as indicated in Table 4.15 and 56.25 % of nodes have pressure within the recommended limit.

After changing the existing diameter of the pipe in the distribution system, 93 % of the junctions are in the recommended pressure range of minimum 10 m of H2O and maximum 70m of H2O and only 7 % of the junctions are not in the recommended pressure range. Also 74.29 % of the pipes are in the recommended velocity range of minimum 0.6m/s and maximum 2m/s and only 25.71 % of the pipes are not in the recommended velocity range.

Therefore, control of the flow velocity in water distribution networks should be maintained in order to avoid water stagnation which causes sediment deposition in the pipe.

From the result of water quality analysis revealed that the two parameters particularly the Fluoride (F^-) and Phosphate PO_4^{-3}) higher than the standard value as indicated in the above table 4.19. High geogenic fluoride concentration in groundwater (>1.5mg/l) are associated with a variety of geological and climate conditions. Such as granite basement aquifer, aird climates and alkaline volcanic rocks are conditions highly associated with fluoride. Phosphate indicator of anthropogenic contamination, over all regarding to the above two parameters the Bodit town water supply service enterprise needed to have treatment intervention.

5.2 Recommendation

- The existing water sources are not sufficient to satisfy even water demand of the present dwellers of the town as to the analysis. To address the shortage of water supply of the town in terms of coverage and demand, the predominant approach (satisfy the supply deficit) should be developing new sources or additional borehole should be drilled to fulfill the current gap between water demand and water supply.
- As the only source of water for the town is borehole, watershed works including, soil and water conservation practice must be done to enhance the recharge process for sustainability purpose.
- It is most recommended that houses located at far end of town should have additional pressure tanks installed near their homes and use booster pumps to solve the problems of poor negative pressures at their locations.
- Regarding the water quality, the two parameters particularly the Fluoride (F^-) and Phosphate PO_4^{-3}) higher than the standard value in the Town as indicated in the table 4.19.The Bodit Town Water supply of Service Enterprise needed to have an intervention like to set remedial measure and treatments.

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Appendix A: Pipe Simulation Report During Peak Hour (8:00 hr.) Before Optimization

Label	Start Node	Stop Node	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Velocity (m/s)	Head loss Gradient (m/km)
P1	J1	RES-800m3	2,395	250	HDPE	130	1.39	8.898
P2	J3	J1	376	180	HDPE	130	1.2	10.057
P3	J1	J2	439	180	HDPE	130	1.43	13.772
P4	RES-2000m3	J20	341	250	HDPE	130	0.75	2.872
P5	J2	J4	995	75	HDPE	130	1.62	48.656
P6	J2	J5	502	100	HDPE	130	2.69	79.733
P7	J3	J6	611	100	HDPE	130	1.7	34.019
P8	J3	J7	1,100	100	HDPE	130	1.24	18.836
P9	J7	J13	1,259	50	HDPE	130	0.97	30.025
P10	J7	J6	444	100	HDPE	130	0.08	0.119
P11	J7	J12	843	63	HDPE	130	1.17	32.505
P12	J6	J12	968	100	HDPE	130	1.54	28.226
P13	J11	J5	826	100	HDPE	130	2.04	47.732
P14	J15	J21	261	100	HDPE	130	1.65	32.009
P15	J5	J4	412	75	HDPE	130	1.01	20.283
P16	J4	J8	394	63	HDPE	130	2.06	93.232
P17	J8	J9	783	63	HDPE	130	0.33	3.069
P18	J8	J10	335	63	HDPE	130	0.11	0.398
P19	J10	J9	643	100	HDPE	130	0.5	3.529
P20	J10	J11	454	100	HDPE	130	1	12.769
P21	J12	J13	276	100	HDPE	130	1.8	37.754
P22	J13	J15	675	100	HDPE	130	1.85	39.92
P23	J11	J14	444	100	HDPE	130	0.82	8.784
P24	J10	J16	440	100	HDPE	130	0.37	1.979
P25	J9	J17	501	100	HDPE	130	0.31	2.299
P26	J17	J16	838	100	HDPE	130	0.46	3.047
P27	J14	J16	409	100	HDPE	130	0.71	6.776
P28	J15	J14	957	100	HDPE	130	0.08	0.188
P29	J16	J19	622	75	HDPE	130	0.93	17.358
P30	J17	J18	584	75	HDPE	130	1.08	22.967
P31	J19	J18	759	100	HDPE	130	0.71	6.797
P32	J20	J19	402	75	HDPE	130	1.92	66.78
P33	J20	J21	605	75	HDPE	130	1.37	35.457
P34	J18	J31	786	100	HDPE	130	1.03	13.347
P35	J19	J30	749	75	HDPE	130	1.06	22.062
P36	J20	J29	773	100	HDPE	130	2.25	56.959

P37	J21	J23	276	100	HDPE	145	1.83	31.717
P38	J21	J22	246	40	HDPE	130	2.54	233.849
P39	J23	J24	457	90	HDPE	130	0.91	13.614
P40	J24	J25	371	50	HDPE	130	1.05	35.022
P41	J23	J27	481	75	HDPE	130	2.04	74.245
P42	J24	J26	547	50	HDPE	130	0.96	29.355
P43	J28	J27	268	63	HDPE	130	0.61	9.788
P44	J27	J36	522	140	HDPE	130	0.62	3.951
P45	J29	J28	482	90	HDPE	130	1.63	39.891
P46	J29	J30	324	90	HDPE	130	0.34	2.148
P47	J31	J30	667	100	HDPE	130	0.29	1.305
P48	J31	J32	728	63	HDPE	130	0.62	10.153
P49	J31	J33	670	75	HDPE	130	0.95	18.017
P50	J30	J34	584	75	HDPE	130	1.02	20.707
P51	J29	J37	869	100	HDPE	130	1.25	19.304
P52	J28	J35	548	63	HDPE	130	0.76	11.872
P53	J35	J36	305	90	HDPE	130	0.59	5.969
P54	J35	J41	253	90	HDPE	130	0.77	9.995
P55	J41	J37	423	50	HDPE	130	0.92	27.18
P56	J34	J38	393	90	HDPE	130	0.53	4.923
P57	J34	J33	620	63	HDPE	130	0.22	1.453
P58	J38	J33	1,161	90	HDPE	130	0.36	2.442
P59	J38	J37	292	75	HDPE	130	0.75	11.743
P60	J36	J42	959	75	HDPE	130	1.01	20.422
P61	J41	J42	519	75	HDPE	130	1.23	29.356
P62	J37	J40	234	90	HDPE	130	1.99	57.545
P63	J40	J39	615	75	HDPE	130	0.23	1.321
P64	J40	J43	303	75	HDPE	130	2.16	82.781
P65	J42	J43	399	90	HDPE	130	1.39	29.732
P66	J43	J44	447	90	HDPE	130	2.67	98.9
P67	J44	J45	348	100	HDPE	130	1.58	29.53
P68	J45	J46	997	75	HDPE	130	1.02	20.788
P69	J45	J47	1,741	75	HDPE	130	1.04	21.323
P70	J44	J48	2,121	75	HDPE	130	0.27	1.748

Appendix B: Junction Simulation Report During Peak Hour (8:00 hr.) Before Optimization

Label	X (m)	Y (m)	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
J1	371,798.61	766,885.50	2,089.80	0.94	2,140.00	50.10
J2	372,094.76	767,117.09	2,090.43	2.78	2,133.95	43.43
J3	372,030.32	767,181.03	2,088.90	2.14	2,136.22	47.22
J4	372,766.49	767,105.90	2,060.15	3.92	2,085.52	25.32
J5	372,497.32	767,417.81	2,079.85	1.41	2,093.88	14.01
J6	372,480.47	767,593.40	2,075.90	1.78	2,115.44	39.46
J7	372,169.92	767,910.15	2,066.60	4.19	2,115.49	48.79
J8	373,035.06	767,391.61	2,058.52	3.89	2,048.80	-9.70
J9	373,712.97	767,200.49	2,017.72	3.38	2,046.40	28.62
J10	373,251.24	767,647.45	2,057.60	1.25	2,048.67	-8.91
J11	372,939.88	767,977.80	2,062.65	1.62	2,054.47	-8.17
J12	372,826.55	768,275.55	2,052.30	0.88	2,088.10	35.73
J13	372,652.75	768,489.59	2,018.80	1.06	2,077.69	58.78
J14	373,262.12	768,282.04	2,055.10	1.06	2,050.57	-4.52
J15	373,096.30	768,972.10	2,005.50	1.25	2,050.75	45.16
J16	373,538.56	767,980.20	2,041.80	1.34	2,047.80	5.99
J17	374,120.83	767,401.43	2,015.52	0.77	2,045.25	29.66
J18	374,469.38	767,869.57	2,007.11	1.38	2,031.83	24.68
J19	373,963.69	768,434.67	2,045.20	0.88	2,037.00	-8.19
J20	373,684.67	768,723.52	2,047.90	0.94	2,063.83	15.89
J21	373,272.22	769,165.12	2,001.50	0.86	2,042.39	40.81
J22	373,275.28	769,349.65	1,990.77	2.45	1,984.91	-5.85
J23	373,449.00	769,377.00	1,999.60	1.97	2,033.64	33.97
J24	373,485.33	769,806.72	1,970.40	1.44	2,027.41	56.90
J25	373,254.32	770,096.48	1,962.80	1.58	2,014.43	51.53
J26	373,745.71	770,182.66	1,960.77	1.44	2,011.36	50.49
J27	373,727.35	769,752.35	1,981.60	1.01	1,997.93	16.30
J28	373,912.15	769,558.05	2,015.00	3.95	2,000.56	-14.41
J29	374,248.30	769,213.71	2,031.00	0.93	2,019.78	-11.20
J30	374,474.03	768,982.69	2,022.00	0.61	2,020.47	-1.52
J31	374,935.36	768,502.56	1,971.90	0.66	2,021.34	49.34
J32	375,426.10	768,035.00	1,945.00	1.49	2,013.95	68.81
J33	375,328.98	769,043.92	1,957.42	0.93	2,009.28	51.75
J34	374,856.30	769,422.53	1,992.00	1.41	2,008.38	16.34
J35	374,332.47	769,910.09	1,994.62	1.65	1,994.05	-0.57

J36	374,104.86	770,113.18	1,966.03	1.06	1,995.87	29.78
J37	374,837.40	769,847.90	2,003.10	0.59	2,003.01	-0.09
J38	375,103.41	769,727.88	1,990.20	1.79	2,006.44	16.21
J39	375,576.71	769,917.56	1,964.12	0.78	1,988.74	24.58
J40	374,974.30	770,037.40	1,994.70	1.62	1,989.56	-5.13
J41	374,496.65	770,096.34	1,995.70	0.98	1,991.52	-4.17
J42	374,818.35	770,503.59	1,984.90	0.82	1,976.28	-8.60
J43	375,151.02	770,284.10	1,984.20	1.1	1,964.43	-19.73
J44	375,409.40	770,648.50	1,975.70	0.61	1,920.26	-55.33
J45	375,753.51	770,703.64	1,961.00	4.51	1,909.96	-50.93
J46	376,639.80	770,460.46	1,947.00	3.47	1,889.23	-57.65
J47	376,448.15	771,795.62	1,880.00	3.52	1,872.84	-7.15
J48	376,005.95	772,524.42	1,932.84	0.91	1,916.55	-16.26

Appendix C: Pipe Simulation Report During Peak Hour (8:00 hr.) After Optimization

Label	Start Node	Stop Node	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Velocity (m/s)	Head loss Gradient (m/km)
P1	J1	RES-800m3	2,395	280	HDPE	130	2.31	20.033
P2	J3	J1	376	200	HDPE	130	1.4	11.765
P3	J1	J2	439	280	HDPE	130	1.57	9.865
P4	RES-2000m3	J20	341	250	HDPE	130	0.75	2.88
P5	J2	J4	995	140	HDPE	130	0.93	8.311
P6	J2	J5	502	315	HDPE	130	1.01	3.814
P7	J3	J6	611	200	HDPE	130	1.13	7.903
P8	J3	J7	1,100	110	HDPE	130	0.6	4.987
P9	J7	J13	1,259	50	HDPE	130	0.66	14.672
P10	J7	J6	444	110	HDPE	130	0.31	1.488
P11	J7	J12	843	63	HDPE	130	0.63	10.472
P12	J6	J12	968	180	HDPE	130	1.19	9.793
P13	J11	J5	826	200	HDPE	130	1.83	19.254
P14	J15	J21	261	180	HDPE	145	1.23	8.502
P15	J5	J4	412	140	HDPE	130	1.29	15.425
P16	J4	J8	394	200	HDPE	130	0.93	5.479
P17	J8	J9	783	110	HDPE	130	1.09	14.975
P18	J8	J10	335	110	HDPE	130	1.45	25.17
P19	J10	J9	643	110	HDPE	130	0.61	5.126
P20	J10	J11	454	160	HDPE	130	0.5	2.301
P21	J12	J13	276	140	HDPE	130	2.01	34.992

P22	J13	J15	675	180	HDPE	130	1.21	10.24
P23	J11	J14	444	180	HDPE	130	1.77	20.63
P24	J10	J16	440	110	HDPE	130	1.73	35.153
P25	J9	J17	501	140	HDPE	130	0.76	5.821
P26	J17	J16	838	63	HDPE	130	0.65	11.033
P27	J14	J16	409	180	HDPE	130	1.64	17.952
P28	J15	J14	957	75	HDPE	130	0.43	4.166
P29	J16	J19	622	280	HDPE	130	0.95	3.874
P30	J17	J18	584	110	HDPE	130	0.92	10.977
P31	J19	J18	759	50	HDPE	130	0.44	6.904
P32	J20	J19	402	250	HDPE	130	0.93	4.219
P33	J20	J21	605	125	HDPE	130	0.95	8.675
P34	J18	J31	786	110	HDPE	130	0.64	5.643
P35	J19	J30	749	140	HDPE	130	0.83	6.729
P36	J20	J29	773	160	HDPE	130	1.09	9.562
P37	J21	J23	276	140	HDPE	130	0.8	6.305
P38	J21	J22	246	50	HDPE	130	1.62	78.428
P39	J23	J24	457	63	HDPE	130	1.87	77.666
P40	J24	J25	371	50	HDPE	130	1.05	35.022
P41	J23	J27	481	63	HDPE	130	1.27	38.001
P42	J24	J26	547	50	HDPE	130	0.96	29.355
P43	J28	J27	268	50	HDPE	130	0.12	0.624
P44	J27	J36	522	75	HDPE	130	0.65	8.979
P45	J29	J28	482	90	HDPE	130	0.96	14.962
P46	J29	J30	324	110	HDPE	130	0.99	12.52
P47	J31	J30	667	40	HDPE	130	0.43	8.766
P48	J31	J32	728	40	HDPE	130	1.55	93.007
P49	J31	J33	670	63	HDPE	130	0.9	20.026
P50	J30	J34	584	75	HDPE	130	0.7	10.281
P51	J29	J37	869	180	HDPE	130	0.94	6.383
P52	J28	J35	548	40	HDPE	130	0.59	15.505
P53	J35	J36	305	50	HDPE	130	0.59	11.944
P54	J35	J41	253	75	HDPE	130	0.06	0.102
P55	J41	J37	423	50	HDPE	130	0.86	23.986
P56	J34	J38	393	50	HDPE	130	0.5	8.859
P57	J34	J33	620	40	HDPE	130	0.22	2.516
P58	J38	J33	1,161	90	HDPE	130	0.29	1.656
P59	J38	J37	292	75	HDPE	130	0.12	0.368
P60	J36	J42	959	40	HDPE	130	0.27	3.795
P61	J41	J42	519	75	HDPE	130	0.04	0.04
P62	J37	J40	234	125	HDPE	130	1.79	32.22

P63	J40	J39	615	40	HDPE	130	0.81	28.388
P64	J40	J43	303	160	HDPE	130	0.94	7.305
P65	J42	J43	399	63	HDPE	130	0.18	1.031
P66	J43	J44	447	110	HDPE	130	1.78	37.161
P67	J44	J45	348	110	HDPE	130	1.58	29.53
P68	J45	J46	997	63	HDPE	130	1.45	48.764
P69	J45	J47	1,741	63	HDPE	130	1.47	50.02
P70	J44	J48	2,121	50	HDPE	130	0.61	12.598

Appendix D: Junction Simulation Report During Peak Hour (8:00 hr.) After Optimization

Label	X (m)	Y (m)	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
J1	371,798.61	766,885.50	2,089.80	0.94	2,108.74	19
J2	372,094.76	767,117.09	2,090.43	2.78	2,104.40	14
J3	372,030.32	767,181.03	2,088.90	2.14	2,104.32	15
J4	372,766.49	767,105.90	2,060.15	3.92	2,096.13	36
J5	372,497.32	767,417.81	2,079.85	1.41	2,102.48	23
J6	372,480.47	767,593.40	2,075.90	1.78	2,099.49	24
J7	372,169.92	767,910.15	2,066.60	4.19	2,098.83	32
J8	373,035.06	767,391.61	2,058.52	3.89	2,093.97	35
J9	373,712.97	767,200.49	2,017.72	3.38	2,082.24	64
J10	373,251.24	767,647.45	2,057.60	1.25	2,085.54	28
J11	372,939.88	767,977.80	2,062.65	1.62	2,086.59	24
J12	372,826.55	768,275.55	2,052.30	0.88	2,090.00	38
J13	372,652.75	768,489.59	2,018.80	1.06	2,080.36	61
J14	373,262.12	768,282.04	2,055.10	1.06	2,077.43	22
J15	373,096.30	768,972.10	2,005.50	1.25	2,073.45	68
J16	373,538.56	767,980.20	2,041.80	1.34	2,070.09	28
J17	374,120.83	767,401.43	2,015.52	0.77	2,079.33	64
J18	374,469.38	767,869.57	2,007.11	1.38	2,072.92	66
J19	373,963.69	768,434.67	2,045.20	0.88	2,067.68	22
J20	373,684.67	768,723.52	2,047.90	0.94	2,065.98	18
J21	373,272.22	769,165.12	2,001.50	0.86	2,071.23	70
J22	373,275.28	769,349.65	1,990.77	2.45	2,051.95	61
J23	373,449.00	769,377.00	1,999.60	1.97	2,069.49	70
J24	373,485.33	769,806.72	1,970.40	1.44	2,033.95	63
J25	373,254.32	770,096.48	1,962.80	1.58	2,020.98	58
J26	373,745.71	770,182.66	1,960.77	1.44	2,017.91	57

J27	373,727.35	769,752.35	1,981.60	1.01	2,051.21	69
J28	373,912.15	769,558.05	2,015.00	3.95	2,051.38	36
J29	374,248.30	769,213.71	2,031.00	0.93	2,058.59	28
J30	374,474.03	768,982.69	2,022.00	0.61	2,062.64	41
J31	374,935.36	768,502.56	1,971.90	0.66	2,068.48	96
J32	375,426.10	768,035.00	1,945.00	1.49	2,000.76	56
J33	375,328.98	769,043.92	1,957.42	0.93	2,055.07	97
J34	374,856.30	769,422.53	1,992.00	1.41	2,056.63	65
J35	374,332.47	769,910.09	1,994.62	1.65	2,042.88	48
J36	374,104.86	770,113.18	1,966.03	1.06	2,046.52	80
J37	374,837.40	769,847.90	2,003.10	0.59	2,053.04	50
J38	375,103.41	769,727.88	1,990.20	1.79	2,053.15	63
J39	375,576.71	769,917.56	1,964.12	0.78	2,028.04	64
J40	374,974.30	770,037.40	1,994.70	1.62	2,045.51	51
J41	374,496.65	770,096.34	1,995.70	0.98	2,042.90	47
J42	374,818.35	770,503.59	1,984.90	0.82	2,042.88	58
J43	375,151.02	770,284.10	1,984.20	1.1	2,043.29	59
J44	375,409.40	770,648.50	1,975.70	0.61	2,026.69	51
J45	375,753.51	770,703.64	1,961.00	4.51	2,016.40	55
J46	376,639.80	770,460.46	1,947.00	3.47	1,967.76	21
J47	376,448.15	771,795.62	1,880.00	3.52	1,929.31	49
J48	376,005.95	772,524.42	1,932.84	0.91	1,999.97	67

Appendix E: Junction Simulation Report Low Consumption Period @ Night time 1:00 hr. Before Optimization

Label	X (m)	Y (m)	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
J1	371,798.61	766,885.50	2,089.80	0.15	2,149.67	60
J2	372,094.76	767,117.09	2,090.43	0.43	2,147.57	57
J3	372,030.32	767,181.03	2,088.90	0.34	2,148.48	59
J4	372,766.49	767,105.90	2,060.15	0.61	2,130.16	70
J5	372,497.32	767,417.81	2,079.85	0.22	2,131.02	51
J6	372,480.47	767,593.40	2,075.90	0.28	2,140.93	65
J7	372,169.92	767,910.15	2,066.60	0.65	2,141.17	74
J8	373,035.06	767,391.61	2,058.52	0.61	2,110.36	52
J9	373,712.97	767,200.49	2,017.72	0.53	2,105.27	87
J10	373,251.24	767,647.45	2,057.60	0.2	2,105.76	48
J11	372,939.88	767,977.80	2,062.65	0.25	2,108.56	46
J12	372,826.55	768,275.55	2,052.30	0.14	2,125.51	73
J13	372,652.75	768,489.59	2,018.80	0.16	2,119.04	100
J14	373,262.12	768,282.04	2,055.10	0.16	2,104.87	50
J15	373,096.30	768,972.10	2,005.50	0.2	2,100.41	95
J16	373,538.56	767,980.20	2,041.80	0.21	2,103.08	61
J17	374,120.83	767,401.43	2,015.52	0.12	2,100.64	85
J18	374,469.38	767,869.57	2,007.11	0.22	2,073.03	66
J19	373,963.69	768,434.67	2,045.20	0.14	2,072.79	28
J20	373,684.67	768,723.52	2,047.90	0.15	2,059.03	11
J21	373,272.22	769,165.12	2,001.50	0.13	2,091.49	90
J22	373,275.28	769,349.65	1,990.77	0.38	2,089.64	99
J23	373,449.00	769,377.00	1,999.60	0.31	2,089.42	90
J24	373,485.33	769,806.72	1,970.40	0.23	2,089.22	119
J25	373,254.32	770,096.48	1,962.80	0.25	2,088.80	126
J26	373,745.71	770,182.66	1,960.77	0.23	2,088.70	128
J27	373,727.35	769,752.35	1,981.60	0.16	2,068.84	87
J28	373,912.15	769,558.05	2,015.00	0.62	2,066.35	51
J29	374,248.30	769,213.71	2,031.00	0.14	2,065.38	34
J30	374,474.03	768,982.69	2,022.00	0.1	2,068.14	46
J31	374,935.36	768,502.56	1,971.90	0.1	2,069.44	97
J32	375,426.10	768,035.00	1,945.00	0.23	2,069.20	124
J33	375,328.98	769,043.92	1,957.42	0.14	2,067.45	110
J34	374,856.30	769,422.53	1,992.00	0.22	2,067.14	75
J35	374,332.47	769,910.09	1,994.62	0.26	2,067.07	72
J36	374,104.86	770,113.18	1,966.03	0.16	2,068.31	102
J37	374,837.40	769,847.90	2,003.10	0.09	2,065.59	62

J38	375,103.41	769,727.88	1,990.20	0.28	2,066.83	76
J39	375,576.71	769,917.56	1,964.12	0.12	2,065.40	101
J40	374,974.30	770,037.40	1,994.70	0.25	2,065.43	71
J41	374,496.65	770,096.34	1,995.70	0.15	2,066.72	71
J42	374,818.35	770,503.59	1,984.90	0.13	2,066.10	81
J43	375,151.02	770,284.10	1,984.20	0.17	2,065.23	81
J44	375,409.40	770,648.50	1,975.70	0.1	2,063.81	88
J45	375,753.51	770,703.64	1,961.00	0.7	2,063.48	102
J46	376,639.80	770,460.46	1,947.00	0.54	2,062.81	116
J47	376,448.15	771,795.62	1,880.00	0.55	2,062.28	182
J48	376,005.95	772,524.42	1,932.84	0.14	2,063.69	131

Appendix F: Junction Simulation Report Low Consumption Period @ (Night time 1:00 hr. After Optimization

Label	X (m)	Y (m)	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)
J1	371,798.61	766,885.50	2,089.80	0.15	2,119.79	30
J2	372,094.76	767,117.09	2,090.43	0.43	2,116.20	26
J3	372,030.32	767,181.03	2,088.90	0.34	2,116.84	28
J4	372,766.49	767,105.90	2,060.15	0.61	2,110.33	50
J5	372,497.32	767,417.81	2,079.85	0.22	2,114.46	35
J6	372,480.47	767,593.40	2,075.90	0.28	2,113.21	37
J7	372,169.92	767,910.15	2,066.60	0.65	2,113.22	47
J8	373,035.06	767,391.61	2,058.52	0.61	2,108.47	50
J9	373,712.97	767,200.49	2,017.72	0.53	2,097.24	79
J10	373,251.24	767,647.45	2,057.60	0.2	2,097.29	40
J11	372,939.88	767,977.80	2,062.65	0.25	2,097.63	35
J12	372,826.55	768,275.55	2,052.30	0.14	2,103.63	51
J13	372,652.75	768,489.59	2,018.80	0.16	2,093.27	74
J14	373,262.12	768,282.04	2,055.10	0.16	2,085.20	30
J15	373,096.30	768,972.10	2,005.50	0.2	2,085.32	80
J16	373,538.56	767,980.20	2,041.80	0.21	2,073.70	32
J17	374,120.83	767,401.43	2,015.52	0.12	2,095.06	79
J18	374,469.38	767,869.57	2,007.11	0.22	2,091.12	84
J19	373,963.69	768,434.67	2,045.20	0.14	2,069.71	24
J20	373,684.67	768,723.52	2,047.90	0.15	2,065.67	18
J21	373,272.22	769,165.12	2,001.50	0.13	2,082.88	81
J22	373,275.28	769,349.65	1,990.77	0.38	2,082.26	91
J23	373,449.00	769,377.00	1,999.60	0.31	2,082.62	83
J24	373,485.33	769,806.72	1,970.40	0.23	2,081.48	111

J25	373,254.32	770,096.48	1,962.80	0.25	2,081.07	118
J26	373,745.71	770,182.66	1,960.77	0.23	2,080.97	120
J27	373,727.35	769,752.35	1,981.60	0.16	2,070.94	89
J28	373,912.15	769,558.05	2,015.00	0.62	2,066.56	51
J29	374,248.30	769,213.71	2,031.00	0.14	2,066.45	35
J30	374,474.03	768,982.69	2,022.00	0.1	2,068.55	46
J31	374,935.36	768,502.56	1,971.90	0.1	2,088.48	116
J32	375,426.10	768,035.00	1,945.00	0.23	2,086.30	141
J33	375,328.98	769,043.92	1,957.42	0.14	2,071.77	114
J34	374,856.30	769,422.53	1,992.00	0.22	2,068.54	76
J35	374,332.47	769,910.09	1,994.62	0.26	2,066.66	72
J36	374,104.86	770,113.18	1,966.03	0.16	2,069.48	103
J37	374,837.40	769,847.90	2,003.10	0.09	2,066.45	63
J38	375,103.41	769,727.88	1,990.20	0.28	2,068.33	78
J39	375,576.71	769,917.56	1,964.12	0.12	2,065.71	101
J40	374,974.30	770,037.40	1,994.70	0.25	2,066.27	71
J41	374,496.65	770,096.34	1,995.70	0.15	2,066.53	71
J42	374,818.35	770,503.59	1,984.90	0.13	2,066.47	81
J43	375,151.02	770,284.10	1,984.20	0.17	2,066.22	82
J44	375,409.40	770,648.50	1,975.70	0.1	2,065.69	90
J45	375,753.51	770,703.64	1,961.00	0.7	2,065.36	104
J46	376,639.80	770,460.46	1,947.00	0.54	2,063.79	117
J47	376,448.15	771,795.62	1,880.00	0.55	2,062.56	182
J48	376,005.95	772,524.42	1,932.84	0.14	2,064.83	132

Appendix G: Pipe Simulation Report Low Consumption Period @ Night time 1:00 hr. Before Optimization

Label	Start Node	Stop Node	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Velocity (m/s)	Head loss Gradient (m/km)
P1	J1	RES-800m3	2,395	250	HDPE	130	0.76	2.893
P2	J3	J1	376	180	HDPE	130	0.65	3.178
P3	J1	J2	439	180	HDPE	130	0.81	4.789
P4	RES-2000m3	J20	341	250	HDPE	130	0.42	0.981
P5	J2	J4	995	75	HDPE	130	0.93	17.49
P6	J2	J5	502	100	HDPE	130	1.67	32.936
P7	J3	J6	611	100	HDPE	130	0.98	12.357
P8	J3	J7	1,100	100	HDPE	130	0.7	6.64
P9	J7	J13	1,259	50	HDPE	130	0.72	17.58
P10	J7	J6	444	100	HDPE	130	0.18	0.544
P11	J7	J12	843	63	HDPE	130	0.86	18.582
P12	J6	J12	968	100	HDPE	130	1.13	15.918
P13	J11	J5	826	100	HDPE	130	1.51	27.194
P14	J15	J21	261	100	HDPE	130	1.7	34.154
P15	J5	J4	412	75	HDPE	130	0.29	2.077
P16	J4	J8	394	63	HDPE	130	1.48	50.27
P17	J8	J9	783	63	HDPE	130	0.49	6.503
P18	J8	J10	335	63	HDPE	130	0.73	13.741
P19	J10	J9	643	100	HDPE	130	0.22	0.762
P20	J10	J11	454	100	HDPE	130	0.68	6.176
P21	J12	J13	276	100	HDPE	130	1.39	23.482
P22	J13	J15	675	100	HDPE	130	1.52	27.6
P23	J11	J14	444	100	HDPE	130	0.8	8.33
P24	J10	J16	440	100	HDPE	130	0.67	6.084
P25	J9	J17	501	100	HDPE	130	0.66	9.226
P26	J17	J16	838	100	HDPE	130	0.45	2.91
P27	J14	J16	409	100	HDPE	130	0.56	4.362
P28	J15	J14	957	100	HDPE	130	0.46	4.654
P29	J16	J19	622	75	HDPE	130	1.62	48.671
P30	J17	J18	584	75	HDPE	130	1.6	47.285
P31	J19	J18	759	100	HDPE	130	0.14	0.318
P32	J20	J19	402	75	HDPE	130	1.34	34.241
P33	J20	J21	605	75	HDPE	130	1.71	53.688
P34	J18	J31	786	100	HDPE	130	0.58	4.571
P35	J19	J30	749	75	HDPE	130	0.53	6.212

P36	J20	J29	773	100	HDPE	130	0.79	8.21
P37	J21	J23	276	100	HDPE	145	0.84	7.521
P38	J21	J22	246	40	HDPE	130	0.4	7.514
P39	J23	J24	457	90	HDPE	130	0.14	0.438
P40	J24	J25	371	50	HDPE	130	0.16	1.125
P41	J23	J27	481	75	HDPE	130	1.51	42.777
P42	J24	J26	547	50	HDPE	130	0.15	0.943
P43	J28	J27	268	63	HDPE	130	0.59	9.313
P44	J27	J36	522	140	HDPE	130	0.3	1.025
P45	J29	J28	482	90	HDPE	130	0.32	1.998
P46	J29	J30	324	90	HDPE	130	0.71	8.52
P47	J31	J30	667	100	HDPE	130	0.36	1.95
P48	J31	J32	728	63	HDPE	130	0.1	0.326
P49	J31	J33	670	75	HDPE	130	0.36	2.97
P50	J30	J34	584	75	HDPE	130	0.27	1.703
P51	J29	J37	869	100	HDPE	130	0.12	0.241
P52	J28	J35	548	63	HDPE	130	0.23	1.313
P53	J35	J36	305	90	HDPE	130	0.48	4.072
P54	J35	J41	253	90	HDPE	130	0.26	1.361
P55	J41	J37	423	50	HDPE	130	0.26	2.669
P56	J34	J38	393	90	HDPE	130	0.2	0.806
P57	J34	J33	620	63	HDPE	130	0.12	0.494
P58	J38	J33	1,161	90	HDPE	130	0.16	0.536
P59	J38	J37	292	75	HDPE	130	0.43	4.224
P60	J36	J42	959	75	HDPE	130	0.31	2.298
P61	J41	J42	519	75	HDPE	130	0.22	1.189
P62	J37	J40	234	90	HDPE	130	0.19	0.719
P63	J40	J39	615	75	HDPE	130	0.04	0.043
P64	J40	J43	303	75	HDPE	130	0.16	0.656
P65	J42	J43	399	90	HDPE	130	0.34	2.204
P66	J43	J44	447	90	HDPE	130	0.42	3.178
P67	J44	J45	348	100	HDPE	130	0.25	0.949
P68	J45	J46	997	75	HDPE	130	0.16	0.668
P69	J45	J47	1,741	75	HDPE	130	0.16	0.685
P70	J44	J48	2,121	75	HDPE	130	0.04	0.056

Appendix H: Pipe Simulation Report Low Consumption Period @ Night time 1:00 hr. After Optimization

Label	Start Node	Stop Node	Length (m)	Diameter (mm)	Material	Hazen-Williams C	Velocity (m/s)	Head loss Gradient (m/km)
P1	J1	RES-800m3	2,395	280	HDPE	130	2	15.366
P2	J3	J1	376	200	HDPE	130	1.13	7.871
P3	J1	J2	439	280	HDPE	130	1.42	8.176
P4	RES-2000m3	J20	341	250	HDPE	130	2.17	20.454
P5	J2	J4	995	140	HDPE	130	0.77	5.904
P6	J2	J5	502	315	HDPE	130	0.96	3.472
P7	J3	J6	611	200	HDPE	130	0.97	5.936
P8	J3	J7	1,100	110	HDPE	130	0.48	3.286
P9	J7	J13	1,259	50	HDPE	130	0.69	15.847
P10	J7	J6	444	110	HDPE	130	0.03	0.024
P11	J7	J12	843	63	HDPE	130	0.66	11.381
P12	J6	J12	968	180	HDPE	130	1.19	9.891
P13	J11	J5	826	200	HDPE	130	1.88	20.373
P14	J15	J21	261	180	HDPE	145	1.29	9.335
P15	J5	J4	412	140	HDPE	130	1.03	10.026
P16	J4	J8	394	200	HDPE	130	0.85	4.722
P17	J8	J9	783	110	HDPE	130	1.07	14.339
P18	J8	J10	335	110	HDPE	130	1.68	33.365
P19	J10	J9	643	110	HDPE	130	0.07	0.085
P20	J10	J11	454	160	HDPE	130	0.28	0.756
P21	J12	J13	276	140	HDPE	130	2.09	37.578
P22	J13	J15	675	180	HDPE	130	1.31	11.779
P23	J11	J14	444	180	HDPE	130	2.09	28.029
P24	J10	J16	440	110	HDPE	130	2.18	53.663
P25	J9	J17	501	140	HDPE	130	0.65	4.352
P26	J17	J16	838	63	HDPE	130	1.02	25.499
P27	J14	J16	409	180	HDPE	130	2.09	28.1
P28	J15	J14	957	75	HDPE	130	0.07	0.127
P29	J16	J19	622	280	HDPE	130	1.25	6.411
P30	J17	J18	584	110	HDPE	130	0.71	6.744
P31	J19	J18	759	50	HDPE	130	0.94	28.198
P32	J20	J19	402	250	HDPE	130	1.48	10.047
P33	J20	J21	605	125	HDPE	130	1.8	28.469
P34	J18	J31	786	110	HDPE	130	0.49	3.362
P35	J19	J30	749	140	HDPE	130	0.37	1.547

P36	J20	J29	773	160	HDPE	130	0.32	1.01
P37	J21	J23	276	140	HDPE	130	0.29	0.94
P38	J21	J22	246	50	HDPE	130	0.25	2.52
P39	J23	J24	457	63	HDPE	130	0.29	2.496
P40	J24	J25	371	50	HDPE	130	0.16	1.125
P41	J23	J27	481	63	HDPE	130	1	24.291
P42	J24	J26	547	50	HDPE	130	0.15	0.943
P43	J28	J27	268	50	HDPE	130	0.7	16.341
P44	J27	J36	522	75	HDPE	130	0.35	2.8
P45	J29	J28	482	90	HDPE	130	0.1	0.221
P46	J29	J30	324	110	HDPE	130	0.7	6.482
P47	J31	J30	667	40	HDPE	130	0.84	29.882
P48	J31	J32	728	40	HDPE	130	0.24	2.989
P49	J31	J33	670	63	HDPE	130	1.01	24.947
P50	J30	J34	584	75	HDPE	130	0.02	0.016
P51	J29	J37	869	180	HDPE	130	0.02	0.005
P52	J28	J35	548	40	HDPE	130	0.05	0.173
P53	J35	J36	305	50	HDPE	130	0.51	9.258
P54	J35	J41	253	75	HDPE	130	0.14	0.499
P55	J41	J37	423	50	HDPE	130	0.06	0.189
P56	J34	J38	393	50	HDPE	130	0.11	0.533
P57	J34	J33	620	40	HDPE	130	0.33	5.211
P58	J38	J33	1,161	90	HDPE	130	0.4	2.961
P59	J38	J37	292	75	HDPE	130	0.54	6.441
P60	J36	J42	959	40	HDPE	130	0.25	3.143
P61	J41	J42	519	75	HDPE	130	0.06	0.122
P62	J37	J40	234	125	HDPE	130	0.24	0.767
P63	J40	J39	615	40	HDPE	130	0.13	0.912
P64	J40	J43	303	160	HDPE	130	0.12	0.165
P65	J42	J43	399	63	HDPE	130	0.14	0.617
P66	J43	J44	447	110	HDPE	130	0.28	1.194
P67	J44	J45	348	110	HDPE	130	0.25	0.949
P68	J45	J46	997	63	HDPE	130	0.23	1.567
P69	J45	J47	1,741	63	HDPE	130	0.23	1.607
P70	J44	J48	2,121	50	HDPE	130	0.09	0.405

Appendix G Water Quality Test Result

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report

(Drinking Water Quality)

Client	
Contact person	Libenu Lemma
Sample Number	9786c
Date of Sampling	#N/A (Ethiopian, EC)
Date of Testing (dd/mm/yyyy)	15/11/2015 (Ethiopian, EC) (International)
Nature of Sample	
Source	BH
Depth [m]	

Zone	wolaita
Woreda	damot gala/ bodity
Kebele	bodity
Village	AGAZA
Site Name	
GPS (UTM) Northing	771636
GPS (UTM) Easting	374807
Alttitude [m]	1914
Sample taken by	Libenu Lemma

Analysis results

Item	Unit	Result	Standard
pH	-	6.8	6.5 - 8.5
Temperature	[°C]	20.1	-
Conductivity	[μS/cm]	253	-
TDS	[mg/L]	127	1000
Turbidity	[FTU]	4	5
Total Chlorine [Cl_2]	[mg/L]	0.14	5
Total Hardness	[mg/L as $CaCO_3$]	150	300
Calcium Hardness	[mg/L as $CaCO_3$]	70	-
Magnesium Hardness	[mg/L as $CaCO_3$]	80	-
Total Alkalinity	[mg/L as $CaCO_3$]	180	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	180	-
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	0.26	1.5
NH_4^+ Ammonium	[mg/L]	0.33	-
Na^+ Sodium	[mg/L]	13.7	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	9.0	-
Ca^+	Calcium	[mg/L]	28.0	100
Mg^+	Magnesium	[mg/L]	19.4	30
Fe	Iron	[mg/L]	0.12	0.3
Cu^{2+}	Copper	[mg/L]	0.33	2
Mn^{2+}	Manganese	[mg/L]	0.30	0.5
Cr^{6+}	Chromium	[mg/L]	0.03	0.05
Cl^-	Chloride	[mg/L]	<10	250
F^-	Fluoride	[mg/L]	1.96	1.5
Br_2	Bromine	[mg/L]	0.29	-
NO_2^-	Nitrite	[mg/L]	0.02	3
NO_3^-	Nitrate	[mg/L]	6.6	50
SO_4^{2-}	Sulfate	[mg/L]	2	250
PO_4^{3-}	Phosphate	[mg/L]	0.25	-
HCO_3^-	Bicarbonate	[mg/L]	220	-
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:
Values that exceed WHO guidline are underlined.

Remark:
Fluoride $ turbidityContent of the analysed water sample exceeds the WHO guideline and Ethiopian standard set for drinking water.Therefore,the water is not suitable for drinking purpose unless it is treated before supply to the community.Note that the water sample was taken by the client.

Analyzed on 15/11/2015 *by* ***Zerihun sebsibe*** *Signature*

Approved on 28/11/2015 *by* W/R/S/M/C Signature

Southern Nations Nationalities and People's Regional State Water Irrigation And Mine Development Bureau

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report

(Drinking Water Quality)

Client		Zone	wolaita
Contact person	Libenu Lemma	Woreda	damot gala/ bodity
Sample Number	9785c	Kebele	ada koisha
Date of Sampling	#N/A (Ethiopian, EC)	Village	ada koisha no -1
Date of Testing (dd/mm/yyyy)	15/11/2015 (Ethiopian, EC) (International)	Site Name	
		GPS (UTM) Northing	773220
Nature of Sample		GPS (UTM) Easting	376219
Source	BH	Alttitude [m]	1903
Depth [m]		Sample taken by	Libenu Lemma

Analysis results

Item	Unit	Result	Standard
pH	-	6.9	6.5 - 8.5
Temperature	[°C]	20.1	-
Conductivity	[µS/cm]	347	-
TDS	[mg/L]	174	1000
Turbidity	[FTU]	4	5
Total Chlorine [Cl_2]	[mg/L]	0.05	5
Total Hardness	[mg/L as $CaCO_3$]	160	300
Calcium Hardness	[mg/L as $CaCO_3$]	80	-
Magnesium Hardness	[mg/L as $CaCO_3$]	80	-
Total Alkalinity	[mg/L as $CaCO_3$]	220	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	220	-
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	0.17	1.5
NH_4^+ Ammonium	[mg/L]	0.22	-
Na^+ Sodium	[mg/L]	25.4	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	11.0	-
Ca^+	Calcium	[mg/L]	32.0	100
Mg^+	Magnesium	[mg/L]	19.4	30
Fe	Iron	[mg/L]	0.15	0.3
Cu^{2+}	Copper	[mg/L]	0.25	2
Mn^{2+}	Manganese	[mg/L]	0.10	0.5
Cr^{6+}	Chromium	[mg/L]	0.02	0.05
Cl^-	Chloride	[mg/L]	<10	250
F^-	Fluoride	[mg/L]	<u>2.00</u>	1.5
Br_2	Bromine	[mg/L]	0.11	-
NO_2^-	Nitrite	[mg/L]	0.01	3
NO_3^-	Nitrate	[mg/L]	4.0	50
SO_4^{2-}	Sulfate	[mg/L]	<2	250
PO_4^{3-}	Phosphate	[mg/L]	0.46	-
HCO_3^-	Bicarbonate	[mg/L]	268	-
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:

Values that exceed WHO guidline are underlined.

Remark:

Fluoride Content of the analysed water sample exceeds the WHO guideline and Ethiopian standard set for drinking water.Therefore,the water is not suitable for drinking purpose unless it is treated before supply to the community.Note that the water sample was taken by the client.

Analyzed on 15/11/2015 *by* ***Zerihun sebsibe*** *Signature*

Approved on 28/11/2015 *by* *W/R/S/M/D* *Signature*

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report

(Drinking Water Quality)

Client		Zone	Welayta
Contact person		Woreda	Damot Gale
Sample Number	9810C	Kebele	Addis Ketema
Date of Sampling	6/11/2015 (Ethiopian, EC)	Village	Lukanda area
Date of Testing (dd/mm/yyyy)	14/11/2015 (Ethiopian, EC) 21/07 2023 (International)	Site Name	Water pt after 2000 c.m reserv.
		GPS (UTM) Northing	769398
Nature of Sample		Easting	374347
Source	BH	Alttitude [m]	2024
Depth [m]		Sample taken by	Lebenu Lemma

Analysis results

Item	Unit	Result	Standard
pH	-	6.9	6.5 - 8.5
Temperature	[°C]	21.1	-
Conductivity	[μS/cm]	282	-
TDS	[mg/L]	141	1000
Turbidity	[FTU]	<u>6</u>	5
Total Chlorine [Cl_2]	[mg/L]	0.03	5
Total Hardness	[mg/L as $CaCO_3$]	69	300
Calcium Hardness	[mg/L as $CaCO_3$]	47	-
Magnesium Hardness	[mg/L as $CaCO_3$]	22	-
Total Alkalinity	[mg/L as $CaCO_3$]	297	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	297	-
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	0.73	1.5
NH_4^+ Ammonium	[mg/L]	0.94	-
Na^+ Sodium	[mg/L]	116.4	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	4.0	-
Ca^+	Calcium	[mg/L]	18.8	100
Mg^+	Magnesium	[mg/L]	5.3	30
Fe	Iron	[mg/L]	0.01	0.3
Cu^{2+}	Copper	[mg/L]	0.10	2
Mn^{2+}	Manganese	[mg/L]	<0.1	0.5
Cr^{6+}	Chromium	[mg/L]	0.01	0.05
Cl^-	Chloride	[mg/L]	10	250
F^-	Fluoride	[mg/L]	<u>2.02</u>	1.5
Br_2	Bromine	[mg/L]	<0.05	-
NO_2^-	Nitrite	[mg/L]	0.03	3
NO_3^-	Nitrate	[mg/L]	8.8	50
SO_4^{2-}	Sulfate	[mg/L]	<2	250
PO_4^{3-}	Phosphate	[mg/L]	12.00	-
HCO_3^-	Bicarbonate	[mg/L]	362	-
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:

Values that exceed WHO guidline are underlined.

Remark:

Fluoride Content & turbidity of the analysed water sample exceeds the WHO guideline and Ethiopian standard set for drinking water.Therefore,the water is not suitable for drinking purpose unless it is treated before supply to the community.Note that the water sample was taken by the client.

Analyzed on 14/11/2015 *by* Abate Bekele Signature

Approved on 26/11/2015 *by* WRSMD Signature

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report

(Drinking Water Quality)

Client			Zone	Welayta
Contact person			Woreda	Damot Gale
Sample Number	9801C		Kebele	Chawa Kara
Date of Sampling	6/11/2015 (Ethiopian, EC)		Village	Chawa Kara
Date of Testing (dd/mm/yyyy)	14/11/2015 (Ethiopian, EC)		Site Name	0
	21/07 2023 (International)		GPS (UTM) Northing	768002
Nature of Sample			GPS (UTM) Easting	375135
Source	BH		Alttitude [m]	1929
Depth [m]			Sample taken by	Lebenu Lemma

Analysis results

Item	Unit	Result	Standard
pH	-	6.4	6.5 - 8.5
Temperature	[°C]	22	-
Conductivity	[µS/cm]	187	-
TDS	[mg/L]	94	1000
Turbidity	[FTU]	4	5
Total Chlorine [Cl_2]	[mg/L]	<0.02	5
Total Hardness	[mg/L as $CaCO_3$]	68	300
Calcium Hardness	[mg/L as $CaCO_3$]	50	-
Magnesium Hardness	[mg/L as $CaCO_3$]	18	-
Total Alkalinity	[mg/L as $CaCO_3$]	124	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	124	-
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	0.85	1.5
NH_4^+ Ammonium	[mg/L]	1.10	-
Na^+ Sodium	[mg/L]	40.7	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	7.0	-
Ca^+	Calcium	[mg/L]	20.0	100
Mg^+	Magnesium	[mg/L]	4.4	30
Fe	Iron	[mg/L]	0.10	0.3
Cu^{2+}	Copper	[mg/L]	0.07	2
Mn^{2+}	Manganese	[mg/L]	<0.1	0.5
Cr^{6+}	Chromium	[mg/L]	<0.01	0.05
Cl^-	Chloride	[mg/L]	<10	250
F^-	Fluoride	[mg/L]	1.30	1.5
Br_2	Bromine	[mg/L]	<0.05	-
NO_2^-	Nitrite	[mg/L]	0.08	3
NO_3^-	Nitrate	[mg/L]	16.7	50
SO_4^{2-}	Sulfate	[mg/L]	2	250
PO_4^{3-}	Phosphate	[mg/L]	5.80	-
HCO_3^-	Bicarbonate	[mg/L]	151	-
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:
Values that exceed WHO guidline are underlined.

Remark:
The test result indicates that all the parameters measured meet the WHO guideline and Ethiopian standard set for drinking water. Note that the water sample was taken by the client.

Analyzed on 14/11/2015 *by* ***Abate Bekele*** *Signature*

Approved on 26/11/2015 *by* *W/R/S/M/D* *Signature*

Southern Nations Nationalities and People's Regional State Water Irrigation And Mine Development Bureau

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report
(Drinking Water Quality)

Client		Zone	wolaita
Contact person	Libenu Lemma	Woreda	damot gala/ (bodity town)
Sample Number	9789c	Kebele	shasha Gala
Date of Sampling	15/11/2015 (Ethiopian, EC)	Village	primary school
Date of Testing (dd/mm/yyyy)	15/11/2015 (Ethiopian, EC) (International)	Site Name	primary school/(resirevare 800m3
		GPS (UTM) Northing	764956
Nature of Sample		GPS (UTM) Easting	370415
Source	BH	Alttitude [m]	2149
Depth [m]		Sample taken by	Lebenu Lemma

Analysis results

Item	Unit	Result	Standard	Item		Unit	Result	Standard
pH	-	<u>6.0</u>	6.5 - 8.5	K^+	Potassium	[mg/L]	8.6	-
Temperature	[°C]	20	-	Ca^+	Calcium	[mg/L]	32.0	100
Conductivity	[µS/cm]	135	-	Mg^+	Magnesium	[mg/L]	14.6	30
TDS	[mg/L]	68	1000	Fe	Iron	[mg/L]	0.26	0.3
Turbidity	[FTU]	5	5	Cu^{2+}	Copper	[mg/L]	0.56	2
Total Chlorine [Cl_2]	[mg/L]	0.16	5	Mn^{2+}	Manganese	[mg/L]	0.50	0.5
Total Hardness	[mg/L as $CaCO_3$]	140	300	Cr^{6+}	Chromium	[mg/L]	0.05	0.05
Calcium Hardness	[mg/L as $CaCO_3$]	80	-	Cl^-	Chloride	[mg/L]	10	250
Magnesium Hardness	[mg/L as $CaCO_3$]	60	-	F^-	Fluoride	[mg/L]	<u>2.02</u>	1.5
Total Alkalinity	[mg/L as $CaCO_3$]	200	500	Br_2	Bromine	[mg/L]	0.33	-
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	200	-	NO_2^-	Nitrite	[mg/L]	0.08	3
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-	NO_3^-	Nitrate	[mg/L]	44.0	50
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-	SO_4^{2-}	Sulfate	[mg/L]	8	250
Dissolved NH_3	[mg/L]	<u>0.44</u>	1.5	PO_4^{3-}	Phosphate	[mg/L]	0.72	-
NH_4^+ Ammonium	[mg/L]	3.15	-	HCO_3^-	Bicarbonate	[mg/L]	244	-
Na^+ Sodium	[mg/L]	40.8	-	CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:

Values that exceed WHO guidline are underlined.

Remark:

Fluoride Content of the analysed water sample exceeds the WHO guideline and Ethiopian standard set for drinking water.Therefore,the water is not suitable for drinking purpose unless it is treated before supply to the community.Note that the water sample was taken by the client.

Analyzed on 12/11/2015 *by* ***Zerihun*** Signature

Approved on 26/11/2015 *by* Signature

Southern Nations Nationalities and People's Regional State Water, Irrigation And Mine Development Bureau

Habtemariam Tilahun Beyene
Water Resource Study & M...
Director

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report

(Drinking Water Quality)

Client		Zone	Welayta
Contact person		Woreda	Damot Gale
Sample Number	9808C	Kebele	Boditi korke
Date of Sampling	6/11/2015 (Ethiopian, EC)	Village	0
Date of Testing (dd/mm/yyyy)	13/11/2015 (Ethiopian, EC) 20/07 2023 (International)	Site Name	Water point
		GPS (UTM) Northing	767798
Nature of Sample		GPS (UTM) Easting	372355
Source	BH	Alttitude [m]	2084
Depth [m]		Sample taken by	Lebenu Lemma

Analysis results

Item	Unit	Result	Standard
pH	-	6.8	6.5 - 8.5
Temperature	[°C]	21.2	-
Conductivity	[µS/cm]	290	-
TDS	[mg/L]	145	1000
Turbidity	[FTU]	4	5
Total Chlorine [Cl_2]	[mg/L]	0.02	5
Total Hardness	[mg/L as $CaCO_3$]	75	300
Calcium Hardness	[mg/L as $CaCO_3$]	45	-
Magnesium Hardness	[mg/L as $CaCO_3$]	30	-
Total Alkalinity	[mg/L as $CaCO_3$]	160	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	160	-
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	1.10	1.5
NH_4^+ Ammonium	[mg/L]	1.42	-
Na^+ Sodium	[mg/L]	59.9	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	9.0	-
Ca^+	Calcium	[mg/L]	18.0	100
Mg^+	Magnesium	[mg/L]	7.3	30
Fe	Iron	[mg/L]	0.01	0.3
Cu^{2+}	Copper	[mg/L]	0.20	2
Mn^{2+}	Manganese	[mg/L]	<0.1	0.5
Cr^{6+}	Chromium	[mg/L]	<0.01	0.05
Cl^-	Chloride	[mg/L]	<10	250
F^-	Fluoride	[mg/L]	<u>2.03</u>	1.5
Br_2	Bromine	[mg/L]	<0.05	-
NO_2^-	Nitrite	[mg/L]	0.04	3
NO_3^-	Nitrate	[mg/L]	11.0	50
SO_4^{2-}	Sulfate	[mg/L]	<2	250
PO_4^{3-}	Phosphate	[mg/L]	28.70	-
HCO_3^-	Bicarbonate	[mg/L]	195	-
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:
Values that exceed WHO guidline are underlined.

Remark:
Fluoride Content of the analysed water sample exceeds the WHO guideline and Ethiopian standard set for drinking water.Therefore,the water is not suitable for drinking purpose unless it is treated before supply to the community.Note that the water sample was taken by the client.

Analyzed on 13/11/2015 *by* ***Abate Bekele*** Signature

Approved on 26/11/2015 *by* *W/R/S/M/D*

Southern Nations, Nationalities and Peoples Regional State Water, Irrigation And Mine Development Bureau

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report

(Drinking Water Quality)

Client	
Contact person	
Sample Number	9804C
Date of Sampling	6/11/2015 (Ethiopian, EC)
Date of Testing (dd/mm/yyyy)	11/11/2015 (Ethiopian, EC) 18/07 2023 (International)
Nature of Sample	
Source	BH
Depth [m]	

Zone		Welayta
Woreda		Damot Gale
Kebele		Boditi keera
Village		Wendra
Site Name		0
GPS (UTM)	Northing	768756
	Easting	372055
Alttitude [m]		1986
Sample taken by		Lebenu Lemma

Analysis results

Item	Unit	Result	Standard
pH	-	6.2	6.5 - 8.5
Temperature	[°C]	21.4	-
Conductivity	[µS/cm]	277	-
TDS	[mg/L]	139	1000
Turbidity	[FTU]	<1	5
Total Chlorine [Cl_2]	[mg/L]	<0.02	5
Total Hardness	[mg/L as $CaCO_3$]	54	300
Calcium Hardness	[mg/L as $CaCO_3$]	32	-
Magnesium Hardness	[mg/L as $CaCO_3$]	22	-
Total Alkalinity	[mg/L as $CaCO_3$]	153	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	153	-
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	0.37	1.5
NH_4^+ Ammonium	[mg/L]	0.47	-
Na^+ Sodium	[mg/L]	61.6	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	7.5	-
Ca^+	Calcium	[mg/L]	12.8	100
Mg^+	Magnesium	[mg/L]	5.3	30
Fe	Iron	[mg/L]	0.01	0.3
Cu^{2+}	Copper	[mg/L]	<0.04	2
Mn^{2+}	Manganese	[mg/L]	<0.1	0.5
Cr^{6+}	Chromium	[mg/L]	<0.01	0.05
Cl^-	Chloride	[mg/L]	<10	250
F^-	Fluoride	[mg/L]	<u>1.76</u>	1.5
Br_2	Bromine	[mg/L]	<0.05	-
NO_2^-	Nitrite	[mg/L]	0.03	3
NO_3^-	Nitrate	[mg/L]	10.1	50
SO_4^{2-}	Sulfate	[mg/L]	<2	250
PO_4^{3-}	Phosphate	[mg/L]	20.10	-
HCO_3^-	Bicarbonate	[mg/L]	187	-
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:
Values that exceed WHO guidline are underlined.

Remark:
Fluoride Content of the analysed water sample exceeds the WHO guideline and Ethiopian standard set for drinking water.Therefore,the water is not suitable for drinking purpose unless it is treated before supply to the community.Note that the water sample was taken by the client.

Analyzed on 11/11/2015 *by* ***Abate Bekele*** Signature

Approved on 26/11/2015 *by* W/R S/M/D Signature

Southern Nations Nationalities and Peoples Regional State Water, Irrigation And Mine Development Bureau

Southern Nations, Nationalities and People's Regional State

Water Irrigation and Mine Development Bureau

Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report

(Drinking Water Quality)

Client	
Contact person	
Sample Number	9806C
Date of Sampling	6/11/2015 (Ethiopian, EC)
Date of Testing (dd/mm/yyyy)	12/11/2015 (Ethiopian, EC) 19/07 2023 (International)
Nature of Sample	
Source	BH
Depth [m]	

Zone	Welayta
Woreda	Damot Gale
Kebele	Boditi korke
Village	Water sup. Office
Site Name	Reservoir (2000 c.m)
GPS (UTM) Northing	768637
GPS (UTM) Easting	373429
Alttitude [m]	2014
Sample taken by	Lebenu Lemma

Analysis results

Item	Unit	Result	Standard
pH	-	6.7	6.5 - 8.5
Temperature	[°C]	21.3	-
Conductivity	[µS/cm]	282	-
TDS	[mg/L]	141	1000
Turbidity	[FTU]	3	5
Total Chlorine [Cl_2]	[mg/L]	0.03	5
Total Hardness	[mg/L as $CaCO_3$]	65	300
Calcium Hardness	[mg/L as $CaCO_3$]	45	-
Magnesium Hardness	[mg/L as $CaCO_3$]	20	-
Total Alkalinity	[mg/L as $CaCO_3$]	150	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	150	-
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	0.85	1.5
NH_4^+ Ammonium	[mg/L]	1.10	-
Na^+ Sodium	[mg/L]	53.9	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	8.0	-
Ca^+	Calcium	[mg/L]	18.0	100
Mg^+	Magnesium	[mg/L]	4.9	30
Fe	Iron	[mg/L]	0.01	0.3
Cu^{2+}	Copper	[mg/L]	0.04	2
Mn^{2+}	Manganese	[mg/L]	0.1	0.5
Cr^{6+}	Chromium	[mg/L]	0.01	0.05
Cl^-	Chloride	[mg/L]	<10	250
F^-	Fluoride	[mg/L]	2.02	1.5
Br_2	Bromine	[mg/L]	0.05	-
NO_2^-	Nitrite	[mg/L]	0.03	3
NO_3^-	Nitrate	[mg/L]	3.5	50
SO_4^{2-}	Sulfate	[mg/L]	2	250
PO_4^{3-}	Phosphate	[mg/L]	23.50	-
HCO_3^-	Bicarbonate	[mg/L]	183	-
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:

Values that exceed WHO guidline are underlined.

Remark:

Fluoride Content [illegible] of the analysed water sample exceeds the WHO guideline and Ethiopian standard set for drinking water.Therefore,the water is not suitable for drinking purpose unless it is treated before supply to the community.Note that the water sample was taken by the client.

Analyzed on 12/11/2015 *by* ***Abate Bekele*** Signature

Approved on 26/11/2015 *by* *W/R/S/M/D* Signature

Southern Nations Nationalities and People's Regional State Water Irrigation And Mine Development Bureau

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Physico-Chemical Analysis Report

(Drinking Water Quality)

Client	
Contact person	
Sample Number	9808C
Date of Sampling	6/11/2015 (Ethiopian, EC)
Date of Testing (dd/mm/yyyy)	13/11/2015 (Ethiopian, EC) 20/07 2023 (International)
Nature of Sample	
Source	BH
Depth [m]	

Zone		Welayta
Woreda		Damot Gale
Kebele		Boditi korke
Village		0
Site Name		Water point
GPS (UTM)	Northing	767798
	Easting	372355
Alttitude [m]		2084
Sample taken by		Lebenu Lemma

Analysis results

Item	Unit	Result	Standard
pH	-	6.8	6.5 - 8.5
Temperature	[℃]	21.2	-
Conductivity	[µS/cm]	290	-
TDS	[mg/L]	145	1000
Turbidity	[FTU]	3	5
Total Chlorine [Cl_2]	[mg/L]	0.02	5
Total Hardness	[mg/L as $CaCO_3$]	75	300
Calcium Hardness	[mg/L as $CaCO_3$]	45	-
Magnesium Hardness	[mg/L as $CaCO_3$]	30	-
Total Alkalinity	[mg/L as $CaCO_3$]	160	500
Bicarbonate Alkalinity	[mg/L as $CaCO_3$]	160	-
Carbonate Alkalinity	[mg/L as $CaCO_3$]	0	-
Hydroxide Alkalinity	[mg/L as $CaCO_3$]	0	-
Dissolved NH_3	[mg/L]	1.10	1.5
NH_4^+ Ammonium	[mg/L]	1.42	-
Na^+ Sodium	[mg/L]	59.9	-

Item		Unit	Result	Standard
K^+	Potassium	[mg/L]	9.0	-
Ca^+	Calcium	[mg/L]	18.0	100
Mg^+	Magnesium	[mg/L]	7.3	30
Fe	Iron	[mg/L]	0.01	0.3
Cu^{2+}	Copper	[mg/L]	0.20	2
Mn^{2+}	Manganese	[mg/L]	0.1	0.5
Cr^{6+}	Chromium	[mg/L]	0.01	0.05
Cl^-	Chloride	[mg/L]	10	250
F^-	Fluoride	[mg/L]	<u>2.03</u>	1.5
Br_2	Bromine	[mg/L]	0.05	-
NO_2^-	Nitrite	[mg/L]	0.04	3
NO_3^-	Nitrate	[mg/L]	11.0	50
SO_4^{2-}	Sulfate	[mg/L]	2	250
PO_4^{3-}	Phosphate	[mg/L]	28.70	-
HCO_3^-	Bicarbonate	[mg/L]	195	-
CO_3^{2-}	Carbonate	[mg/L]	0	-

Note:

Values that exceed WHO guidline are underlined.

Remark:

Fluoride Content & turbidity of the analysed water sample exceeds the WHO guideline and Ethiopian standard set for drinking water.Therefore,the water is not suitable for drinking purpose unless it is treated before supply to the community.Note that the water sample was taken by the client.

Analyzed on 13/11/2015 *by* ***Abate Bekele*** Signature

Approved on 26/11/2015 *by* W/R/S/MD Signature

Southern Nations, Nationalities and People's Regional State
Water Irrigation and Mine Development Bureau
Water Resouce Study and Management Directorate

Bacteriological Analysis Report

(Drinking Water Quality)

Client Contact Person		Zone	Welayta
		Woreda/Town	Damot Gale
Sample Number	9854B	Kebele	Boditi korke
Date of Sampling	6/11/2015 (Ethiopian, EC)	Village	Water sup. Office
Date of Testing	#N/A (Ethiopian, EC)	Site Name	Reservoir (2000 c.m) Booster
	19/07 2023 (International)	GPS Northing	768637
Nature of Sample		(UTM) Easting	373429
Source	BH	Alttitude [m]	2014
Depth [m]		Sample taken by	Lebenu Lemma

Analysis results

Items	Result	Unit	Reference			
			WHO Guideline	Incubation		Media
				Temperature	Time	
Total Coliform	0	[CFU/100mL]	0	37 ℃	24 hours	m-Colibule 24-broth
E.*Coli* (Fecal Coliforms)	0	[CFU/100mL]	0	37 ℃	24 hours	m-Colibule 24-broth

Note:
The underline shows values that exceed WHO guideline values set for drinking water

Remark:

There is no coliform bacteria detected in 100ml water sample analysed, and therefore, the water is bacteriologically suitable for drinking purpose.

Analyzed on 12/11/2015 *by* Abate Bekele *Signature*

Approved on 26/11/2015 *by* W/R/S/M/D *Signature*

Southern Nations Nationalities and People's Regional State Water Irrigation And Mine Development Bureau