JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACAULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HAYDRAULIC ENGINEERING MASTERS PROGRAM

ASSESSING SUSTAINABILITY OF URBAN WATER SUPPLY AND DISTRIBUTION SYSTEM: A CASE STUDY OF BODITI TOWN

BY: FIKRE GEBRETSADIK

A THESIS SUBMITED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUERMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

NOVEMBER, 2017

JIMMA, ETHIOPIA

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APPROVAL PAGE

This thesis “Assessing sustainability of urban water supply and distribution system: The case of Boditi Town, Southern Nation Nationalities and peoples Region (SNNPR), Ethiopia is approved by the following approval board committee in partial fulfillment of the requirement for the degree of master of science in hydraulic engineering.

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DECLARATION

I, the undersigned, declare that this thesis “Assessing sustainability of urban water supply and distribution system: The case of Boditi Town, Southern Nation Nationalities and peoples Region (SNNPR), Ethiopia is my original work and has not been presented for a degree in this or any other university and all sources of material used for the thesis have been fully acknowledged.

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ABSTRACT

Population growth has put pressure on current water supply throughout the world. Similarly in our country the supply of water to satisfy the demand of water for towns is a crucial problem. The study town drinking water coverage and per capita demand is less than the standard and the people of the town are complaining about water supply most of the time, due to facing scarcity of supply, even there exists water supply; some parts of the distribution system not afford water to private customer connection. This study was conducted to assess sustainability of urban water supply and distribution system. Water distribution network system was developed and evaluated by water-Cad 6.5 soft-ware and GPS data, Arc-GIS 10.1 soft-ware used to delineate study area, water loss estimated by water balance method and geometric growth method used for population estimation. Primary data were obtained from face to face interview and questionnaire with study area livelihoods, Boditi town water service office workers and key informants, viewing sampling locations and water point and photograph of relevant site. Secondary data obtained from: related studies, reports of town water service office and from Zonal Water Resource, Mineral and Energy office, journals, and meteorology offices at zonal and regional level. Statistical method used to analyze the data obtained from both data sources. Based on the findings, for private connection users, for public tap users, in-house connection and the averaged current water consumption of the town were 16.7, 5.8, 37.9, and 11.9L/c/d respectively and the current water supply coverage of the town was at the level of 69.6%. The average water loss of the water distribution system found to be 33.2%. The distribution system analysis showed that 9% of junctions had above maximum, 2% of junction had below minimum and 89% of junctions had normal operating pressures. 30% of pipes in the distribution system had head loss greater than 15 m/Km. The current water production was estimated to be 371,535 m^3/year and the projected population and water demand for 2023 estimated to be 88079 and 1012688m^3/year respectively. This indicates that, water supply has to be raised by 641153m^3/year. The sustainable water supply can be assured through demand based supply and supplementing the existing supply with additional sources.

Key words: pressure zone, Sustainable water supply, Water demand, Water loss, Water supply,

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AMCOW	African Ministers' Council on Water
AWWA	American water works association
BH	Bore Hole
BTWSO	Boditi Town water service office
CSA	Central statistics agency
DGWWRO	Damot Gale Woreda water resource office
GIS	Geographical Information system,
GPS	Global Positioning System
HGL	Hydraulic grade line
HMWSSB	Hyderabad Metropolitan Water Supply and Sewerage Board
IWA	International water association
PI	Performance Indicator
MDG	Millennium development goal
MoFED	Ministry of Finance and Economic Development
MoWR	Ministry of Water Resource
NGOS	Non-governmental organizations
NMAHBD	National Meteorological Agency Hawassa Branch Directorate
OECD	Organization for Economic Cooperation and Development
SNNPR	Southern nation, nationality and peoples region
UAP	Universal Access Plan

UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
UNICEF	United Nations Institute for Children's Education Fund
UNESCO	United Nations Educational, Scientific, and Cultural Organization,
US	United States
USAID	United States Agency for International Development
WBG	World Bank Group
WHO	World Health Organization

1. INTRODUCTION

1.1 Back ground

Water is the lifeblood of the world and is considered as a national resource of utmost importance. Next to oxygen, water is the most important element for human survival. It is the most vital of all public services. Water scarcity affects the entire community, so any thing that disturbs the provision and supply of water tends to disturb the survival of humanity. Water supply is indispensable in both rural and urban areas. Therefore, the accessibility to adequate clean water, to produce food for both rural and urban population, is just one aspect of the role played by water in meeting basic needs and contributing to development (UNESCO, 2006). All resources that nourish life owe their existence to water…From the tiniest algae to the giant mammals along with everything they live on, feed on, and make possible their breeding are the creation of water as former UN secretary General Kofi Annan once said (Informer, 2010). Water is an important environmental factor affecting human health. The quality and reliable supply of good, safe drinking water is fundamental to have a healthy community and to its economic and social development.

Temperature rise of 2ºC might results 1-4 billion people of developing countries were experiencing water shortage. The water scarcity is mainly related with climate change, which results in short duration of precipitation seasons, or decrease in ground water recharge or surface water. These undermine the conjunctive use of surface and ground water. As a result freshwater distribution becomes scarce. Practically freshwater distribution problems are resulted in increasing the gap between the supply and demand. Water scarcity describes the existing and potential supply of water, or it describes the present and future demands or needs for water.

Global climate change, population growth, industrial and agricultural growth increase the demand for water(Stern, 2007). “Growing population will further increase the demand for water and there are limited cost-effective water supplying augmentation options. Water supply augmentation requires a number of years for planning, huge amount of capital, trained man power to have reliable water supply (Darmaratna, 2010). In addition; water is required to protect vital ecosystems. For example, aquatic ecosystems depend on water flows, land and water resources management must insure that vital ecosystems are maintained. In all, terrestrial and aquatic ecosystems need water to maintain their functioning plants transpire and evaporate water;

animals drink water; fish and amphibians need water to live in. Worldwide the agricultural use of water takes the largest fraction-about 69%, while 23% goes to industries and the rest 8% for domestic use (Engleman R., 1993).

Many basins worldwide are facing perceived water shortage due to increasing demands on water from all sectors (Mollinga, 2006). This indicates, water is becoming scarce and its demand is increasing over for various uses. The percentage of people served with some form of improved water supply rose from 79 (4.1 billion people) in 1990 to 82% (4.9 billion people) in 2000 and at the beginning of 2000 one-sixth (1.1 billion people) of the world's population was without access to improved water supply, majority of the people live in Asia and Africa (UNICEF&WHO, 2000). According to official government office data, water supply coverage has risen from 19% in 1990 (11% in rural 70% in urban) to 66% in 2009 (62% in rural, 89% in urban), (AMCOW, 2009/10).

The study town water supply coverage was 69.6% which was below the country's coverage figure. In addition, population of the study Town complains about the shortage of water supply and to some areas of the Town the supply system has low pressure/ even no water in the distribution system (Report, 2016/17). These problems influence the water use of population in the study town.

Water quantity/supply is also another important parameter, to describe the supply and demand to quantify. In urban areas, water is distributed by piped systems. Water distribution system in urban areas are continuously evolving to balance the increase in demand arising from urban development, change in consumption patterns, industrial development and other domestic uses. The water distribution systems are interconnected systems to satisfy the water demand of the urban centers. In water distribution network systems there are problems such as inequalities in service provision between rich and poor, water loss. These indicate that, water distribution inefficiencies.

Water loss in water supply systems ranges from 15 to 30% in the developed world but elsewhere it is likely to range from 30 to 60%(Bridges, 1994a). Since water loss exists in distribution system, the loss has to be reduced, because revenue from water supply decreases and the water supply does not balance the demand. To display/introduce water loss reduction strategy, the service provision should be evaluated or monitored by using performance indicators. Performance indicators are widely used as an assessment tool to evaluate the performance of water supply services. The IWA, WBG, have introduced performance indicators to assess the performances of water supply services industry (Ong, 2007).

The study town, water supply service provision was not evaluated in preference to performance indicators, due to lack of awareness, shortage of capital and shortage of trained personnel. Based on the above mentioned problems, this study assessed sustainability of water supply and distribution system of the town.

1.2. Statement of the problem

The majority of the world's population without access to improved water supply or sanitation services live in Africa and Asia (UNICEF&WHO, 2000). Drinking water has received considerable attention recently, however, the marked difference between increasing demand and shrinking supplies illustrates that our progress towards sustainable management of this vital resource has been less than adequate (Susan, 2003). Water shortages, weak public utilities, and poor management practices lead the public to depend on poor supply. Poor farming practices, poor environmental management, poor sanitation facilities, high population growth. According to Damot Gale District water resource office annual report, the current drinking coverage is 30%, this indicates that there is a high shortage of drinking water. According to Bodity Town Water Service Office annual report (Report, 2016/17), drinking water coverage is 69.6%.In addition, the people of Boditi town are complaining about water supply, most of the time people are facing scarcity of domestic water supply. Even there exists water supply; some parts of the distribution system not afford water to private customer connections.

Figure 1.1 Around Faate BH when surround ing people fetching water

This indicates that, performance of distribution system has problem or has low performance. The water distribution system of Boditi Town is only branched and one direction flow system, not in looped line flow. According to U.S. Department of the Interior Bureau of Reclamation,(U.S.DIBR, 2006) looped lines minimize head loss in the pipe since the flow of delivered water from two directions requires less flow in each pipeline than if all of the flow was from one direction in one pipeline. Looped lines also offer the advantage of maintaining service in the event of a line break. The current water supply is carried out by pumping from boreholes, there is no storages/reservoirs, water from boreholes come and reach into the distribution system and then go to the consumers. This indicates that, the distribution system is not divided into different pressure zones and has no reservoirs to get enough pressure.

This study therefore, specifically investigated the water supply and demand gap, water losses and serviceable pressures in distribution network and initiate intervention measures to address the mentioned problems

1.3. Objective

1.3.1. General objective

The general objective of the study is to assess sustainability of urban water supply and distribution system of Boditi Town.

1.3.2. Specific objectives

Specific objectives of the study are:-

1. To identify the major water supply problems of the town ,
2. To determine the existing and future water supply and demand in the water supply System,
3. To estimate water loss in distribution network,
4. To recommend the major existing water supply options to sustainable water supply to the system

1.4. Research Questions

1. What are the major water supply problems of the town?
2. How water supply balances water demand at present and future?
3. What would be the water loss in water distribution network?
4. What are the major water supply options to sustainable water supply to the system

1.5. Significance of the study

The study will be significant for the community to use safe potable drinking water. The concerned body will solve the problems on performances of distribution system. Additional water sources will be obtained and the supply demand problems will be solved. The government, NGOS, resource analysts and managers will use the result of the study in order to solve the problem, apply performance indicators to monitor and evaluate the supply system. The study can be used by other researchers with water related problems for further study in the field. The study may give clue to manage/conserve their environment in case to develop ground water source. The current water distribution system or utility efficiencies will be assessed in order to indicate the performance level. According to Bodity Town Water Service Office (Report, 2016/17), the current drinking coverage is about 69.6%, this indicates that there is shortage of drinking water supply, so that the result of sustainable water supply assessment will give clue to develop other water harvesting or water resource development strategies for the study area and to the near communities.

1.6. Limitations of the study

The finance resource inadequacy was critical problem. This is due to assessing sustainability of water supply and distribution systems consists a lot of aspects. Some of them are financial, technical, social, environmental, political, institutional, and similar. Even though there was limitation, by using advisors advice, efficient use of resources, and using opportunities effectible reduced the limitation.

1.7. Scope of the study

The study principally emphasized on sustainable water supply distribution system interns of supply matches demand, water loss, pressure and flow rate. In this research water distribution system analysis evaluated by hydraulic network analysis software Water Cad 6.5, study area delineated by Arc-GIS 10.1 and GPS data, water loss estimated by water balance method, geometric growth method used for population estimation. The research conducted from June 2017 up to November 2017.

2. LITERATURE REVIEW

2.1. Performance Indicators in water supply systems

Climate change, population growth, anthropogenic activities are interrelated and their interaction results in environmental deterioration. Environmental deterioration highly stresses the water bodies. Water bodies stressed by a number of factors that resulting in water quality change, supply shortage. Water scarcity is one problem, and at the same time, more than 50% of the urban water lost through leaks and breaks occurring in the distribution system mainly due to lack of efficient water loss reduction strategies. If half of this water volume was saved, 200 million people would have access to safe water without any further investment (Kanakoudis, 2011).

According to (Kanakoudis, 2011).different associations such as IWA, AWWA have designed water auditing tools and methodologies to assess the water supply systems and the methodology include water balance assessment and databases performance indicators. The water balance refers to water produced by a system enters into the supply/distribution system and some of the water be consumed and some of the water be lost in the distribution system.

Table 2.1 IWA Best practice (Radivojevic, 2008)

System input volume	Authorized consumption	Billed authorized consumption	Billed metered consumption	Revenue water (RW)
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	None Revenue water(NRW)
			Unbilled unmetered consumption	
	Water loss	Apparent loss	Unauthorized consumption	
			Metering inaccuracy	
		Real loss	Leakage on transmission /distribution mains	
			Leakage and overflows at utility storage tanks	
			Leakage on service connections up to consumers metering	

IWA Best Practice water balance and technical Performance indicators recommended by Water Loss Task Force have proven, it is more demanding and makes water utilities install metering devices and collect data and introduce proactive leakage management to reduce damage and increase efficiency (Radivojevic, 2008). Performance indicators in water sector monitor a progress, or evaluate the outcomes of the supply system.

Performance indicators are guide map, facts and figures which can evaluate performances of water supply organizations. Performance indicators in water supply system apply to six major aspects of the supply system: water resource PIs, personnel PIs, physical PIs, operational PIs, quality service PIs and financial PIs (USAID, 2008). Water resources PIs promote sustainability of water resource, personnel PIs emphasis efficiency of job function, physical PIs emphasis on condition of physical assets, quality of service PIs stands to protect the customer's interest, financial PIs used to safeguard the financial status service provision (Ong, 2007) and operational PIs emphasis on the technical aspects of the distribution system (AMCOW, 2009/10).

Service quality PIs are widely used as an assessment tool to evaluate the performance of water supply service through monitoring called performance indicator monitoring (USAID, 2008) and it track down the following data on: volume, pressure, numbers and categories of customers, billing and collection ratio, renovation works and repairs carried out or to be carried out, reduction in non-revenue water, responses to customer inquiries. Personnel PIs includes the data on: annual training per staff member, staff cost as a percentage company cost, labor productivity (Radivojevic, 2008). Financial PIs comprises of data on: unit operating cost per m^3, operating cost coverage ratio (ratio of total annual billed revenues to total annual operating cost (Radivojevic, 2008). Technical operational PIs in water utilities track down the data on: unaccounted for water/water loss, percentage of metered connections, water production and consumption, population served, staff/1000 connections, electricity consumption, water quality monitoring, facility failure, water coverage (Corton, 2007).

2.2. Water Loss in distribution systems.

Water losses in an urban water supply system includes the water losses along trunk mains (from source to treatment plant, from plants to reservoir and from reservoir to the junction within reticulation system); within treatment plant; within the distribution system; and within consumer's premises. Water losses in distribution system are categorized into two. They are physical loss (real loss): pipe breaks and leaks, storage overflows, house connection leaks, and commercial loss (apparent loss): metering errors, water theft and billing anomalies. A study by (Radivojevic, 2008) indicates that water loss is the difference between the system input volumes and authorized consumption volumes, or system input volume equals to the sum of authorized consumption volume and water loss volume.

A study by (Kleemeier, 2000), improved water supply schemes in many developing countries are not functioning properly. According to (Zeyede, 2004), in Ethiopia the problems related to water supply are attributed mainly to lack of maintenance of previously constructed systems, lack of community involvement when the earlier water systems were built, lack of spare parts and local maintenance capabilities. Moreover, as in many other countries in sub-Saharan Africa, the water facilities may not be operating properly due to various technical problems. A recent survey made by (UNDP, 2006), indicates that 29% of hand pumps and 33% of mechanized boreholes were not functional, mainly due to lack of maintenance. A study by (Sharma, 2008) indicates that a water supply system for water utility has water losses and these results in poor service provision, no cost coverage, lack of reinvestments. In any water supply system, if there is water loss water demand becomes high and the supply provision face problem.

The water supply systems are interconnected systems to satisfy the water demand of urban centers. In the distribution network systems there are problems such as inequalities in service provision, inefficiency. A study done by (Bridges, 1994b) shows water loss in water supply systems ranges from 15 to 30% in the developed world but elsewhere it is likely to range from 30 to 60%. Another study by (KammerD., 2003) indicates that, in Southern Africa water loss figures vary from 16 for Walvis Bay in Namibia up to 65% for Mwanza in Tanzania, and as a comparison, for many countries in Europe water loss has a level of 10% in the recommended value, and mean level of water loss for water utilities in developed countries is 16%. Performance indicators in water supply system or utility system explaining efficiencies of systems measured by using: water resource PIs, physical PIs, operational PIs quality service PIs, personal PIs and financial PIs (Ong, 2007)

2.3. Water supply/water production

Domestic water supply is as being water used for all usual domestic purposes including consumption, bathing and food preparation (WHO, 2004). For a certain given community the provision of domestic water should consider the quantity of water that is supplied in relation to the population, living standards, and climatic factors. The MDG has a target to halve the proportion of people who are unable to reach or to afford safe drinking water by 2015 (UN, 2005). This declaration has no specified volume of domestic water or quantity to be supplied. The global assessment of water supply and sanitation data, as being the availability of at least 20 liters per person per day from a source within one kilometer of the users dwelling (UNICEF&WHO, 2000).

To supply consumer demand at present and in the future, there should be enough water quantity. Availability of sufficient amount of water can be affected by a number of factors such as source water capacity, consumer population demand and storage/reservoir capacity. When the source supply is inadequate, one has to take water conservation measures or one has to find an extra water supply source. Water conservation refers to demand-side options that are demand management through tariff structures, pricing and use of water efficient technology, education and information. Obtaining additional water supply source refers to supply–side options, i.e, water loss/leakage reduction, supplementing the existing water supply, recycling, ground water use and recharge, rain water harvesting and institutional change (MoWR, 2009),.

The use of potable drinking water makes high contribution to health, production and social development. A study carried out by United Nations Development Program (UNDP, 2006), indicates that nearly one-sixth of the world's population obtains drinking water from unimproved sources, and in many developing areas, progress in expanding clean water coverage is modest not high. Another study by (Harvey, 2008), also shows that "in addition to increasing access through implementation of improved water supplies, it is also necessary to ensure that both new and existing water systems are sustainable, so that access to safe water is sustained for all". Access still varies strongly across geographic regions in the country, and the problem is more pronounced in rural than in urban areas.

A study by (MoFED, 2008), shows Ethiopia has long been characterized by limited access to safe drinking water and sanitation services, for example, in 1990 only 19% ,in 1998 24%, in 2000 28%, in 2004 36%, in 2006 47.3% and in 2007 52.5 % of the country's population had access to a safe drinking water supply. Another report by (MoWR, 2009), indicates that water supply coverage has risen from 19% in1990 to 66 % in 2009 and a target in 2015 99 %. A report by (MoFED, 2006), indicates that the deep-rooted water problems in the country, especially in rural areas, the government has increased resource allocation to provide safe drinking water for its inhabitants, as the report indicates, the proportion of government expenditure that went to water and sanitation infrastructure development grew from 2.8 to 4.5 % between 2000/01 and 2004/05.

According to (CSA, 2006), in Ethiopia, the problem of drinking water supply is further compounded by physical distance and a recent estimate reveals that about 52% of the population traveled half an hour or more to collect water every day. This long travel distance to the nearest water source directly affects women and children, who are mainly responsible for fetching water.

U.N.'S Millennium Development Report (UN, 2005), indicates that the urban population is projected to exceed the rural, for the urban poor residing in such slums, lack of water supply services represents a frightening challenge and multiple Strategically targeted initiatives will be required to meet one of the targets of the MDGs of reducing by half the proportion of people without sustainable access to safe drinking water.

From the above points, at the country level the water resources development and supply systems are in increasing manner. But to the study area, the water supply systems are old, and in addition, the boreholes output is greater than the consumed amount of water Boditi water service office (Report, 2016/17). This indicates that, there is a gap between the amount of water produced and consumed by the people. So this indicates that, supply demand analysis would be made and the future water demand would also be assessed.

2.3. 1.Water Supply Assessment.

Demand for domestic water is increasing as a result of growth of population and urban settlements. Due to these factors planning and analysis of the existing water source is important in order to afford the current/or future water demand and supply.

According to (Rooijen, 2005, Kingsley 2001) indicates that the water supply of Hyderabad city from ground water withdrawal, river pumped to the reservoirs as measured (1950-2004) or projected (2004-2030) by the Hyderabad Metropolitan Water Supply and Sewerage Board(HMWSSB). A study by (Kingsley 2001) indicates that in water supply assessment for planning and management requires know how much water required over a period of time, the quantity and quality of water needed, and the water supply options. Water supply assessment requires estimates of volumes of rivers, streams/springs flow yield, ground water; and other water resources would be developed. Estimates of available water resource yield are important in order to compare current and projected water demand.

2.3.2. Population Served

Water Service coverage in water supply, is the ratio of population with water service to total population in the study area. In developing countries urban population is increasing due to migration to urban centers. Increasing urban population place a stress on water service provision. As a result water demands are increasing and require high capital investment to afford water service for growing population. Households that have low incomes face difficulties in paying for water service. During the period 1990-2000 it is estimated that the global population increased by 15% (5.27 billion to 6.6 billion and within that total figure, the global urban population increased by one-quarter, while the rural population increased by less than 8% (UNEP, 2002).

Water delivered and population served should naturally increase (Corton, 2007). This assertion indicates that, changes occurring in number of connections and network length results water supply network expansion, since there is an increase in population number. Expansion on water transmission pipes do not imply adding more connections only increasing network length, but depicts percentage changes in water delivered, population served and number of connections (Corton, 2007).Population served by water service refers to population with access to water supply, either direct service connection or within reach of public water point (Ncube, 2011.).

2.3. 3. Number of Workers per One Thousand Connections

Staff per one thousand connections is one of the operational performance indicators in water supply sector, indicating labor efficiencies/inefficiencies. A large value suggests the company is using a higher than efficient number of workers on its production process (Corton, 2007)).Staff per one thousand connection, defined as the cost of labor input in the daily operation of a utility measured as a ratio of inputs to outputs (Ncube, 2011.)..

2.3.4. Water Service Coverage

According to Evaluation of Drinking Water and Sanitation Services (Evaluation, 2000) carried out by Pan American Health organization (PAHO), some 77million people lack access to drinking water supply services and majority of those without access are poor (Andrei, 2004).The percentage of people served with some form of improved water supply rose from 79(4.1 billion) in 1990 to 82%(4.9 billion) in 2000, and the majority of people live in Asia and Africa (UNEP, 2002). The estimates of coverage portrayal strong upward trend in access to improved water supply in urban areas, reaching 89% according to government, and Ethiopia's population is predominantly rural, rural water coverage has increased at promising rates since 1990, from 8 to 26% (AMCOW, 2009/10).

In spite it's highly low income per-urban and rural population in addition to low infrastructure development Ethiopia has to making progress in increasing water supply coverage. The water service coverage is low so that water resources development programs, putting advocacy to increase investment in water sector needed. To increase water supply services it has to work hard in the future.

2.4. Water Demand and Consumption

Water demand is always unique to each location, dependent on the alternative existing options, and it is dynamic (change with time). Water demand is a broad field and water demand has varied meanings to Engineers, Economists and Social scientists. They have different aspects of planning and designing of water demand projects. A study of (Parry 1999) indicates that, water demand to Engineers is the amount of water needed to supply a population; to Economist water demand is the willingness to pay for particular level of service; and to Social scientists water demand is basic human need or right which must be addressed in the context of poverty, equity and empowerment of low income groups.

Water demand is influenced by different factors. These factors are water resource availability, population pressure on the water source, developmental level of a society, climate, etc. A study by (Garn, 1998) shows that there are three main factors which affect water demand. These are availability, reliability cost and convenience of existing service relative to proposed options, household income, gender, education, occupation, household attitudes towards government policy and the service provider.

According to (UNESCO, 2000), two billion people (30%), now face water scarcity, and with current growth, it is estimated that by 2025 water stress will affect two thirds of the human population. According to (UN, 2007), estimated that the global population reached 6.7 billion, 5.4 billion of which live in developing countries, and the water resources have not only remained constant but have increasingly been polluted by the growing population.

The rate of abstraction of freshwater has grown rapidly due to the high population growth. As a result, per capita water availability is steadily decreasing. The water scarcity situation is related by the major impacts of climate change on the water resources, environmental deterioration, and the practical distribution problems concerned with time, space and affordability, leading to a widening gap between demand and supply.

Sustainable and reliable development and proper use of water resources require a huge capital investment. Proper water resource planning is imperative for sustainable use of water resources for domestic, industrial, irrigation uses. There is an increasing demand for water among agricultural, industrial, municipal, and environmental uses (HussainIjaz, 2011). In addition, the demand of water varies over 24- hours of a day or this is known as diurnal variation/peak usage.

According to the (OECD, 2004), for residential purposes, each Canadian used about 335 liters of water each day, the Americans, who used around 380 liters of water for residential purposes each day in 2001 and but the average Italian uses about 25 % less water than the average Canadian, the average Swede uses 40% less water, and the average person in France uses 55% less water. According to (Newman, 2006), there is huge variation in water use per person, between 1987 and 2003 people living in Cambodia, where the majority do not have access to improved water supplies, used an average of 1.8 m^3 of water each. People in Costa Rica used one hundred times more.

According to (Newman, 2006) the proportion of all water used for domestic purposes was categorized as high domestic use and low domestic use.

Table 2.2 High and low domestic water use of different countries (www. world mapper.org, 1987-2003)

	High domestic use		Low domestic Water Use		
Rank	Country	Value(m^3/person /year)	Rank	Country	Value(m^3/person / year)
1	Australia	487	191	Democratic Republic of Congo	4.8
2	Armenia	281	192	Chad	3.9
3	Canada	259	193	Ethiopia	3.5
4	New Zealand	242	194	Benin	3.5
5	Cuba	225	195	Tanzania	3.0
6	United states	209	196	Mozambique	2.9
7	Singapore	203	197	Uganda	2.6
10	Costa Rica	184	198	Somalia	2.5
11	United Arab Emirates	174	199	Mali	2.2
12	Ecuador	159	200	Cambodia	1.8

2.5. Pipe junction (Node) Pressure Distribution Systems

Water distribution systems serve customers by conveying water for different purposes. Water distribution systems consist of basic components, such as water source, treatment plant and distribution network. The water source may be rivers, ground water wells, reservoirs. The treatment plants disinfect raw water before delivering the water to the customers. The distribution network system consist of pipes, pumps, junctions (nodes),valves, fittings storage tanks/reservoirs ; and deliver water the source or treatment plants to the customers at serviceable pressures.

In water distribution system the water has to get to consumer with a minimum residual pressure at sufficient quantity without degradation of its quality from purification works. In pressure map assessment, the variables considered are the sizes of pipes, pressure heads over the pipe networks at the nodes, elevation and location of service reservoir (Ayanshola, 2006). As described by (AWWA, 1992) the minimum pressure that should be observed at junctions throughout the system varies depending on the type of water consuming sector and regulations governing the distribution system, but a typical operating range is between 40-100psi. The recommended minimum pressure heads varies between 25m and 28m, and the maximum pressure heads vary between 70m and 84m (Bharawaj V., 2001). Pressure heads in water distribution systems must be in standard range, otherwise it is undesirable to have high pressure because it causes more water loss through breaks and leaks

Pressure zones of a given water distribution system is dividing a given service area with significant elevation differences into areas of nearly similar elevations and pressures. Pressure zone is the area surrounded by both a lower and higher elevation. The area surrounded receives water from a given hydraulic grade line (HGL) or pressure from a set water surface.

The design of water distribution systems should strive for efficiency, reliability and durability to have optimum water supply system. U.S. Department of the Interior Bureau of Reclamation (U.S.DIBR, 2006) indicated that efficiency and reliability is accomplished by using gravity rather than pumping where possible and avoiding pressure surges (high pressure).

To achieve efficient and reliable water supply system, the design of the supply system must attain more than one water source to avoid long distance pumping, low head pumping systems to avoid high pressure, more than one storage tanks (reservoirs) per pressure zone where long distances are involved to shorten time of distribution, looped lines from storage tanks in order to deliver water to service connections from more than one directions or minimizes head loss. According to U.S. Department of the Interior Bureau of Reclamation (U.S.DIBR, 2006) utilizing water storage in more than one location affords some added reliability for the water supply system.

Classification of water distribution system of a given area into pressure zones has advantages. These are independent water storages will replenish the others' storage for emergency; provide customers with equal pressure, and more land area served by a given number of pressure zones.

2.6. Option Assessment

According to (Sutherland, 2000), the issues of water supply option assessment provides improved management of existing water supplies, and the demands made upon them, and to the development of new supplies to replace or complement new storage requirements. In water source assessment both the source and user requirements must be considered. The water source describes the physical characteristics such as yield features, sustainability and seasonality. The users requirements describes about volumes of the source, type of use, and timing of use.

As mentioned in (Parry, 1999) demand assessment tool/method in use, i.e. Engineers approach: assumptions based on most feasible option will be used. Option assessment is mainly a target to complement the existing water supply system.

3. MATERIALS AND METHODS

3.1. The study area

3.1.1. Location

Bodity Town is located at 365 km from Addis Ababa and 138km from Hawasa, on the way to Arbaminch, which crosses the town. The Town is located between 6º06" and 7º84" N Latitude and 37º26'12"E and 38º8'9" E Longitude (SNNPR Finance and Economic Development Bureau, 2006(Bureau, 2006). Boditi town is situated /bounded by Damot Gale district, and has an area of 2368.1 ha. The bounding kebeles of Damot Gale district are shashsha Gale, Bala Koyshaa, Ade Aro, Ade Damoota, and Warbira (Figure 2)

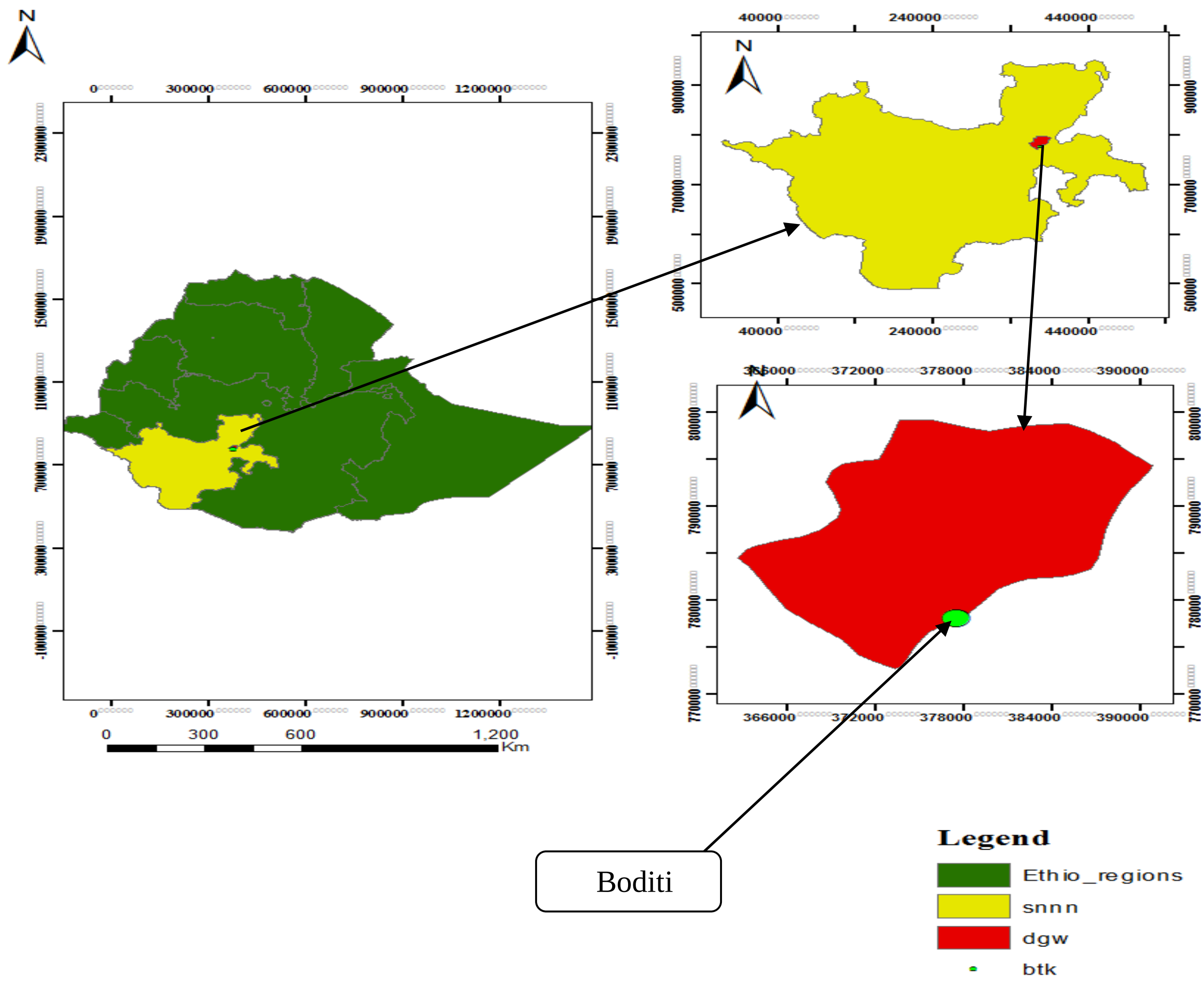

Figure 3.1 Location map of study area

3.1.2. Population

Boditi town has a population of 63863 (Administration, 2016/17) and has two sub-town with nine Kebele(Table 3.1) . In each kebele, 5000 and above population has been living.

Table 1.1 Population number of the study area (Administration, 2016/17)

No.	Year	Male	Female	Total	Variation
1	2014/15	30124	30191	60315	-
2	2015/16	30997	31066	62063	1748
3	2016/17	31896	31967	63863	1800

3.1.3. Climate

The Town is situated in Woynadega climate, characterized by rainy and dry seasons. The long and heavy rainy season occur from June to September, a short and light rainy season in March, April and May. Dry seasons are December, January and February. The study Town has the mean annual rainfall is 1190 mm and the mean annual temperature is24.9^{0}C, (National Meteorological Agency, Hawassa Branch Directorate, 2011).

3.2. Materials

To assess sustainability of urban water supply and distribution system the major materials and software used to conduct the research were Arc-GIS soft-ware, Endnote GPS Garmin 72 (to check coordinates of points of junction nodes reservoir and sources of town water supply).Microsoft Excel, Water-CAD 6.5 software.

3.2.1. Water CAD 6.5

Water CAD 6.5 is powerful software easy to use, which is: A water distribution modeling software used in the modeling and analysis of water distribution systems, used for firefighting flow and constituent concentration analyses, energy consumption and capital cost management; and It is Popular for water supply design. Water CAD provides sensitive access to the tools needed to model complex hydraulic situations. Some of the key features allow us to perform steady state and extended period simulations, analyze multiple time-variable demands at any junction node, quickly identify operating inefficiencies in the system, perform hydraulically equivalent network skelotanization including data scrubbing, branch trimming, and series and parallel pipe removal and efficiently manage large data sets and different “what if” situations with database query and edit tools. Water CAD is selected for this study because of the following reason; water cad is aided with good quality of manual. Its integration with other external software's, like Auto CAD and Microsoft excel. It requires less effort and shorter time to build a model than others do (Amdework, 2012).

3.2.2. Arc-GIS software

Arc-GIS software is GIS (Geographic Information System) that users of it gives simply a location and descriptive data to create maps, tables and charts to apply, in other words ArcGis software that provides location information to build a complete system.

This application is one of the famous and powerful American company ESRI products in the field of geographic information systems applications. The ArcGIS software use GIS that enable users to simply spatial data and descriptive data to create maps, tables and charts to apply, in other words ArcGis software that allows the construction of a full system provides location information. ArcGIS software makes it simple geographical analysis, to more people, without the need to be GIS experts have done (Heasted, 2004).

3.3. Data Sources

Data sources for this study were primary and secondary data sources. Primary data were obtained from face to face interview and questionnaire with study area livelihoods, Boditi town water service office workers, key informants, viewing sampling locations and water point and photograph of relevant site. Secondary data obtained from: related studies, reports of town water service office, from Zonal Water Resource, Mineral and Energy office, journals, and meteorology offices at zonal and regional level.

3.4. Data collection

Data collected from both primary and secondary data sources; by applying statistical method to achieve the stated objectives of the study. The study also included consultation of Town's water supply enterprise workers and discussion with some customers. Data collected from documents include billing/balance sheet, journals, books, reports, internet and unpublished documents. Field survey was made to collect data of the supply system by GPS. and selection of the following data collection indicators.

3.4.1. Indicators selected for data collection

3.4.1.1 Water quantity produced by the boreholes.

Currently Boditi Town water supply is from drilling boreholes. As there was no organized water production data, the water production has been estimated based on the actual yields and the aggregated operating times of the boreholes. The monthly and annual water production was estimated by multiplying actual yields of the boreholes and time of operation. The data for water production for seven years were obtained by reviewing of documents of Town's water supply enterprise.

3.4.1.2 Quantity of water consumed by different customer types.

Monthly water consumption of each customer type was estimated based on the billing data. Billing records are usually used to quantify water consumption that was used to evaluate the water balance (Welday, 2005).

The monthly water consumption data by customer type was obtained from the balance sheet found in the Town's water supply enterprise. The identified customer types are private yard connections, public tap users, commercial and institution centers and in-house connection users. The annual water consumption was estimated based on monthly data.

3.4.1.3 Aggregate operating time of the boreholes.

Water production at a borehole measured through meter installed but water meters installed at the boreholes were not functional. The available data at the boreholes were daily operating time measured in hours documented by operators. The daily operation time in hours was aggregated into monthly and yearly in order to estimate monthly/annual water production of the boreholes.

3.4.1.4 Head loss and Junction pressure

The head loss data are pipe length, diameter, age and roughness. The junction pressure data like elevation is useful to determine junction pressures in the distribution system. These data’s were obtained by operating GPS at every junction in the water distribution network.

3.4.1.5 Population of the study Town.

Base population data of the study town obtained from Boditi Town and Zone Finance and Development Departments. The data was to know the population that is served by the current water supply and to forecast the future population to be served within future design period. In population projection, trends in population growth and seven years base population data were used.

3.4.1.6. Proportion of customers based on service type.

To estimate the current water demand at different customer level, proportion of population would be estimated from billing and balance sheet data. Categorizing population at different consumer groups is important in water demand analysis, to check how much water is consumed by each customer type. In such case, the future water projects may consider people who used less water or those who are unable to pay for water services.

3.4.1.7. Discharges of the boreholes and springs.

The actual discharges of the boreholes are important and basic measurements to estimate the monthly and annual water production of the Town. The data of discharges of the boreholes were obtained from the Town's water supply enterprise and the actual discharges were measured.

3.5. Data Analysis

Statistical techniques used to analyze the data obtained from the primary and secondary data sources. The field survey data for distribution evaluated by using hydraulic network analysis software water-Cad 6.5 to distribution network. The results presented in both quantitative and qualitative terms in the form of mean, median, maps, t-tests such as tables and graphs.

3.6. Water Supply Assessment technique

In this research water hydraulic network analysis software water-Cad 6.5 and GPS used for distribution system analysis and to create water supply system network and Arc GIS software used to delineate study area, water loss estimated by water balance method, geometric growth method used for population estimation. The target populations of the study area were the town livelihoods and other user of the water supply of the town. Random and stratified sampling techniques used and soft skill strategy also applied.

3.7. Water distribution network system

Water distribution network system contains different components of the system and describes how these components are interconnected. These components are nodes and links. Nodes represent features at specific locations and links represent relationships between nodes. The Town's map was used to obtain data concerning the distribution network. GPS readings of elevation and coordinates of a reservoir, pumps at the boreholes and pipe junctions were collected. Input data of pipe are length, size, age, and input data of junction are elevation and base demand.

3.7.1. Nodes

In water distribution system, nodes represent the locations in which pipes connected. There are two types of nodes in the distribution system. These are fixed nodes and junction nodes. Reservoirs and storage tanks are fixed nodes, whose hydraulic grade line (hydraulic head) is the elevation of water above sea level. Junction nodes are nodes whose hydraulic head are not yet determined and the hydraulic head computed in the pipe network analysis.

3.7.2 Junctions

Junctions in water distribution system are locations for two or more pipes to meet; locations to withdraw or inject water demand from/to the system. The junction analysis requires input data such as elevation and base demand. The final results after the analysis were pressure and hydraulic head.

3.7.3 Pipes and head Loss

Pipes are links that convey water from one point in the network to another. The pipe has length, inside diameter, roughness coefficient and minor loss coefficient. Pipe coefficient is related with the pipe material and age, where as minor loss coefficient is related to pipe fittings. As the water flows in the pipe, hydraulic energy is lost because of the friction between the water and pipe surface. Flow direction is from the end at higher hydraulic head (internal energy per weight of water) to that at lower head. The principal hydraulic input parameters for pipes are: start and end nodes, diameter, length, roughness coefficient (for determining head loss), status (open, closed, or contains a check valve).

Head loss in the pipe was analyzed by water-cad 6.5 software; the final outputs for pipes were flow, velocity, head loss and junction pressure. The software assumes that all pipes are full at all times (Rossman, 2000). The assumption considers the potable drinking water flowing in the pipe. The hydraulic head loss by water flowing in a pipe due to friction with the pipe walls was calculated by Hazen-Williams formula (Walski, 2003) which is the most commonly, used head loss equation for drinking water flowing in distribution system.

$$H_f = \frac{10.68LXQ^{1.825}}{C^{1.852}XD^{4.87}} - - - - - - - - - - - - - - - - - - (1)$$

The frictional loss (H_f) is a function of the diameter of the pipe (D) in mm, length of the pipe (L) in m, flow rate (Q) in m^3/s and pipe roughness (C).

Table 3.2 Hazen-William roughness coefficients for pipe materials (Walski, 2003)

Pipe type	Roughness	Pipe type	Roughness
Cast iron new-new unlined	130	Galvanized iron	120
Cast iron 10 years old	113	Polyethylene, PE,PEH	140
Cast iron 20 years old	100	PVC,CPVC	150
Cast iron 30 years old	90	Steel corrugated	60
Cast iron 40 years old	83	Steel New unlined	150

3.7.4 Reservoir

A reservoir is a boundary node that supply water (outflow) or accept water (inflow) that the hydraulic grade unaffected and remain constant in the distribution system. Lakes and ground water wells are represented as reservoirs. Ground water pumping well as a reservoir whose head equals the peziometric head of the ground aquifer (Rossman, 2000). The input data of a reservoir are hydraulic head (water surface elevation) and water quality.

3.7.5 Pumps

Pumps add energy to the water distribution system. They are used to boost the head at desired locations to overcome piping head losses and physical elevation differences. Water distribution systems require two or more pumps to increase the amount of flow or pressure to meet the demand of water at different points in the system (Welday, 2005).

3.7.6. Base demand

In water distribution system, baseline demand comprises customer demand and unaccounted for water (water loss). Nodal demand allocation is carried out by a method called simple unit loading. This method involves counting the number of customers at a given specified area or number of dwelling units/housing units which use water at a given node and multiplying that number by the unit demand (per capita per day). After consumption rates are determined, the water use is spatially distributed as demands or assigned to nodes or allocate average day demands to nodes, and nodal demand is calculated by using (Amdework, 2012):

$$\text{Nodal demand}(\mathrm{N_d}) = \sum \mathrm{P_i}\ \mathrm{X}\ \mathrm{Dj} ----------------- (2)$$

Where N_d is = Nodal demand, P_i is = population who use water from/at each node and D_j = per capital demand.

3.8. Water production of the Town

The Town gets its water supply from ground sources. The main sources of water supply for the Town are from drilling boreholes (Table 3.3).

Table 3.3 Production capacity of BH's and related data's (BTWSO, 2016/17)

Borehole	X coordnate	Y coordnate	Elevation(m)	Discharge (l/s)	Design period	BH distance from the town (km)	Construction Time
Faate	372463	767926	2089	3	20	1.5	1989/90
Keera	372906	768948	2006	3	20	1	2002/03
Dooge	374404	770695	1950	2.5	20	2.5	2002/03
Meles	373537	770224	1955	10	20	3.5	2014/15
Chayna	373631	769758	1990	-	15	2	1987/88
Chawukare(1)	375882	767299	1928	0.5		4	2010/11
Chawukare(2)	375239	768209	1952	10	20	1.8	2015/16
Kingnaham	375761	771111	1966	4	20	2	2011/12

The water is pumped from the boreholes and reaches consumer premises by pump and gravity flow. Based on the aggregate operating time and actual discharges of each borehole, the daily, monthly and yearly water production was calculated by the relationship:

$$V_{prod(L)} = BH_{disch(L/_s)}\ X\ BH_{working\ time(s)} --------------- (3)$$

Where, V_{prod} = total volume produced by the borehole in liters, BH_{disch} = discharge of borehole in liter/second and $BH_{working\ time}$ = aggregate working time of the borehole in seconds. The volume of water produced each borehole to be estimated in cubic meter per month and per year(Figure no.5).

3.9. Water consumption

Individual meter readings are collected from five Kebeles in the Town billed and compiled. Billing records are usually used to quantify water consumption. Billing records is equivalent to the consumption that can be used for water balance calculations (Welday, 2005).The yearly water consumption has been aggregated from the private connected, public taps, in-house connected, institutional and commercial center meters.

While water consumption data was reviewed, differences in some consecutive months were observed. This difference might be caused by non-regular readings of the meters. In such cases, the water enterprise has designed checking mechanism and new meter installation practices. As observed from monthly individual water consumption, on one hand large consumption and on the other hand small consumption were seen. Despite this variation, the aggregated values were not affected much as the lower and higher individual values can be balanced to each other.

The average daily per capita consumption was used to indicate the water supply coverage of the Town. To calculate the daily water consumption, the annual water consumption was converted to average daily per capita consumption and by using population data of the Town (Welday, 2005).

$$W_{Cons}(liter/person/day) = \frac{Annual\ consumption(m^3)X1000L/m^3}{population\ number of the Town X\ 365} ------(4)$$

Where, W_{cons} = per capita water consumption in liter/person/day.

3.10. Water loss estimation

The water loss of the town was estimated, based on the annual production of boreholes and water consumed by the inhabitants of the Town. Based on registered data (system input volume and consumed volume) the water loss was estimated i,e. system input volume is the sum of authorized water consumption and water loss ((Radivojevic, 2008).; (KammerD., 2003)

The total water loss of the Town was quantified based on the total annual water production that was aggregated from the working hours of the six boreholes and distributed to the system, and the water billed that was aggregated from the customer meter readings. The water balance method was used to estimate the water loss in the distribution system. This method calculates the total water loss in the distribution system from total flows not for a limited time period (Jastin, 1993.). This describes the difference between inflows to the distribution system and all types of water consumption.

$$\text{total water loss}(\%) = \frac{[W_{\text{tot.prod}} - W_{\text{tot.cons(billed)}}]\text{X100}}{W_{\text{tot.prod}}} ------(5)$$

Where, $W_{\text{tot.prod}}$ = total water produced, $W_{\text{tot.cons}}$ = total water consumed.

3.11. Water demand assessment

Water demand is the total volume of water used to meet different uses and it includes the water loss in distribution system. The water use from delivery to consumption is metered; demand assessment is a relatively straight forward exercise. This indicates that, the presence of measured physical data such as volumes of water produced and volumes of water consumed are available demand assessment is easy to carry out.

Water demand forecasting is component based and the demand is broken down into different components and a baseline demand in every component is assessed from a base year to a particular date in the future (Sutherland, 2000). Water demand assessment is the amount of water needed to supply population, the assessment requires data collection on existing water consumption patterns, number and types of facilities and levels of service in use, potential demand for future upgrading, operation and maintenance arrangements (Parry 1999), *(Rooijen, 2005).,* (Kingsley 2001).

This approach depends on current water consumption, projected population growth, service delivery mode or customer types and demand types. Water demand assessment needs planning the changes with respect to levels and trends in the past and current water consumption.

3.11.1. Housing units and family Size of the Town

The estimated housing units in the Town from Boditi Town Municipality source show that there are about 8046 housing units, of which 5840 urban and 2206 rural houses, showing ratio of housing unit to population 1: 4.6 (Boditi Town municipality and agriculture unit, 2013 reports). During field data collection on elevation of pipe junctions, housing units were estimated and cross checked with the municipality report.

3.11.2. Service delivery mode and water consumption

The Town's water service delivery has five modes. These are private yard connections, public taps, in-house connections, commercial centers and institution centers. The per capita water consumption of each customer group/ service level was estimated based on annual water consumption and population data. The level of water consumption by per capita per day was compared for different years.

3.12. Water demand projection

According to (MoWE, 2010), the Government of Ethiopia produced Universal Access plan to achieve 98% for rural and 100% urban access for water supply and sanitation by 2012, the first phase until 2012 setting per capita consumption rural 15 L/c/d in 1.5 Km and urban 20 L/c/d in 0.5 Km service radius. The target year 2012 was moved to 2016 which would be improved in the second phase and subsequent phase would be adopted. In estimating domestic water demand general design standards were adopted: 30 to 50 L/c/d for urban centers, 15 to 25 L/c/d for rural areas, and the urban domestic water demand is thus projected as being 30 L/c/d for short term, 40 L/c/d for medium term and 50 L/c/d for long term (MoWR, 2006).

The Town's domestic water demand projection followed the extended Universal Access Plan for the first five years 20 L/c/d and short term water demand projection 30 L/c/d. Since Boditi Town is classified as category small and medium sized town, commercial and institutional water demand was estimated at 5% of the domestic water demand (MoWR, 2006).

The study Town is a per-urban town which has rural settlements and livestock production is an integral part of a community. Livestock keeping made people to increase income and the proportion of diet such as milk, butter and cheese. Livestock water demand was incorporated in water demand projection

The future domestic water demand was based on estimation of water demand per mode of service (2007-2013) and estimated population. Domestic water demand for ten years (2013-2023) has followed the extended UAP (2012-2016), and short term general design of MoWR

2002. Domestic water demand adopted the per capita water consumption to make the demand forecast for the coming 10 years (MoWR, 2006).

$$DWD = P_n X AWD --------------------- (6)$$

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

3.12.1 Population projection

Population refers to the total number of human inhabitants of a specified or special area of a country, a city, or a continent at a given period of time. Human population is given a great emphasis and studied for various reasons, for example, for resource allocation, socio-economic development, policy implication, adjust situations to existing conditions. The base population data (2013) was obtained from the Zonal and Bodit Town Finance and Development Offices which was established by (CSA, 2007). Several models are used for population projection but to minimize uncertainties that may occur due to improper estimation. Therefore, the constant population growth rate of 4.7% (CSA, 2007) was assumed and geometrical increase method was adopted for future population forecast. Population projection adapted to geometric growth rate model, in which the growing towns and cities having large expansion (Chatterjee, 2004):

$$P_t = P_0(1+r)^n -------------------(7)$$

Where, P_t = projected population at future time, P_0 = Base population, r = Growth rate in percent, n = number of years.

3.12.2 Commercial and institutional water demand

The water demand of towns include the needs of such commercial and institutional consumers as public schools, clinics, hospitals, offices, shops, bars, restaurants, and hotels. This type of water demand is usually linked directly to population size. For small- and medium-sized towns, population of 30,000 to 80,000, it was estimated at 5% of the domestic water demand, and for larger towns, the estimate was 10% (MoWR, 2006).Since the study Town has a small-sized population, commercial and institutional demand was estimated as 5% of the domestic water demand.

3.12.3. Livestock water demand

The production of livestock is an integral part of a community because livestock are valued assets. Livestock production requires water for their metabolic processes and water is essential for livestock like humans. Livestock production places demand on water. It is estimated that livestock industries consume 8% of the global water supply, with most of that water being used for intensive, feed-based production (Schlink, 2010).Water intake of a livestock depends upon the size, feed, location; and one tropical livestock unit which weighs 250 Kg (live weigh) requires less than 50litres/ day derived from drinking water and moisture in animal feeds (Pedin, 2002). The range for drinking water requirements for the stock types: milking cow 45 liters/day, dry cow and mature cattle 30 liters/day, sheep 3 liters/day and goat 3.5- 5 liters/day (Rout, 2007). Dairy cows and beef cattle daily water consumption is in the range of 45-55 liters per day per animal (Waterhouse, 1982).

Urban average daily demand is considered to be the combined total of demand from domestic, commercial and institutional, industrial, livestock and system losses per day (MoWR, 2006).

3.13. Option assessment

The projected population of the study town requires extra water supply. The projected need for more water means we must examine supply options more strategically (DEFRA, 2008). The two rivers of the town walcha and charake, additional bore holes, four springs (Seesona, Shaamina, Bol’o and Woysha, rain water, ground water were distinguished as options.

4. RESULTS AND DISCUSSIONS

4.1 Water distribution system

4.1.1. Source of water supply system

The water supply by pipeline for the Town began before1980 and new water distribution system was connected with the old system. The water was diverted from Walacha River, the source of which is side of mount Damota. The water supply of the Town developed and fed by drilling boreholes (Figure 4.1).

 Faate BH	 Dooge BH
 Keera BH	 Kingnham BH
 Chayna BH	 Chawkare BH

Figure 4.1 Study area bore holes

The Faate borehole pumps the water to a 100 m^3 reservoir at an elevation of 2089 m above sea level and to the main distribution system (Figure 4.2). The other six boreholes: Keera, Dooge, Meles, Chawkare(1), Chawukare(2) and Kingnaham directly pump their water to the main pipelines and then to the distribution system. The Chayna BH, which stopped pumping, because of aquifer had no water to the drilled distance (Figure 4.3). The Chayna and Dooge boreholes pressure mains intersect at junction point 0373912 E and 0768919 N and at an altitude of 2044 m above sea level with 63.5 mm and 76.2 mm diameter of galvanized iron pipes.

Figure 4.2 Faate BH and it's100 m^3 reservoir

The Faate and Keera boreholes pressure mains intersect at junction point 0373184 E and 0768378 N and at an altitude of 2059 m above sea level with 50.8 mm and 63.5 mm Galvanized iron pipe. The two combinations of the four boreholes again intersect in front of Boditi Post Office across asphalt road, at junction of 0373513 E and 0768507 N with altitude of 2059 m above sea level.

Figure 4.3 Chayna BH which is stopped pumping now

4.1.2. Water distribution network

The network is composed of various materials such as: galvanized iron, HDPE and PVC pipes. Most of the water distribution system of Boditi Town has branching pattern, which consist of main line, sub mains, branches. Service connections were connected from sub mains and branches. Out of 14,614 m mainlines, 29% (4297 m) pipes have diameter less than 50mm and Out of 5619 m sub-mains, 21% (1194 m) pipes have diameter less than 38 mm based on the design criteria.

4.1.2.1. Water distribution network analysis

The network analysis result of unit head loss and pressure (*Appendix 4)*. The minimum and maximum operating pressure in the water distribution system are expected to be 15 and 70 m (MoWR, 2006). In the distribution system, 12 (9%) junctions had above the maximum operating pressure (70 m) and 3(2%) junctions had below the minimum operating pressure (15m) and the remaining 126(89%) junctions had normal operating pressure (*Appendix no.4*) With the age of pipes, their internal surfaces become rough which reduces the flow with a fixed pressure supply. The head loss gradient is allowed to be ≤15 m/km) (Project, 2003). In the distribution system, 30% or 44 pipes (6165m) had head loss greater than 15 m/Km (*Appendix 4*). And their ages were 16 - 40 years. For example, in the distribution network, mains and sub mains from Catholic Church to Damot Gale District Finance Office, west of Health Center, west of Idiget primary school, east and south of Warka Sefer, in front of Public Library, east of Tobacco Enterprise, pipes of Faate borehole had unit head loss greater than 15 m/km.

In the distribution network, the diameters of main lines at the west of Health Center, west of Idiget primary school and east of Warka Sefer have diameter less than 50 mm. These are 1549m (11%) or 19 pipes of the total main lines. Their diameter was ≤ 150 mm and their age was 16-20 years. Four percent (One pipe) 4% the length of which was 200 m of the total sub-mains, in front of Public Library had diameter ≤ 38 mm and their age was 31-40 years. The head losses of these pipes were found to be greater than 15 m/km (*appendix 4*)

The flow velocity of water in distribution system shall be kept between 0.6 and 2 m/s (MoWR, 2006). To prevent sedimentation, the velocity should not be lower than 0.6m/s and to prevent erosion and high head losses, it should not be more than 2 m/s. But in the study area there are lower and higher flow velocities present than recommended The other values of pressure, unit headloss, velocity, head loss were shown in (*appendix 3and 4*).).

There are extremes of high and low pressures throughout the system due to topographic variation of the Town. The area of Faate borehole near to the asphalt road, is marked by high pressure above 70m. Since the topography of the town slopes to the east and areas starting from Tobacco Enterprise downward along the asphalt road is marked by hgh pressure above 70 m. On the other hand, areas starting from back side of Damot Gale District Finance Office, Post Office, infront and back side of Town's Manucipality, Stadium Sefer, Public Library, marked by low pressure areas. Areas starting from back side of Post office to Selam area marked by very low pressures, below 15 meters. The other areas, most parts of the distribution system marked by serviceable pressures or pressure range in between 15 and 70 m.

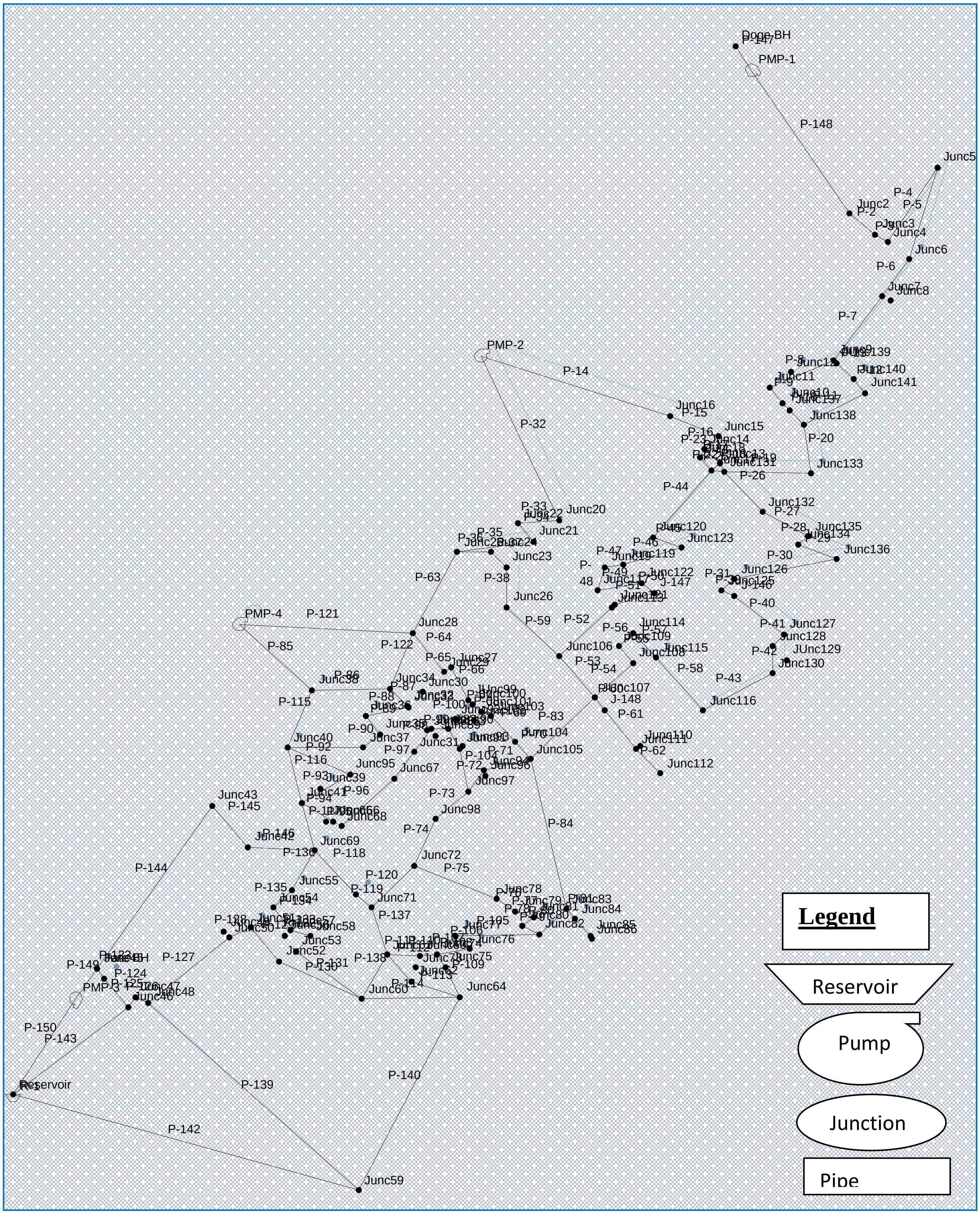

Figure 4.4 Water distribution network analysis of Boditi town

Areas starting from Tobacco Enterprise to the east highly slopes down and marked high pressure zone in the distribution system. These areas marked from junction nine to one. In these areas, water is pumped in to distribution system along the slope. The water has got energy from both pump and gravity. The pressure of these areas are increasing marked up to 90 meters at the junction five (Figure 4.5).

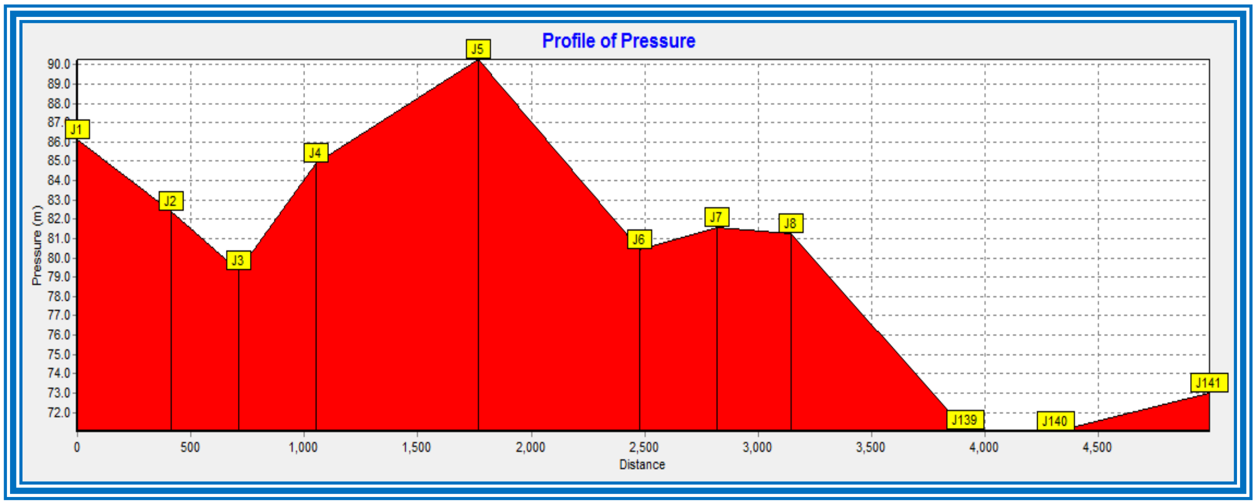

Figure 4.5 Pressure profile of some junctions around Tobacco enterprise

4.1.2.2. Base demand

Nodal water demand allocation was carried out by multiplying the number population who consume water at a given node and average daily water demand (per capita per day). In 2017 the average water production of the Town was estimated to be 371535 m^3. 633/day of water was used to allocate average daily demands to 97 nodes/ junction (*Appendix 3*) .

4.2. Water production and Consumption

The water production of the study Town was from the boreholes which were operated every day. The estimated average yield of boreholes (L/s): Faate, Keera, dooge, meles, Chayna, chawukare1, chawukare 2 and kingnam 3, 3, 2.5,10, 0,0.5,10 and 4 respectively. The aggregate production capacity of the sources is estimated to be 33 L/s [Table 3.3].

Based on the discharges and aggregated working time of each borehole, the monthly and annual water productions were estimated by multiplying the actual discharge of each borehole with the total operation time.

The total water production by boreholes in 2015/2016 and 2016/2017 were 284151m^3/year and 371535m^3/year respectively. Based on Figure 4.6, variation of water volumes for a given borehole in two years were different due to variation in operation time of the boreholes.

Based on Figure 4.6 both water supply and consumption were increasing from year to year. Water production for the supply from 2011 to 2016 indicates that it was increasing, but the change was insignificant. This indicates that a few improvements were made to increase water production. In 2017 production had significant change that is due to Chawukare BH had started pumping better than the other. Therefore drilling additional BH had significant contribution to sustainable water supply to the town.

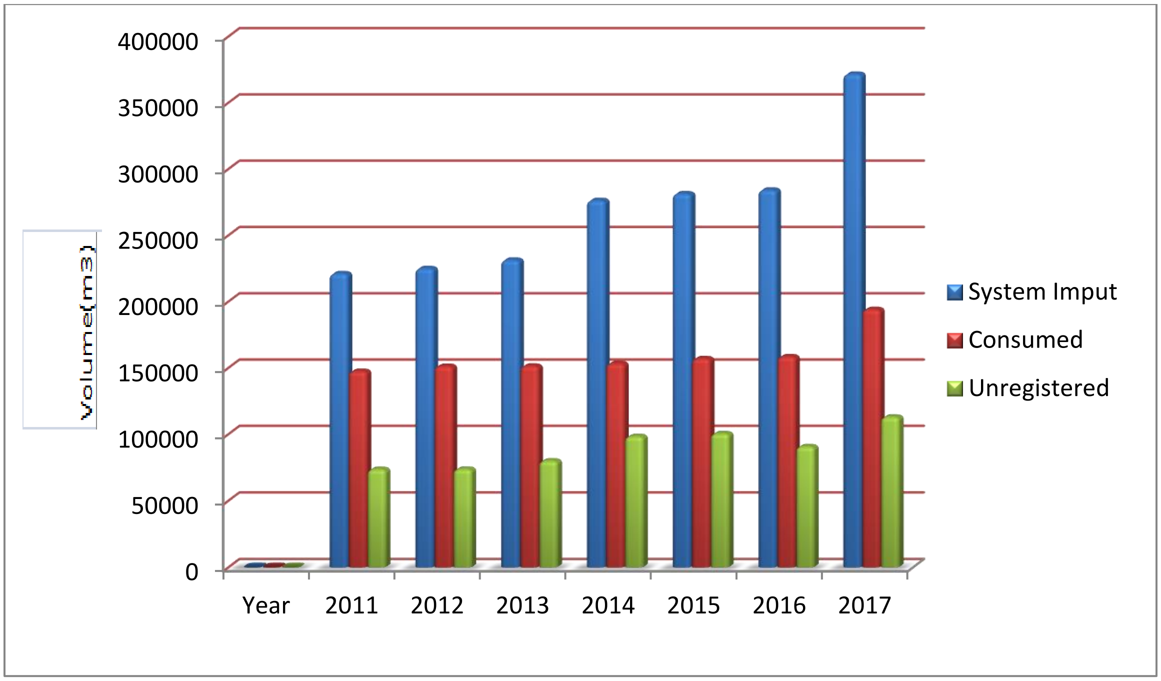

Figure 4.6 Water production, consumption and unregistered volume of study area from 211 to2017

4.3 Water los of distribution system.

In the last seven years both water production and consumption were increasing from 2011 to 2017. However, the annual water loss decreases from 20011 to the 2012 and increasing from 2012 to 2013 and continue likely. But when we compare the 2011 with 2017 there is reduction that shows water loss in general has some reduction. In 2017, the annual water produced and distributed to the system within specified year was 371535 m^3 and the aggregated annual water loss as derived from the (Expression no. 5) was 112971m^3 which account to 30.4%.

The average water loss as derived from the above expression accounts of 33.2% (Table .4.1). Key informants of the Town's water supply enterprise workers were asked about the condition of the enterprise from 2015 to 2017. They confirmed that, organizational management was improved; leak detection and maintenance measures were improved from 2015 to 2017. But for the years especially 2013 and 2015 water loss was due to lack of maintenance, shortage of resource, and most of the time at the leak points, water moves into the soil, but not moves to the surface. Water production and consumption were not balancing with each other. There was disparity between water supply and demand. Performance on water loss from 2011 to 2012 remained nearly constant. This indicates that no considerable effort was made to improve water supply system. The water supply enterprise of the study Town has to reduce water loss to improve water supply.

Table 4.1 Water balance of Boditi Town water supply system (2011-2017)

Water balance (year)	System Input volume(m^3)	Consumed Volume (m^3)	Unregistered volume (m^3)	UFW (Water loss %)
2011	221025	147456	73569	33.2
2012	224936	151207	73729	32.7
2013	231309	151359	79950	34.6
2014	276275	153246	928284	33.6
2015	281364	156973	100447	35.7
2016	*284151*	158429	90644	31.9
2017	371535	258564	112971	30.4

4.4 Water demand assessment

4.4.1 Pipe connections and service delivery mode

The connection profile (Table 4.2) indicates that, the number of new connections with in four years from 2011 to 2014 increased by 17.8%. But from 2014 to 2017 within four year the number of connection was 22.3%, which indicates there is incremental increase of connection from year to year). That shows the number of connections increases with development of government institutions, small diversified business activities, residence houses. This in turn increases the water demand in the Town.

Table 4.2 Connection profiles by mode of service (20011 - 2017)

Customer type	Number of connections						
	2011	2012	2013	2014	2015	2016	2017
Private connections	1914	1919	2158	2221	2253	2317	2476
Institutions	79	82	88	94	97	103	117
Commercial centers	199	201	203	241	259	297	392
Public taps	23	25	28	28	29	30	32
In-house connections	18	20	22	27	42	70	140
Others	-	-	-	20	33	41	60
Total	2233	2247	2497	2631	2713	2858	3217

4.4.2 Service delivery mode and number of customers

In commercial centers, population estimation only considers persons who live in a commercial center. The Town's water supply enterprise deliver water supply to customer groups and the estimated population shown in Table 4.3.

The number of population in each customer type was increasing from 20011 to 2017. Based on population data 2017, the proportion of people who use public tap accounts 45.7%, private connection accounts 39%, commercial center accounts 3%, in-house connection accounts 0.7% and people who have no direct access to the supply system 11.6%. As shown in Table 4.3, from 2014 to 2015 about 50% increase in population number (Table 4.3), which is due to four kebeles (Faate, Sibaye-Korke, H/Boditi and chochcha) were incorporated to the town from Damt-Gale worada. The number of population increases with development of government institutions, small diversified business activities, and residence house construction. This again increases the water demand in the Town.

Table 4.3 Estimation of population based on mode of service

Customer type	Number of population							
	Year							
	2011	2012	2013	2014	2015	2016	2017	Population % (2017)
Private taps	11060	11828	12420	12750	23823	24515	24907	39
Commercial	896	905	913	951	1749	1800	1916	3
Public taps	13602	14133	14712	15109	27805	28611	29185	45.7
In-house	81	90	101	98	422	434	447	0.7
Others	3470	3520	3762	3868	7117	7323	7408	11.6
Total population	29,109	30,477	31,908	32,776	60315	62063	63863	100.0

4.4.3 Water consumption by customer type

The water consumed by each customer type was estimated on basis of balance sheet and billing data of the Town's water supply service enterprise. The balance sheet clearly indicated that institutional, commercial center, in-house, public tap and private tap water consumption were put in quantifiable numbers. The break down and estimation of Water consumption by customer categories for the last seven years were shown in Table 4.4.

Based on the Table 4.4, both total annual water consumption and consumption by customer type were increased over the last seven years. The total water consumption in 2017 accounted to 258,564 m^3, the highest water consumption 57.2% was accounted for private customers, 7.7% institutions, 7.8% commercial, 25.9% public tap customers and 1.4% in-house customers (Table 4.4).

Table 4.4 Water consumption by mode of service (2011- 2017)

Customer type	Water consumed in m^3						
	Year						
	2011	2012	2013	2014	2015	2016	2017
Private taps	90325	91031	94182	94693	95826	98659	147,960
Institutions	12,003	12,148	13,236	13803	14090	114202	19,914
Commercial	10,170	10,463	11,258	11905	12,195	12309	20,097
Public taps	31,892	32,720	31,528	39642	40607	40984	66913
In-house	1,063	1854	2,154	2181	2234	2254	3,680
Total	147,453	151,207	151,359	153246	156973	158429	258564

4.4.4 Daily Per capita water consumption

Based on the data and inadequate water production, there is water loss in the distribution system, mainly physical losses. Inadequate water production together with frequent interruption in operation, the Town's production of water is lower than the expected amount. The water that reaches the customer is less compared to low production and high loss. This implies that the amount of water that can reach individual person per day in the Town is less. The daily water consumption of each customer type was estimated based on water consumed and population number of each customer type. The daily water consumption of each customer type was estimated (Table 4.5).

Water consumption of the study Town was estimated based on the amount of water supplied rather than the actual demand. People having in-house connection service about 0.3% of the total population consumed 37.9 L/c/d, private yard connection service about 37.9% of the total population consumed 16.7 L/c/d and the remaining population 46% which have access to drinking water are served by public taps use 5.8 L/c/d. In Boditi Town, in-house connection the highest, private tape connection the medium, and public tap the lowest water use. The Town's average 11.9 L/c/d assumed as everyone gets equal amount of water (Table 4.5).

Table 4.5 Per capita per day by mode of service (2011-2017)

Customer type	Water consumption per person per day							Average
	Year							
	2011	2012	2013	2014	2015	2016	2017	
Private connection (L/c/d)	23.2	21.6	20.8	12.8	11.0	11.1	16.3	16.7
Public taps (L/c/d)	6.4	6.3	5.9	7.2	4.0	4.7	6.3	5.8
In-house connection (L/c/d)	36.0	56.4	58.0	60.0	14.5	18.0	22.6	37.9
Town's average (L/c/d)	14.3	14.8	14.5	13.9	12.8	7.1	7.9	11.9

4.5. Domestic water supply coverage

The water supply coverage of the Town has been evaluated based on the average per capita water consumption. The average per capita water consumption has been derived from yearly water consumption of different customers and their consumption aggregated from individual water meters.

Based on Table 4.6, water supply coverage increased from 2011 to 2012, and then decreased from 2012 to 2015, there is fluctuation. A lot of population immigration to the town, shortage of resource, skilled man power, water loss, and the likes made fluctuation. The current water supply coverage of the Town was at the level of 69.6%. Boditi Town was category III town of population size between 30,000-80,000 and the Town's target was to supply 20 L/c/d (MoWR, 2009). The long term (2012-2016), urban water supply coverage is expected to grow from 74% in 2002 to 100% in 2016 (MoWE, 2011). The water supply coverage value does not indicate whether the population has access to sufficient amount of water, but it was compared to minimum survival WHO and local standards of per capita per day water use. Performance indicator on water supply coverage remained below the selected target 100% of (MoWE, 2011).The Town has low domestic water use, has high demand, and the Supply options should be increased.

Table 4.6 Water supply coverage of Boditi Town

Year	Water consumption (m^3/yr)	Consumption per capita (L/person/day)	Water supply coverage (%)
2011	147456	14.3	66.7
2012	151207	14.8	67.2
2013	151359	14.5	65.4
2014	153246	12.8	55.5
2015	156973	7.1	55.7
2016	158429	7.9	55.8
2017	258564	11.9	69.6

4.6. Water Demand Projection

The growth potential of Boditi Town has a basis in which the Town's administration is under effort to provide basic services such as education, health center, residential and commercial houses. Business establishments such as: hotels, shops, wood and metal workshops, textile and tailoring, local breweries, urban agriculture in dairy production are becoming increasing in number. The amount of water use is affected by change in population, water use technology, climate, and economic change.

4.6.1 Population projection

Population of Boditi Town has been increasing rapidly. Population projection of the Town was adapted to the National Statistical Report of Population and housing Census of 2007 by using 2017 population data as a base year with growth rate of 4.7% and using (Expression no.7), population of 63863 in 2017 is projected to 88079 in 2023(Figure 4.7), an addition of 24,216 people. Water demand projection of the Town depended on the size of population to be served, institutions and social establishments, commercial activities, and a detailed analysis of past 7 years water consumption trends.

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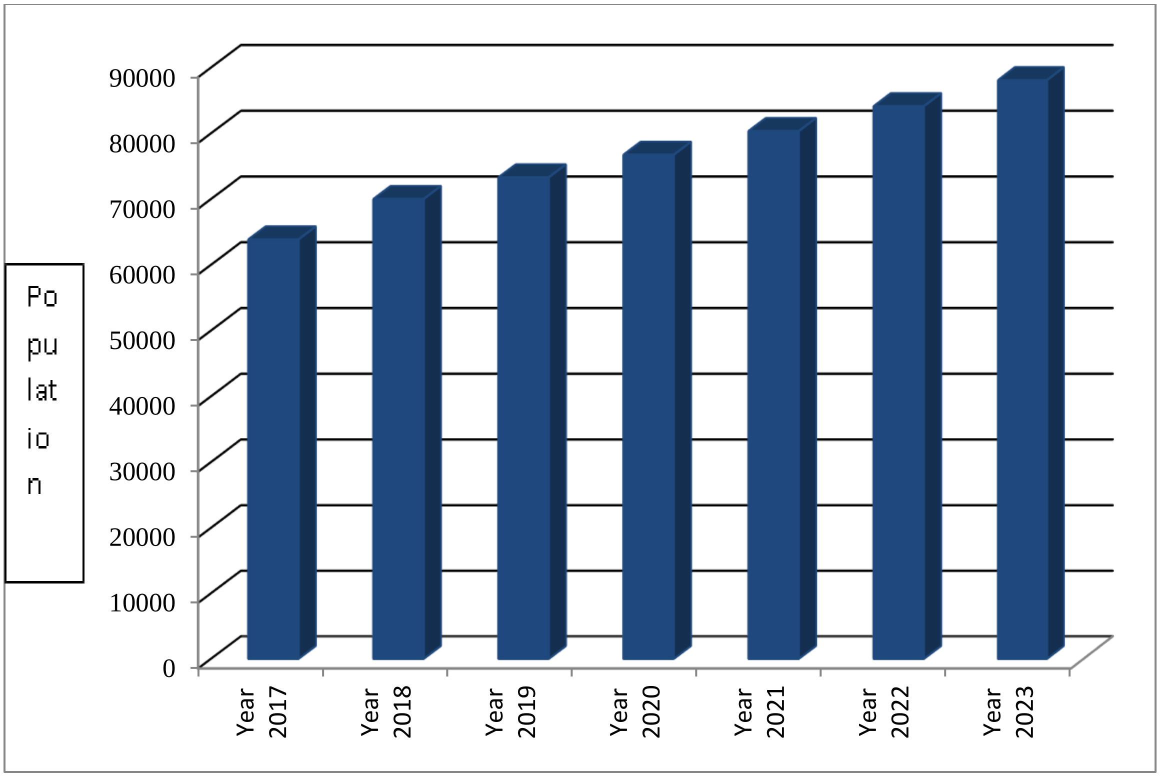

Figure 4.7 Population growth of Boditi town

4.6.2 Projected water demand

The total projected water demand for 2023 would be 1,012,688 m^3/year (Expression no.4 and projected number of population) only for Domestic, Commercial and institutional water demand (m^3/year) (Table 4.7) without estimating water loss. Therefore more than 1,012,688 m^3/year water will be required. The current water production was estimated to371535 m^3/year. This indicates, water supply should be raised by more than 641153 m^3/year with in seven years. Therefore, supplementing the existing water supply and reduction of water loss in distribution system is imperative activities.

Table 4.7 Projected Water demand (m^3/year) for the year 2015 to 2023

Year	2018	2021	2023
Population number	70007	80349	88079
Average per capita domestic water demand (L/c/d)	20	30	30
Domestic water demand (m^3/year)	511051	879822	964465
Commercial and institutional water demand (m^3/year)	25553	43991	48223
Total	536604	923813	1012688

4.7 .Option assessment

Option assessment was done to supplement the current supply system in 2023 due to: established target population, the balance between supply and demand, the level of water loss in the distribution system. Depending upon high future water demand approximately 641153 m^3/yr of a supplemental water source would be required to meet the projected demand. Potential supplemental supplies would develop additional water supplies to the town include: four springs (Seesona, Shaammina, Bol"o and Woysha), two rivers (Walacha and Charaake) ground water wells.

Based on conducted questionnaire and interview on study town population; 52% springs, 31% rivers, 12 % ground wells and 5% others(Figure 4.8) identified as water supply options. Indicates using springs is the best option to sustainable water supply to the town.

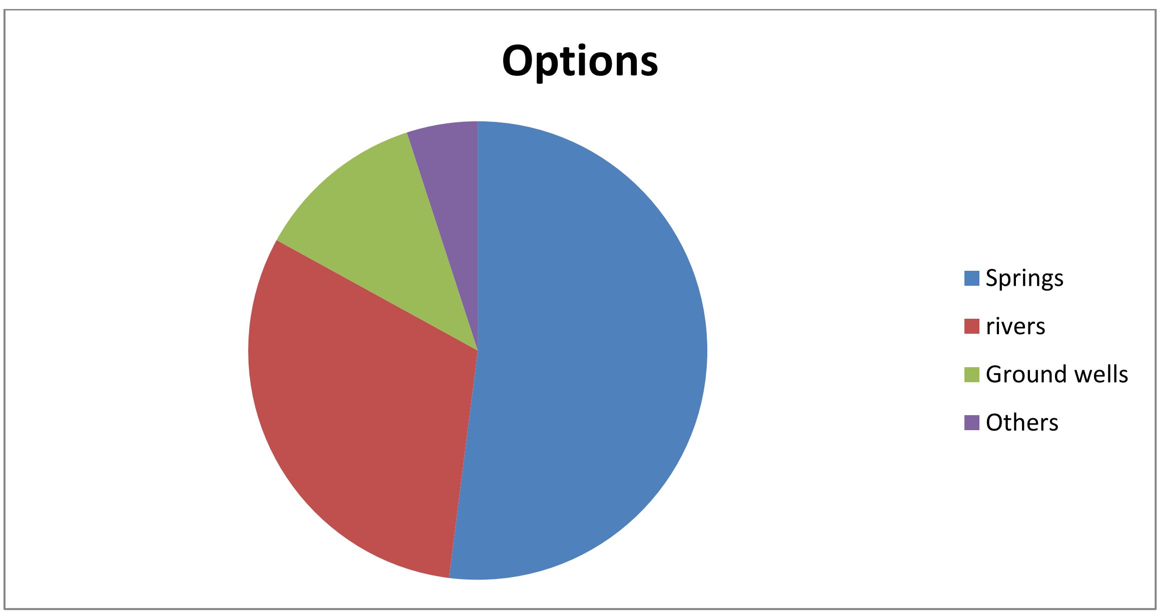

Figure 4.8 Water supply options of the study area

4.8. The major water supply problems of the study area

Table 4.8 the major identified problem s of the study area

Types of Problems	Number of Respondents in each Kebeles (As the most severe problem)					Tota no.	In %
	Faate	Dooge	Hagaza	Chawkare	Giddo		
Age and size of the pipes	15	12	16	24	21	86	16.7
Pressure problem(blow and above serviceable pressure)	10	9	10	14	20	63	12.3
Lack of reservoir	44	38	46	50	25	203	39.5
Flow velocity (lower and higher than recommended)	13	2	14	11	15	55	10.7
Lack of skilled man power in service office	11	8	11	18	5	62	12.0
Others	7	3	11	15	6	42	8.2

From the identified problem lack of reservoir is the most severe problem and age and size of the pipes, Pressure problem and lack of skilled man power were second and third ranked problems (Table 4.8).

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Both the water supply and consumption were evaluated based on the annual water production and consumption using population data of the Town. The current water supply of the Town found to be 371535m^3/year. The current water consumption of different customer groups was also estimated. For private yard connections, public tap users, in-house connection, and the Town's average per capita per day the consumption rates were found to be 16.7, 5.8, 37.7 and 11.9 respectively.

Compared to Universal Access Plan, the water supply target of the Town was 20 L/c/d. The current water supply and demand were below the selected target. Hence, the performance level of water supply that obtained in this study was below the selected target or below the standards recommended by UAP.Despite the low water supply of the Town, the total water loss is found to be high; the water loss was found to be 30.2% of the total water production in 2017. Compared to the selected target for water loss which is 20%, the water loss of 30.2% has a negative impact on water supply to satisfy increasing demand and to increase revenue. The performance level obtained in this study was below the selected targets.

Out of 141 junctions analyzed in the distribution system, 9% of the junctions have above the maximum operating pressure (70 m) and 2% of the junctions have below the minimum operating pressure (15 m). In the distribution system of the Town, 30% of pipes (6165 m) have head loss gradient greater than 15 m/Km and their ages were greater than 16-40 years. In the distribution link analysis, 11% mainline pipes (1549 m) and 4% of sub-main pipes (200 m) have less diameters than the Minimum Design Criteria. As a result, their head loss gradients become greater 15 m/Km.

The performance levels obtained in this study based on both age and diameter of the pipes were above the selected target. The performance levels of pressures were below and above the selected target. Unit head losses in water distribution pipes ≤15 m/Km, the minimum and maximum operating pressures in the distribution system are 15m and 70m respectively. The violation of performances of unit head loss, pressure in accordance with Design Criteria results in low and high water pressures in the distribution system. The low pressure creates shortage of water and high pressure creates pipe burst in the distribution system.

5.2. Recommendation

Based on the finding conclusion I believe the following recommendations are helpful in achieving efficient provision of sustainable water supply in Boditi Town.

- Constructing reservoir/ tanker, which store water from all boreholes and putting it on hill area of the town can contribute to sustainable water supply by reducing water loss, allows for gravitational distribution system. Which intern can prevent water supply at the time of electricity stopped.
- The Town's water supply enterprise and concerned bodies should close the gap between supply and demand through supplemental water source to augment the current supply system.
- Since the per capita per day water consumption is low, water supply enterprise of the Town has to increase the access for private tap connections, public tap connections and for people who have no direct access to the supply system to meet the millennium development goal which sets water supply access for all.
- Population data is the determining factor in water supply planning. Therefore, actual population growth should be periodically adjusted.
- To reduce water loss in distribution system, renewal of aged pipes and installing properly sized pipes for mains and sub-mains is crucially important.
- To maintain serviceable pressures or to have minimum and maximum pressure ranges in the supply system, pressure zoning along with reservoir installation should be made.
- Pipe installation need to be looped to have low flow velocities, maintain the pipe in the event of line break and reduce head losses.
- Developing skilled, good attitudinal, team sprit worker s in the service office.
- Giving training, awareness giving meetings for employers and the society of the town on sustainable supply of the town.

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Appendices

Appendix.1. Questioner and/Interview for beneficiaries

The main objective of this questionnaire is to collect information about the sustainability of urban water supply system. The other objectives are to gather information about the technical factors, environmental factors, financial factors, health factors, socio- economic factors and the like. Your information helps me to find the causes for the non functionality of urban water supply system. So, please tell me the real information if possible.

Thank you for your cooperation!!

I. Socio-economic characteristics of Households

<table>
<tr><td rowspan="2">Name of the water Point/kebele</td><td colspan="3">Information giver HH</td><td rowspan="2">HH size</td><td rowspan="2">HH's Head</td><td rowspan="2">Marital status</td><td rowspan="2">Education</td></tr>
<tr><td>Name</td><td>Gender</td><td>Age</td></tr>
<tr><td></td><td></td><td>1.male
2.female</td><td></td><td></td><td>1.male
2.female</td><td>1.married
2.unmarried
3.Divorced
4.Widowed</td><td>1. illiterate
2. grade 1-8
3. grade 9-12
4.Abovegrade 12
5.Read and write</td></tr>
</table>

II. Identification of Demand responsiveness and non-functionality factors of the services.

1. How many years have you lived in this area? --

2. What are the major problems of water supply of the town? --
----

3. How severe are problems with water service in your town? a. low b. fair c. strong d. very strong e. No problem

4. What are the major causes and challenges of water supply shortage of the town? -----------------
----

5. At what time is the supply of water be/has a critical problem? --------------------------------------
----

6. For which water use the problem is most serious? A. drinking b. washing c. cooking d. bathing d. other

7. What are the main sources of water used for your house hold? a. Piped water b. protected spring c. Unprotected spring d. River/pond e. Rain water f. Protected well g. Unprotected well h. If other verify

8. How the water supply of the town for your household usage? a. Very good b. Good c. Satisfy d. Poor

9. How about the efficient use of the water, for you, your neighbor, your kebele/town.

a. Very good b. Good c. Satisfy d. Poor

10. Is the water equally distributed to all kebele or HH's? a. Yes b. Not If not what is the reason? ---

11. What would be the sustainable remedial solution of the water scarcity in your opinion? -------
----

III. Identification of type of Participation of beneficiaries and developmental process of water supply system

12. Have you participated in the development processes of the water supply service? a. Yes b. No.

13. What type of participation did you have during the water supply service development?

a. Cash b. Labor contribution c. contribution of local materials d. Idea e. Others

14. What is the average distance from your home to your previous and current source of water? You can use local measurements. ---

15. Does the present source of water help you reduce the amount of time required to fetch water? If so, how much time? How about the future? ---
----

16. What about women's participation in sustainable use of water? -----------------------------------
----

17. How strongly do you feel about users paying water fees? a. Expensive b. Fair c. Inexpensive d. I don't know. Explain based on ability. --
----

18. Do you usually pay a fee for your water service? a. Yes b. No If yes, how much did you pay? For how much? --
----

19. Are there any educational sessions given in your communities regarding use of drinking water? a. Yes b. No c. don't Know. Explain --
----

20. How many sessions did you attend? --
----

21. If your answer for Q19 is No; what prevented you from participating? ---------------------------
----

22. Do you get benefit from the education given? a. Yes b. No c. don't know. Justify-------------
----

23. If your answer for Q21 is yes; what are the benefits to you? --

24. What type of container do you use to fetch water? --

25. For what purpose do you fetch water? Circe all that you use water a. HH drinking and food preparation b. Bathing and washing clothes c. Animal drinking d. irrigation of crops e. Other

26. What is your daily water use? (In litters)--

27. How satisfied are you with number of hours water available? a. excellent b. very good c. good d. somehow e. poor

28. Have you satisfied with the quantity available? a. Very much b. It depends on season c. No. Justify---

29. What is your overall satisfaction with the service? a. excellent b. very good c. good d. Fair e . bad.

30. How you long stand in line a long time, when the service stopped? -------------------------------

31. How do you evaluate the quality of the construction of the project water source? a. excellent b. very good c. good d. Fair e. Bad

32. Is the system being repaired? How often? by whom?---

33. Currently are there any defects in catchments or wells? a. Yes b. No. explain. ---------------
----

34. Does community had financial capacity to sustain the service? a. Yes b. No c. don't know

35. Who is the owner of the scheme? a. the community b. local gov't c. don't know d. NGOs e. others

36. Do you think that the available water supply is sufficient for the community? a. yes b. No justify---

37. How frequently are repair needed? ---

38. How many times in a year does your water source need repair? a. once in a year b. twice a year c. three times a year d. more than three times a year e. no need

39. Is there anything else you would like to say about your sustainable water supply and distribution system ? ---
----

Appendix .2

Questionnaire and/or interview discussed with the town water experts and leaders

The main objective of this questionnaire is to collect information about the sustainability of urban water supply system. The other objectives are to gather information about the technical factors, environmental factors, financial factors, health factors, socio- economic factors and the like. Your information helps me to find the causes for the non functionality of urban water supply system. So, please tell me the real information if possible.

Thank you for your cooperation!!

III. Identification of water points and their capacity of supply

Name of the water Point	Capacity of water point (squ.meter/day/year)	Water-point sub-town	Kebele	no. of user Population	Additional
Total					

IV. Identification of Demand responsiveness and non-functionality factors of the services.

1. How many years have you worked in this office? --

2. What are the major problems of water supply of the town?

A.based on man power -------------------------------- ---

B. based on finance---

C. based on distribution system---

D. Livelihoods’ --

E. other sectors---

F. other ---

3. How severe are problems with water service in your town? ---

4. What are the major causes and challenges of water supply shortage of the town?----------------

5. At what time is the supply of water be/has a critical problem? ---------------------------------------

6. For which water use the problem is most serious? A. drinking b. washing c. cooking d. bathing d. other

7. What are the main sources of water used by the people of the town? a. Piped water b. protected spring c.Unprotected spring d. River/pond e. Rain water f. Protected well g. Unprotected well h. If other verify

8. What are the main sources of water used for the people of the town? a. Bare-hole b. Dam c. River d. other

9. How about the efficient use of the water, for you, your neighbor, your kebele/town.

a. Very good b. Good c. Satisfy d. Poor

10. Is the water equally distributed to all kebele or HH's/sub- town? a. Yes b. Not If not what is the reason? ---

III. Identification of type of Participation of beneficiaries and developmental process of water supply system

1. How do you prepare water projects? --

2. Do you make a baseline survey before the project and what situations do you examine? ---

3. Did the communities participate in the project? ---

4. Did communities participate in choosing place of construction for the hand dug wells and spring developments? --

5. Did women participate in the processes involved? --

6. Did your organization give chance to the community in choosing the type of technology of the water points constructed? --

7. How do you know the yield of the well or the spring that your organization constructing is enough for the community consumption? --

8. Had your organization helped the community in organizing water committee in the community? --

9. Does the water committee helpful or the community and also the sustainability of the water point? --

10. Have your organization followed demand driven approach? --

11. Did your organization helped the community in institutionalizing the hand dug wells and spring developments ?---

12. Did you make contractor supervision? ---

13. Do you think that your staff technicians are enough for the town water supply systems and also capable enough? ---

14. Do you give support for the community members after construction of the project? ------------

15. What problems do you see in the processes of implementing the town water supply systems? ---

16. At what season does the water point digging occur? --

17. Have you and workers participated in the development processes of the water supply service? a. Yes b. No. in what and what benefit do you get? ---

18. What type of participation did population of the town have during the water supply service development?

a. Cash b. Labor contribution c. contribution of local materials d. Idea e. Others

19. What is the average distance from your home to your previous and current source of water? You can use local measurements. --

20. Does the present source of water help you reduce the amount of time required to fetch water? If so, how much time? How about the future? ---

21. How strongly do you feel about users paying water fees? a. Expensive b. Fair c. Inexpensive d. I don't know. Explain based on ability. ---

22. Do people usually pay a fee for your water service? a. Yes b. No If yes, how much did you pay? For how much? ---

23. Are there any educational sessions given in your communities regarding use of drinking water? a. Yes b. No c. don't Know. Explain ---

24. How many times ? --

25. If your answer for Q19 is No; what prevented you from giving training? -------------------------

26. Do they get benefit from the education given? a. Yes b. No c. don't know. Justify------------

27. If your answer for Q21 is yes; what are the benefits to them? -------------------------------------

28. What type of container do you and communities use to fetch water? ------------------------------

29. For what purpose do they fetch water? Circe all that you use water by rank a. HH drinking and food preparation b. Bathing and washing clothes c. Animal drinking d. irrigation of crops e. Other

30. What is daily water use per person? (In litters)---

31. How satisfied the community with number of hours water available? a. excellent b. very good c. good d. somehow e. poor

32. Have you/population satisfied with the quantity available? a. Very much b. It depends on season c. No. Justify---

33. How you long stand in line a long time, when the service stopped? -------------------------------

34. How do you evaluate the quality of the construction of the project water source? a. excellent b. very good c. good d. Fair e. Bad

V. **System maintaining points**

1. Is the system being repaired? How often? by whom?--

2. Currently are there any defects in catchments or wells? a. Yes b. No. explain. ----------------

3. Does community had financial capacity to sustain the service? a. Yes b. No c. don't know

4. Who is the owner of the scheme? a. the community b. local gov't c. don't know d. NGOs e. others

5. Do you think that the available water supply is sufficient for the community? a. yes b. No justify---

6. How frequently are repair needed? --

7. How many times in a year does your water source need repair? a. once in a year b. twice a year c. three times a year d. more than three times a year e. no ne

VI. **Other important points**

1. What would be the sustainable remedial solution of the water scarcity in your opinion? ---------
----

2. Is there anything else you would like to say about your sustainable water supply and distribution system ? ---

Appendix 3 Network Table - Nodes

Node ID	Demand CMD	Head m	Pressure m	Node ID	Demand (CMD)	Head (m)	Pressure (m)
J1	0.00	2090.08	86.08	J23	0.00	2071.38	24.38
J2	0.00	2087.42	82.42	J24	4.00	2071.37	30.37
J3	0.00	2085.36	79.36	J25	25.10	2081.06	37.06
J4	0.00	2084.88	84.88	J26	7.00	2081.47	32.47
J5	39.10	2084.27	90.27	J27	0.00	2082.19	24.19
J6	0.00	2084.44	80.44	J28	10.00	2081.99	31.99
J7	0.00	2083.55	81.55	J29	12.00	2082.23	24.23
J8	15.10	2083.28	81.28	J30	0.00	2085.28	26.28
J9	1.50	2081.35	69.35	J31	4.00	2085.27	27.27
J10	2.50	2079.32	56.32	J32	0.00	2087.38	28.38
J11	4.00	2079.14	55.14	J33	0.00	2087.62	28.62
J12	6.00	2079.05	57.05	J34	6.00	2087.58	32.58
J13	0.00	2077.41	55.41	J35	3.00	2094.50	36.50
J14	0.00	2077.43	43.43	J36	3.00	2094.49	38.49
J15	18.60	2077.40	50.40	J37	9.50	2098.75	39.75
J16	0.00	2078.68	47.68	J38	14.60	2104.97	55.97
J17	1.00	2077.20	44.20	J39	4.00	2101.94	41.94
J18	1.50	2077.38	42.38	J40	7.00	2101.85	46.85
J19	4.00	2072.62	28.62	J41	0.00	2102.95	39.95
J20	14.60	2071.41	27.41	J42	0.00	2119.32	52.32
J21	2.20	2071.39	26.39	J43	16.10	2119.28	58.28
J22	1.00	2071.39	28.39	J44	10.00	2167.19	84.19
J45	24.68	2152.17	67.17	J68	18.30	2102.36	42.36
J46	20.15	2139.43	59.43	J69	9.00	2102.67	39.67
J47	0.00	2138.30	58.30	J70	2.60	2103.15	42.15
J48	15.60	2137.30	61.30	J71	6.80	2102.06	39.06
J49	0.00	2131.57	59.57	J72	1.70	2102.06	46.06
J50	2.50	2130.78	55.78	J73	0.00	2100.83	42.83
J51	2.00	2126.26	52.26	J74	3.00	2100.60	43.60
J52	3.00	2126.22	61.22	J75	2.80	2100.51	43.51
J53	4.50	2126.21	58.21	J76	6.00	2100.37	47.37
J54	2.30	2119.31	52.31	J77	1.50	2100.29	46.29

J55	1.60	2119.30	54.30	J78	11.00	2100.10	52.10
J56	1.50	2114.48	47.48	J79	2.50	2100.27	54.27
J57	0.00	2111.49	45.49	J80	0.00	2099.52	48.52
J58	5.00	2108.25	40.25	J81	0.00	2099.23	56.23
J59	0.00	2105.05	39.05	J82	2.00	2098.73	53.73
J60	3.80	2105.02	40.02	J83	5.00	2090.21	54.21
J61	4.00	2102.58	43.58	J84	0.00	2088.10	50.10
J62	0.00	2101.45	44.45	J85	2.70	2087.73	48.73
J63	0.00	2100.63	47.63	J86	12.00	2087.64	42.64
J64	8.00	2100.10	49.10	J86	12.00	2087.64	42.64
J65	0.00	2102.80	39.80	J87	0.00	2084.45	26.45
J66	0.00	2102.73	43.73	J88	0.00	2084.19	27.19
J67	0.00	2102.67	43.67	J89	0.00	2083.61	25.61
J90	0.00	2082.86	23.86	J115	12.00	2065.57	29.57
J91	0.00	2081.72	23.72	J116	11.10	2063.20	33.20
J92	0.00	2081.80	24.80	J117	0.00	2067.42	19.42
J93	4.30	2081.68	23.68	J118	2.00	2073.29	30.29
J94	2.50	2081.49	34.49	J119	2.00	2072.73	30.73
J95	0.00	2081.47	29.47	J120	4.00	2072.67	30.67
J96	8.00	2081.37	28.37	J121	2.00	2072.66	25.66
J97	3.00	2081.37	31.37	J122	0.00	2068.88	25.88
J98	0.00	2081.37	33.37	J123	2.00	2066.91	22.91
J99	0.00	2081.00	22.00	J124	10.00	2066.77	31.77
J100	0.00	2080.97	21.97	J125	2.00	2065.98	27.98
J101	0.00	2080.97	22.97	J126	6.00	2065.75	30.75
J102	0.00	2081.07	26.07	J127	2.50	2065.27	41.27
J103	0.00	2063.79	10.79	J128	0.00	2065.25	42.25
J104	6.00	2063.56	11.56	J129	2.00	2065.21	45.21
J105	30.20	2061.23	11.23	J130	9.00	2065.19	42.19
J106	2.00	2066.28	20.28	J131	4.00	2077.36	46.36
J107	1.50	2066.09	27.09	J132	6.00	2066.75	40.75
J108	7.10	2066.07	28.07	J133	11.10	2064.56	49.56
J109	1.00	2066.09	23.09	J134	3.50	2066.71	43.71
J110	0.00	2061.80	29.80	J135	5.00	2066.44	44.44
J111	1.00	2061.69	34.69	J136	2.00	2066.39	50.39
J112	6.50	2061.18	36.18	J137	3.50	2078.65	59.65

J113	1.00	2066.76	18.76	J138	10.10	2078.57	60.57
J114	1.00	2066.27	24.27	J139	2.00	2081.07	71.07
				J140	2.00	2081.02	71.02
				J141	7.00	2080.99	72.99

Appendix 4 Network Table – Links

Link ID	Flow (CMD)	Velocity (m/s)	Unit Head loss (m/km)	Link ID	Flow (CMD)	Velocity (m/s)	Unit Head loss (m/km)
P1	-16.23	0.06	0.14	P24	7.20	0.04	0.17
P2	236.79	0.87	20.53	P25	1.00	0.01	0.00
P3	236.79	0.87	20.53	P26	4.00	0.02	0.06
P4	166.76	0.61	10.72	P27	4.00	0.04	0.23
P5	39.10	0.22	2.17	P28	-25.10	0.14	1.69
P6	127.66	0.47	6.54	P29	-32.10	0.18	2.66
P7	127.66	0.47	6.54	P30	10.00	0.10	1.25
P8	15.10	0.34	7.32	P31	-42.10	0.15	1.48
P9	112.56	0.41	9.17	P32	-234.99	0.86	35.84
P10	66.01	0.38	10.12	P33	4.00	0.02	0.06
P11	10.00	0.15	3.03	P34	-238.99	0.87	36.98
P12	6.00	0.09	1.18	P35	-305.34	1.12	58.19
P13	53.51	0.31	6.86	P36	6.00	0.06	0.48
P14	-14.69	0.08	0.35	P37	-311.34	1.14	60.34
P15	18.60	0.11	0.55	P38	3.00	0.03	0.13
P16	-70.03	0.40	6.38	P39	-317.34	1.16	62.51
P17	-70.03	0.40	6.38	P40	-152.10	0.87	26.81
P18	57.05	0.33	7.72	P41	207.14	0.76	16.02
P19	-35.24	0.20	3.16	P42	-174.73	0.64	17.82
P20	-36.74	0.21	1.93	P43	7.00	0.07	0.55
P21	91.29	0.52	10.42	P44	-185.73	0.68	19.95
P22	192.83	0.49	5.77	P45	-205.18	1.17	71.15
P23	424.57	1.08	37.96	P46	16.10	0.09	0.25
P47	-221.28	1.26	81.83	P55	105.65	0.60	17.12
P48	-257.67	1.47	108.49	P56	105.65	0.60	17.12
P49	362.21	2.07	203.83	P57	103.15	1.05	66.51
P50	337.53	1.93	178.86	P58	7.50	0.08	0.28
P51	-271.21	1.55	119.28	P59	4.50	0.05	0.11
P52	-412.61	2.36	259.46	P59	4.50	0.05	0.11
P53	121.25	0.69	26.86	P60	93.65	0.95	55.61
P54	121.25	0.69	22.10	P61	1.60	0.02	0.03
P62	89.75	0.91	51.40	P66	3.80	0.04	0.15
P63	88.25	0.90	49.82	P68	16.95	0.39	16.92
P64	88.25	0.90	49.82	P65	62.50	0.63	26.29
P69	12.95	0.30	10.28	P67	20.75	0.84	99.89

P71	4.95	0.11	0.93
P72	8.00	0.18	4.21
P73	19.45	0.20	1.62
P74	19.45	0.20	1.43
P75	19.45	0.20	1.63
P76	18.30	0.19	1.45
P77	1.15	0.01	0.01
P78	-7.85	0.18	2.18
P79	52.05	0.53	18.74
P81	1.70	0.01	0.00
P80	43.55	0.44	6.35
P82	43.55	0.25	3.32
P83	45.50	0.26	1.70
P84	42.70	0.24	1.51
P85	12.50	0.13	1.33
P86	11.00	0.11	1.05
P87	24.20	0.14	0.53
P88	21.70	0.32	9.01
P89	21.70	0.32	9.01
P90	21.70	0.32	9.01
P91	19.70	0.80	90.70
P92	14.70	0.60	52.73
P93	14.70	0.34	6.13
P94	12.00	0.27	4.21
P95	66.34	0.67	29.37
P96	66.34	0.67	15.75
P97	66.34	0.67	15.75
P98	66.34	0.67	15.75
P99	24.91	0.36	14.14
P100	24.91	0.36	14.14
P101	41.43	0.42	14.93
P102	41.43	0.42	14.92
P103	23.63	0.24	5.28
P104	13.50	0.14	1.87
P105	11.00	0.11	1.29
P106	11.00	0.25	9.23
P107	3.00	0.02	0.01
P108	0.00	0.00	0.00
P109	180.89	0.46	9.08
P110	205.80	0.52	11.56
P111	-220.21	0.56	13.07
P112	-14.41	0.04	0.09
P113	-14.41	0.15	2.45
P114	9.23	0.16	17.28
P115	-26.97	0.27	7.83
P116	-40.58	0.24	4.40
P117	36.20	0.21	3.33
P118	30.20	0.31	9.66
P119	11.61	0.12	1.16
P120	2.61	0.03	0.10
P121	-4.49	0.05	0.28
P122	-5.49	0.13	2.96
P123	7.50	0.30	21.41
P124	7.50	0.17	5.28
P125	6.50	0.15	4.05
P126	23.10	0.23	6.93
P127	29.59	0.30	9.29
P128	11.10	0.25	10.90
P129	-71.17	0.72	47.23
P130	-37.76	0.38	14.61
P131	-33.41	0.76	83.88
P132	184.80	0.47	9.45
P133	105.54	0.27	2.88
P134	77.26	0.20	1.88
P135	2.00	0.02	0.06
P136	71.26	0.72	47.35
P137	33.50	0.34	11.70
P138	10.00	0.10	1.25
P139	21.50	0.22	5.15
P140	19.50	0.20	4.30
P141	13.50	0.14	2.17

P142	11.00	0.11	0.50	P149	7.00	0.16	4.64
P143	11.00	0.11	0.56	P150	2.00	0.05	0.46
P144	9.00	0.09	0.39	P151	-20.45	0.21	4.69
P145	11.15	0.11	1.53	P152	10.10	0.10	1.27
P146	27.60	0.63	58.90	P153	-34.05	0.35	12.06
P147	11.10	0.25	10.90	P154	-45.05	0.46	7.69
P148	10.50	0.06	0.34				

Appendix-5 Input data of junctions

JunctionID	x-coor	y-coor	Elevation	House No	Population Number	Base demand(CMD)
Doge BH	374304	770480	1952			
Junc1	374726	760078	2004			0
Junc2	374648	769976	2005			0
Junc3	374724	769915	2006			0
Junc4	374760	769892	2007			0
Junc5	374911	770116	1994	389	1789	39.1
Junc6	374824	769839	2004			0
Junc7	374744	769728	2002			0
Junc8	374770	769716	2002	150	690	15.1
Junc9	374599	769539	2012	15	69	1.5
Junc10	374446	769411	2023	25	115	2.5
Junc11	374406	769457	2024	40	184	4
Junc12	374470	769502	2022	60	276	6
Junc13	374255	769229	2033			0
Junc14	374208	769270	2034			0
Junc15	374251	769309	2027	185	891	18.6
Junc16	374106	769372	2031			0
Junc17	374229	769209	2033			1
Junc18	374197	769246	2035			1.5
Junc19	373912	768919	2044			4
Junc20	373775	769060	2044	145	667	14.6
ChaynaBH	373538	769551	1981			
Junc21	373695	768995	2045	22	101	2.2
Junc22	373648	769049	2043	10	46	1
Junc23	373614	768918	2047			0
Junc24	373570	768963	2041	40	184	4
Junc25	373467	768964	2044	250	1150	25.1
Junc26	373616	768798	2049	70	322	7
Junc27	373449	768617	2058			0
Junc28	373332	768721	2050	100	460	10

Junc29	373425	768603	2058	120		552		12
Junc30	373361	768544	2059					0
Junc31	373336	768364	2058	40		184		4
Junc32	373317	768503	2059					0
Junc33	373319	768500	2059					0
Junc34	373264	768554	2055	60		276		6
Junc35	373234	768418	2058	30		138		3
Junc36	373191	768474	2056	30		138		3
Junc37	373184	768378	2059	95		437		9.5
KeeraBH	372811	768747	2002					
Junc38	373030	768550	2049	145		667		14.6
Junc39	373055	768256	2060	40		184		4
Junc40	372956	768377	2055	70		322		7
Junc41	372999	768212	2063					0
Junc42	372839	768081	2067					0
Junc43	372728	768204	2061	150		690		16.1
Junc44	372405	767686	2083	90		414		10
Junc45	372384	767716	2085	245		1127		24.68
Fate BH	372384	767716	2086		0			0
Reservoir	372131	767337	2091					15.6
Junc46	372476	767601	2080	200		920		0
Junc47	372497	767631	2080					2.5
Junc48	372538	767614	2076	155		713		2
Junc49	372765	767825	2072	0			0	3
Junc50	372781	767809	2075	25		115		4.5
Junc51	372844	767839	2074	20		92		2.3
Junc52	372933	767737	2065	30		138		1.6
Junc53	372981	767768	2068	45		207		1.5
Junc54	372913	767899	2067	23		106		0
Junc55	372970	767950	2062	16		74		5
Junc56	372946	767814	2067	15		69		0
Junc57	372965	767829	2066					3.8
Junc58	373023	767813	2068	50		230		4

Junc59	373169	767051	2066			0
Junc60	373180	767625	2065	38	175	0
Junc61	373255	767758	2059	40	184	8
Junc62	373330	767678	2057			20.15
Junc63	373356	767755	2053			0
Junc64	373475	767631	2051	80	368	0
Junc65	373074	768158	2063			0
Junc66	373094	768157	2059			18.3
Junc67	373277	768285	2060	182	837	9
Junc68	373118	768142	2059			18.3
Junc69	373038	768069	2063	90	414	9
Junc70	373163	767938	2061	26	120	2.6
Junc71	373208	767898	2063	68	313	6.8
Junc72	373338	768024	2056	17	78	1.7
Junc73	373342	767718	2058			0
Junc74	373405	767759	2057	30	138	3
Junc75	373433	767721	2057	28	129	2.8
Junc76	373504	767774	2053	60	276	6
Junc77	373463	767814	2054	15	69	1.5
Junc78	373585	767924	2048	110	506	11
Junc79	373642	767888	2046	25	115	2.5
Junc80	373664	767844	2051			0
Junc81	373696	767870	2043			0
Junc82	373712	767820	2045	20	92	2
Junc83	373794	767894	2036	50	230	5
Junc84	373821	767865	2038			0
Junc85	373867	767814	2039	27	124	2.7
Junc86	373871	767805	2045	120	552	12
Junc87	373387	768434	2058			0
Junc88	373377	768428	2057			0
Junc89	373400	768414	2058			0
Junc90	373439	768434	2059			0
Junc91	373475	768375	2058			0
Junc92	373461	768462	2057			0

Junc93	373484	768382	2058	43	198	4.3
Junc94	373545	768310	2047	25	115	2.5
Junc95	373143	768299	2052			0
Junc96	373549	768294	2053	80	368	8
Junc97	373501	768246	2050	30	138	3
Junc98	373400	768163	2048	30	138	3
JUnc99	373501	768520	2059			0
Junc100	373513	768507	2059			0
Junc101	373538	768485	2058			0
Junc102	373517	768458	2055			0
Junc103	373570	768471	2053			0
Junc104	373642	768395	2052	60	276	6
Junc105	373686	768344	2050	281	1289	30.2
Junc106	373774	768651	2046	19	91	2
JUnc107	373882	768528	2039	15	69	1.5
Junc108	373995	768631	2038	61	281	7.1
Junc109	373953	768681	2043	10	46	1
Junc110	374016	768383	2032			0
Junc111	374003	768373	2027	10	46	1
Junc112	374079	768300	2025	55	253	7.5
Junc113	373931	768797	2048	10	46	1
Junc114	373996	768721	2042			0
Junc115	374063	768647	2036	110	506	12
Junc116	374206	768488	2030	91	419	11.1
Junc117	373888	768850	2048			0
Junc118	373937	768899	2043	20	92	2
Junc119	373964	768927	2042	20	92	2
Junc120	374056	769009	2042	40	184	4

Junc121	373941	768806	2047	20	92	2
Junc122	374021	768871	2045			0
Junc123	374141	768977	2044	10	46	2
Junc124	374238	769029	2035	73	332	10
Junc125	374262	768848	2038	17	82	2
Junc126	374301	768883	2035	60	276	6
Junc127	374448	768718	2024	25	115	2.5
Junc128	374416	768682	2023			0
JUnc129	374457	768641	2020	20	92	2
Junc130	374415	768599	2023	90	414	9
Junc131	374268	769203	2031	40	184	4
Junc132	374384	769082	2026	60	276	6
Junc133	374530	769199	2015	110	506	11.1
Junc134	374490	768987	2023	35	161	3.5
Junc135	374524	769010	2022	50	230	5
Junc136	374609	768943	2013	20	92	2
Junc137	374466	769388	2019	35	161	3.5
Junc138	374507	769345	2018	100	460	10.1
JUnc139	374607	769530	2010	20	92	2
Junc140	374657	769480	2010	20	92	2
Junc141	374691	769440	2008	60	276	7

Appendix 6 Input data of links

Pipe Id	Length(m)	Diameter(in)	Type	Age	Roughness
P1	590	2.5	GI	10	113
P2	130	2.5	GI	10	113
P3	100	2.5	GI	10	113
P4	45	2.5	GI	10	113
P5	280	2.5	GI	10	113
P6	68	2.5	GI	10	113
P7	135	2.5	GI	10	113
P8	37	1	HDPE	10	140
P9	240	2.5	GI	31-40	83
P10	201	1.5	GI	31-40	83
P11	60	1.25	GI	31-40	83
P12	71	1.25	GI	31-40	83
P13	278	1.5	GI	31-40	83
P14	57	2	GI	10	113
P15	60	2	GI	10	113
P16	196	2	GI	10	113
P17	1048	2	GI	10	113
P18	27	1.5	GI	31-40	83
P19	57	2	GI	31-40	83
P20	25	2	GI	10	113
P21	440	1.5	GI	10	113
P22	210	3	GI	10	113
P23	564	3	GI	26	90
P24	111	1.5	GI	34	83
P25	75	1.5	GI	34	83
P26	118	1.5	GI	34	83
P27	68	1.5	GI	34	83

P28	240	1.5	GI	34	83
P29	270	1.5	GI	34	83
P30	160	1.5	GI	34	83
P31	29	2.5	GI	34	83
P32	85	2.5	GI	34	83
P33	32	1.5	GI	34	83
P34	57	2.5	GI	34	83
P35	4	2.5	GI	34	83
P36	77	1.5	GI	34	83
P37	114	2.5	GI	34	83
P38	32	1.5	GI	34	83
P39	68	2.5	GI	34	83
P40	232	2	GI	10	113
P41	310	2.5	GI	10	113
P42	179	2.5	GI	26	90
P43	160	1.5	GI	26	90
P44	51	2.5	GI	26	90
P45	230	2	GI	26	90
P46	168	2	PVC	10	150
P47	585	2	GI	21-26	90
P48	72	2	GI	21-26	90
P49	112	2	GI	21-26	90
P50	342	2	GI	26	90
P51	406	2	GI	26	90
P52	107	2	GI	26	90
P53	42	2	GI	26	90
P54	45	2	GI	16	100
P55	335	2	GI	16	100
P56	46	2	GI	16	100
P57	68	1.5	GI	16	100
P58	148	1.5	HDPE	10	140

P59	58	1.5	HDPE	10	140
P60	125	1.5	GI	16	100
P61	148	1.5	GI	16	100
P62	94	1.5	GI	16	100
P63	60	1.5	GI	16	100
P64	65	1.5	GI	16	100
P65	194	0.75	GI	16	100
P66	205	1.5	GI	16	100
P67	32	0.75	GI	16	100
P68	146	1	GI	16	100
P69	110	1	GI	16	100
P70	80	1	GI	16	100
P71	30	1	HDPE	16	140
P72	125	1	GI	16	100
P73	92	1.5	HDPE	16	140
P74	49	1.5	PVC	16	150
P75	37	1.5	HDPE	16	140
P76	217	1.5	HDPE	16	140
P77	107	1.5	HDPE	16	140
P78	217	1	HDPE	16	140
P79	58	1.5	GI	11 - 20	100
P80	193	1.5	GI	11 - 20	100
P81	232	2	PVC	11 - 20	150
P82	70	2	PVC	11 - 20	150
P83	53	2	PVC	11 - 20	150
P84	96	2	PVC	11 - 20	150
P85	60	1.5	GI	11 - 20	100
P86	175	1.5	GI	11 - 20	100
P87	178	2	PVC	11 - 20	150
P88	84	1.25	GI	11 - 20	100
P89	32	1.25	GI	11 - 20	100
P90	55	1.25	GI	11 - 20	100
P91	94	0.75	GI	11 - 20	100
P92	40	0.75	GI	11 - 20	100

P93	60	1	PVC	11 - 20	150
P94	21	1	PVC	11 - 20	150
P95	100	1.5	GI	11 - 20	100
P96	16	1.5	HDPE	11 - 20	140
P97	37	1.5	HDPE	11 - 20	140
P98	48	1.5	HDPE	11 - 20	140
P99	51	1.5	GI	21 - 30	90
P100	80	1.25	GI	21 - 30	90
P101	71	1.5	GI	21 - 30	90
P102	8	1.5	GI	21 - 30	90
P103	115	1.5	GI	21 - 30	90
P104	100	1.5	GI	21 - 30	90
P105	12	1.5	GI	21 - 30	90
P106	11	1	GI	21 - 30	90
P107	73	2	PVC	21 - 30	150
P108	136	1.5	PVC	21 -30	150
P109	135	3	GI	21 -30	83
P110	3	3	GI	21 -30	83
P111	587	3	GI	21 -30	83
P112	31	3	GI	21 -30	83
P113	40	1.5	GI	21 -30	83
P114	29	1.5	GI	21 -30	83
P115	318	1.5	GI	21 -30	83
P116	110	2	GI	21 -30	83
P117	69	2	GI	21 -30	83
P118	241	1.5	GI	21 -30	83
P119	165	1.5	GI	11 20	100
P120	159	1.5	GI	31 – 40	83
P121	68	1.5	GI	31 – 40	83
P122	61	1	GI	31 – 40	83
P123	200	0.75	GI	31 – 40	83
P124	22	1	GI	31 – 40	83
P125	125	1	GI	31 – 40	83
P126	101	1.5	GI	31 – 40	83

P127	53	1.5	GI	31 – 40	83
P128	217	1	GI	31 – 40	83
P129	14	1.5	GI	31 – 40	83
P130	100	1.5	GI	31 – 40	83
P131	70		GI	31 – 40	83
P132	60	3	GI	31 – 40	83
P133	37	3	GI	21 – 30	90
P134	30	3	GI	31 – 40	83
P135	125	1.5	GI	31 – 40	83
P136	80	1.5	GI	31 – 40	83
P137	169	1.5	GI	31 – 40	83
P138	106	1.5	GI	31 – 40	83
P139	180	1.5	GI	31 – 40	83
P140	53	1.5	GI	31 – 40	83
P141	220	1.5	GI	31 – 40	83
P142	55	1.5	HDPE	11 20	140
P143	60	1.5	HDPE	11 20	140
P144	61	1.5	HDPE	11 20	140
P145	37	1.5	GI	31 – 40	83
P146	180	1	GI	31 – 40	83
P147	201	1	GI	31 – 40	83
P148	145	2	GI	31 – 40	83
P149	57	1	GI	31 – 40	83
P150	114	1	GI	31 – 40	83
P151	275	1.5	GI	31 – 40	83
P152	60	1.5	GI	31 – 40	83
P153	201	1.5	GI	31 – 40	83
P154	37	1.5	HDPE	11 - 20	140
P155	70	1.5	GI	11 - 20	100
P156	55	1.5	GI	11 - 20	100

Appendix 7 Figures of the boreholes, pumps

Same of different kind of pumps of the study area

Researcher on the time of field data gathering

Some of Boditi Town Water servitce office workers and operator when field data gathering