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GRADUATE STUDIES PROGRAMS

Assessment of Water Supply Service Provision Limitations and Its Effects in Case of Masha Town, SNNPR, Ethiopia

Thesis on the Degree of Master of Science in Civil and Environmental Engineering

(Major in Water Supply and Environmental Engineering)

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Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirement for the Degree of Master of Science

In

Civil and Environmental Engineering
(Major In water supply and Environmental Engineering)

Approved By Board of Examiners

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DECLARATION

I hereby declare that this submission on title "**Assessment of Masha Town Water Supply Service Provision Limitations and its Effects in Order to Distinguish Ways to Enhance the Service Level**" is my original thesis work and it is not contains material previously published by another person nor which has been accepted for the award of any other academic degree of the University, except I have been used and where due acknowledgement has been made and cited in the reference part of this work.

KUMLACHEW DAKITO GUCHETO

Signature --------------------------------

July, 2019 G.C.

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ABSTRACT

The study focused on the assessment of water supply service provision limitations and its effects in Masha town of south western Ethiopia. In the town, piped water service unavailability and quality was common issues to water users. On the other hand, topography of Masha town is undulating and equity in water service was under question. The study mainly aimed to assess the existing situation of the service, water sources for domestic activities, perception for the low-quality piped water and evaluating the service based on key physiochemical parameters and pressure. Existing water service were assessed based on site visits checklists, questionnaires and interviews of service providers. Out of total 4586 households in the town sample size of 100 were selected using standard procedures. Water quality sample was tested at different locations in water supply system from source to point of supply using photometer, pocket colorimeter and PH meter apparatuses. Pressure of water service in the town were modeled using Water GEMs which was calibrated by actual measured pressure data. The study indicates that existing estimated demand of water for the town was 1477.31 m^3/day and designed capacity of existing water supply system was 803.52 m^3/day (54.39 % of current demand). Existing water production amount was 33% of total production capacity and only 15.56% of total capacity were pumped to central reservoir. The cause for limited service capacity were found to be inefficient institutional capacity of service providers that leads to inappropriate operation and maintenance. The socioeconomic analysis result depicted that all of households were dissatisfied with piped water service and its primary common cause were service unavailability (66 %) and degraded water quality (33%). Water quality test result of the town showed that average concentration of Fe, Mn, PH and Free Cl_2 were 1.430 mg/l, 0.005mg/l, 7.48 and zero respectively. Iron (Fe) was found far high above recommended value of 0.3 mg/l that makes the piped water to be in a very high-risk category. As the model result showed that pipe water pressure was very low in some areas of the town like center of the town where high vertical development was undergoing. Therefore, water supply service of the town has limitations on water quality, availability and equity in the town due to inefficiency of treatment plant and institutional capacity of service providers. The service states has high risk for piped water users and needs water safety planning, household water level treatment practice, upgrading treatment plants and zonal supply for low pressure areas.

Keywords: Water Quality, Masha Town, Water GEMS, Pressure Zone, Piped Water, Photometer.

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ACRONYMS

ADF	African Development Fund
AMCOW	African Ministers' Council on Water
DEM	Digitized Elevation Maps
EPA	United States Environmental Protection Agency
ESA	Ethiopian Standard Agency
IWS	International Water Association
JMP	Joint Monitoring Program
JTU	Jackson Turbidity Unit
MDG	Millennium Development Goal
MoWR	Ministry of Water Resources
NTU	Nephelometric Turbidity Unit
PASDEP	Plan for Accelerated and Sustainable Development to End Poverty
SMCL	Instituted Secondary Maximum Contaminant Levels
UAP	Universal Access Plan
UN	United Nations
UNICEF	United Nations Children's Fund
TCU	True Colour Unit
WHO	World Health Organization
WSP	Water Supply Provision

CHAPTER ONE

1. INTRODUCTION

1.1 General Background

The sustainable provision of adequate and safe drinking water is the most important of all public services. It is one of the essential necessities of life next to oxygen. Anything that disturbs the sustainable provision and supply of water therefore, tends to disturb the very survival of humanity. Former UN Secretary General Kofi Annan once said, "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 creations of water" (Informer, 2010). Thus "All peoples, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of a quality equal to their basic needs".

Having access to safe water is something no human being should be without. Previous estimates state that there are two billion people in the world who lack access to safe drinking water (Onda, Buglio, and Bartram 2012). The implications of drinking unsafe, contaminated water are numerous and still not fully understood. Drinking microbial contaminated water leads to diarrheal diseases, such as cholera. Each year about 760,000 children under the age of five die from diarrheal disease and it is the second leading cause of death in children (WHO, 2014).

The 844 million people who lacked a basic drinking water service in 2015 either used improved sources with water collection times exceeding 30 minutes (limited services), used unprotected wells and springs (unimproved sources), or took water directly from surface water sources. Previous JMP analysis has shown that water collection from unimproved sources and surface water is more likely to take over 30 minutes, representing a double burden.11 Women and girls are responsible for water collection in 8 out of 10 households with water off premises, so reducing the population with limited drinking water services will have a strong gender impact. Of the 10 countries where at least 20 per cent of the national population uses limited services, eight are in sub-Saharan Africa and two are in Oceania. (JMP, 2017)

To provide safe water national targets for Ethiopia are embedded in the Universal Access Plan (UAP), an ambitious national plan launched by the Government of Ethiopia in 2005 with the objective of achieving full access to water supply and sanitation for all Ethiopians by 2012. Following the update of the Plan for Accelerated and Sustainable Development to End Poverty (PASDEP-2) in 2010, these targets were adjusted slightly, and the target date extended to 2015. (AMCOW, 2015)

Even though much was worked on the sector a report by the Central Statistical Agency of Ethiopia in Collaboration with the Ministry of Water, Irrigation and Electricity (MOWIE), World Bank, UNICEF, WHO, and JMP (2017) indicated that 66 percent of the Ethiopian population uses drinking water from improved sources, with distribution varying by place of residence. In rural areas, 59 percent of the population reported using an improved source, usually protected springs, tube wells, and dug wells. Source type also differs by region; almost all households in Addis Ababa and 72 per cent in Tigray reported using improved sources.

Like many other towns in Ethiopia, provision of improved water supply has been a problem in Masha town for a long time and government has been constructing different water supply schemes to solve the problem. Masha town had been getting water service from Wonani, Abelo and Ateso well fields in different time before construction of Wonani water supply treatment plant. Because of high iron contents and frequent failure of electromechanical units of former schemes the treatment plant was constructed and serving by treating the town since 2007 G.C. Because of establishment of institutes and large investments in and around Masha town number of population in the town is highly increasing, demand for the service has raised. Also the town is expanding laterally not accompanied by water supply distribution lines.

In Masha town water can be withdrawn from unprotected hand dug wells from shallow depth even from three to four meters depending on the topography of the well location and can serve all the time for long years. In addition there are perineal rivers crossing the town in different locations and springs in and around territory of the town. Because of easily availability of unimproved water sources in the town, improved water source need to be efficient in access, quality, availability and affordability to be preferred.

1.2 Statement of the Problem

The provision of adequate and reliable water supply in developing countries is becoming a challenge for most water utilities especially public service providers. Water demand has been increasing drastically in these countries due to many factors including population growth as a result of rural to urban migration. As a consequence, in many countries public service utilities have failed to provide consumers with adequate water supply and sanitation services. Apart from service coverage, there are other problems that affect public service providers such as high Unaccounted for Water and financial problems due to a combination of low tariff, poor services, poor consumer records and inefficient billing practices (Victor Kimey, 2008).

As Central Statistical Agency of Ethiopia (2017) report of national study shows that 14 percent of the population collected water from low-risk sources (no detectable E. coli), but 37 percent collected water from very-high-risk supplies. Water from improved sources had about 10 times better quality (20 percent low-risk) than that collected from unimproved sources (2.2 percent low-risk). Water quality was better in large towns (46 percent low-risk) and worse in rural areas (8.4 percent low-risk). The best water quality was in the Addis Ababa region (85 percent low-risk), and the worst in SNNPR (7.2 percent low-risk). Water quality was best in bottled water (53 percent low risk), but this was reported as the main source of drinking water by less than 1 percent of the population. Piped water on premises, used by 14 percent of the population, had relatively good water quality, with 42 percent low risk, and just 8.6 percent very-high-risk. Water collected from kiosks or retailers was typically of good quality (27 percent low-risk) but not widely used. Very-high-risk water was most commonly collected from unimproved sources (69 percent), especially surface water (85 percent) and unprotected dug wells (76 percent).

As study conducted by Water Aid in year 2014 showed that due to its aesthetic conditions people was discouraged to use water with iron contents. 7% of the total sample size of 1,619 and 15% of SNNPR samples are with iron content above the standard as indicated in the report of (WHO & UNICEF, 2010).

Currently there is water supply service for Masha town from treated river water source. The service was limited only in some areas of the town due to limited distribution systems and rapid lateral expansion of the town not supported by water supply infrastructures. Masha town municipality was leasing land totally without providing with infrastructures like water supply pipe lines. Because of establishment of collages and large agro investments within the Woreda, like Haile- Coffee Plantation and East African Tea Plantation, population of the town has highly increased. The topography of the town is undulating and water availability in some areas of the town is under question. In the town there are some peak areas with nearer altitude with reservoir elevation and mostly the areas were not getting sufficient water from the system. The quality of water is also doubtful due to its color and it is common complaints of water users about the service. Because of the pipe water quality people in the town are going far to fetch water from unprotected springs situated at different areas of the town. In addition to this there are number of unprotected hand dug wells in the town where people were fetching water. Ground water level of the area is in shallow depth and water can be reached starting from near four meters depth and most people have access to these sources.

Water supply problem of Masha town differs from most others because of easily availability of these unprotected water sources that are experienced for a long period by users and service provision problem of piped water was sensitive to change water use of the people. Due to this improved water service of the town should be efficient in water quality, availability and affordability.

As Mash town health report of year 2017/18 indicated that Typhoid Fever was the most common disease register in the town next to respiratory Infection. There were also high number of children affected by Diarrheal disease in the town.

Construction of water supply system alone cannot improve the water use of targeted people without proper operation, maintenance and quality control. Existing water supply source of the town is coming to end its design period after few years but no researches were conducted on performance and its service provision. Therefore, assessing water supply services of the town is required to understand the states of existing service, the source of water service limitations and its effects to provide technical and managerial measures to solve the problems. Basically it will provide background information for appropriate design to be considered and sustainable management of new water supply that will be constructed in the near future.

1.3 Objective of the Study

The study aims to assess existing situation of Masha town water service provision problems and its effects so as to show ways to improve the existing water use in town.

The Specific Objectives are:

- To assess current piped water supply service situation of Masha town.
- To identify different Water sources for domestic activities and perception of users for piped water service in Masha town.
- To evaluate pipe water service based on spatial variation of supply pressure and key physicochemical parameters.

1.4 Research Questions

In order to achieve the above mentioned research objectives and seek answers for the stated objectives the following major research questions are designed.

1) What are the current urban water demand, system capacity and service provision level of the town? Is the system serving with full possible potential? How is it operated, and maintained?
2) What are water sources for domestic use in the town? What is perception of consumers about improved water service?
3) How is the service varying spatially interims of supply pressure, free chlorine Content, Fe and Mn content in the town? Which areas of the town have service limitation with the criteria?

1.5 Significance of the Study

Since the research focused on evaluating water supply and service condition in Masha town, it is expected to increase the knowledge and up to date information on limitations of water supply service provision in the town. Therefore, it helps to know appropriate measures that will be taken to improve the existing service level, quality and gaps that will be filled in service provision. River source and distributed water Fe content determination may help to know the cause for esthetic problem compliance and will provide information to designers for appropriate unit designs. It also provide ways to water use improvements of the town and point out research areas to be conducted in some specific issues of the town. It will also serve as a ready working document to policy makers in the water sector, the Non-Governmental Organizations (NGOs), the community and environmental advocates.

1.6. Scope of the Research

This research was mainly focused on the assessment of piped water service and its limitations in Masha town. Water qualities parameters that can be tested in field like Mn, Fe PH and Free chlorine was only included because of time and budget limitations for the study and distance of the study area from laboratory. Household sample size was also calculated accepting ten percent error to manage with available resource. Modeling software were also considered among easily available and commonly used that never requires long time training and high budget. The study area was limited to Masha town and water services of domestic only. The effect of service limitations on commercial sectors were important but it was excluded. The quality of water variations are seasonal and can be affected by maintenance of treatment units and the study never considered the case.

1.7. Structure of the Thesis

Chapter 1: in first chapter the back ground of water supply service provision problems were described from global to specifically study area. Statements of the problem, general objective, specific objectives, and scope and limitation of the research were explained and set in the chapter.

Chapter 2: it includes literature review on water service limitations, requirement of efficient water service, guideline values for physiochemical and bacteriological water qualities. The effect of iron and manganese in water and modeling software were reviewed in the chapter to select for the study.

Chapter 3: methods and material used, sampling techniques, description of the study area in detailed and samples location points of study area were explained.

Chapter 4: it includes the result and discussion of existing situation of piped water service in the town, water quality test result, household survey and modeling of existing system in detailed.

Chapter 5: It includes the conclusion and recommendations of the research.

CHAPTER TWO

2. LITERATURE REVIEW

Issue of safe water is burning and global. Due to this for improvement of water service improvement different researches has been conducting and also new techniques are developed to evaluate system performances. The literature review encompasses the result of various studies, available standards and guide lines to examine the study problem.

2.1 Definition of Some Key Terms

An improved drinking water source- it is defined as a type of drinking water facility or water delivery point that by the nature of its design protects the drinking water source from external contamination, particularly or faecal origin and which can be piped into dwelling, plot or yard, public tap/stand pipe, tube well/borehole, protected dug well, rain water collection and protected springs (Van Norden 2007 as cited by Sutton, 2008).

Access to Water: in urban areas a distance of not more than 200 meters from a home to public stand post may be considered reasonable access. In rural areas, reasonable access implies the person does not have to spend a disproportionate part of the day fetching water for the family's needs.

Basic Service: Drinking water from an improved source, provided collection time is not more than 30 minutes for a round trip, including queuing. (JPM, 2017)

Domestic water supply- WHO defines domestic water as being 'water used for all usual domestic purposes including consumption, bathing and food preparation' (WHO, 2002).

Maintenance involves (a) scheduled or planned activities under normal operating conditions to maintain operational systems, equipment and assets essential to supplying safe water to consumers (including the catchment, raw water storage, abstraction, treatment, distribution and customer interface); and (b) unscheduled activities during unforeseen or emergency situations to bring the water supply system back to normal operating conditions. Most maintenance activities require engagement of operational personnel.

Operations refers to the day-to-day "running" of a water supply system under normal or emergency conditions.

Safely Managed; drinking water from an improved water source that is located on premises, available when needed and free from fecal and priority chemical contamination. (JPM, 2017)

Safe Water: water that does not contain biological or chemical agents directly detrimental to health. It includes treated surface water and untreated but uncontaminated water from protected springs, bore holes, sanitary wells, etc.

2.2 Need for Improved Water Supply

Access to water is a prerequisite for health and livelihood, which is why the MDG target is formulated in terms of sustainable access to affordable drinking water supply. The availability of improved and quality water supply and sanitation infrastructures are widely recognized as an essential component of human rights, social and economic development (ADF, 2005).

Access to safe drinking-water is important as a health and development issue at a national, regional and local level. In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit, since the reductions in adverse health effects and health care costs outweigh the costs of undertaking the interventions. This is true for major water supply infrastructure investments through to water treatment in the home. Experience has also shown that interventions in improving access to safe water favor the poor in particular, whether in rural or urban areas, and can be an effective part of poverty alleviation strategies. (WHO, 2006)

Access to safe drinking-water is essential to health, a basic human right and a component of effective policy for health protection. The importance of water, sanitation and hygiene for health and development has been reflected in the outcomes of a series of international policy forums. This includes, most recently, the adoption of the Sustainable Development Goals by countries, in 2015, which include a target and indicator on safe drinking-water. Further, the United Nations (UN) General Assembly declared in 2010 that safe and clean drinking-water and sanitation is a human right, essential to the full enjoyment of life and all other human rights. These commitments build on a long history of support including the UN General Assembly adopting the Millennium Development Goals in 2000 and declaring the period 2005–2015 as the International Decade for Action, “Water for Life”. (WHO, 2017)

The human right to water specifies that water should be "available continuously and in a sufficient quantity to meet the requirements of drinking and personal hygiene, as well as of further personal and domestic uses, such as cooking and food preparation, dish and laundry washing and cleaning… Supply needs to be continuous enough to allow for the collection of sufficient amounts to satisfy all needs, without compromising the quality of the water."

2.3 Requirements to Improved Water Source

The new JMP service ladders build on the established improved/unimproved facility type classification, thereby providing continuity with past monitoring, and introduce new rungs with additional criteria relating to service levels. Improved drinking water sources are those which, by nature of their design and construction, have the potential to deliver safe water. The JMP subdivides the population using improved sources into three groups according to the level of service provided. In order to meet the criteria for a safely managed drinking water service, people must use an improved source meeting three criteria:

- it should be accessible on premises,
- water should be available when needed, and
- the water supplied should be free from contamination.

Figure 2-2-1: diagram describing criteria for safely managed service (JMP, 2017)

Drinking water, or potable water, is defined as having acceptable quality in terms of its physical, chemical, bacteriological parameters so that it can be safely used for drinking and cooking (WHO, 2004). WHO defines drinking water to be safe if and only if no any significant health risks during its lifespan of the scheme and when it is consumed.

The quantity of available supply must be such that the maximum daily demands of the community are satisfied at all times, even during extended periods of drought or after years of community growth. The water supply for most communities not only needs to meet consumer demand but it needs to meet needed fire-flow demand where fire hydrants are installed for the protection of built areas of the community. The same water that supplies domestic taps also supplies fire hydrants, unless there is a separate water system for fire protection. (Harry, 2008)

Design of water supply systems is usually based on the assumption that water supply is continuous. However, hydraulic and operating conditions change in an intermittent supply. Intermittent water supply generates pressure losses and high inequity in water distribution; e.g. when water demand is high, users further away from the supply points are the most affected because they cannot be supplied with a sufficient amount of water during the early delivery hours. If intermittent water supply is not well planned, it results in supply water inequity for users (Vairavamoorthy et al., 2008).

2.3.1 Availability

The quantity of water collected and used by households has an important influence on health. There is a basic human physiological requirement for water to maintain adequate hydration and an additional requirement for food preparation. There is a further requirement for water to support hygiene, which is necessary for health. Estimates of the volume of water needed for health purposes vary widely. In deriving World Health Organization (WHO) guideline values, it is assumed that the daily per capita consumption of drinking-water is approximately 2 litres for adults, although actual consumption varies according to climate, activity level and diet. Based on currently available data, a minimum volume of 7.5 liters per capita per day will provide sufficient water for hydration and incorporation into food for most people under most conditions. In addition, adequate domestic water is needed for food preparation, laundry and personal and domestic hygiene, which are also important for health. Water may also be important in income generation and amenity uses. (WHO, 2017)

While drinking water should be available in sufficient quantities at all times, it is unlikely that in the short term all countries can attain that level of service. Where services are unreliable or intermittent, households typically store water to ensure that it is available when needed. They may also restrict their consumption when water sources are far away, available only for a few hours a day or at certain times of the year, or out of service.

The availability and sufficiency of drinking water, regardless of quality, is higher for unimproved sources, and thus for rural areas. In urban areas, over half of households reported that water had been unavailable at some time during the previous two weeks or insufficient during the preceding month. (CSAE, 2017)

2.3.2 Accessibility

From the public health standpoint, the proportion of the population with reliable access to safe drinking-water is the most important single indicator of the overall success of a drinking-water supply programme. There are a number of definitions of access (or coverage), many with qualifications regarding safety or adequacy. Access to safe drinking-water for the Millennium Development Goals is currently measured by the WHO/ United Nations Children's Fund (UNICEF) Joint Monitoring Programme for Water Supply and Sanitation through a proxy that assesses the use of improved drinking-water sources by households. An improved drinking-water source is one that by the nature of its construction and design adequately protects the source from outside contamination, in particular by faecal matter. (WHO, 2017)

The reliable supply of safe drinking water is fundamental to a healthy community and to its economic development and access to good, safe drinking water should be the right of every human and hence sustainable water supply service provision and problems related to the sector should be supported by researches.

UNICEF (2010) reports that in 2010, 884 million people in the world use an unimproved drinking water source, and later it has been estimated that in 2015, 672 million people have been using an unimproved drinking water source. The people most vulnerable to water-borne diseases are those who use an unsafe drinking water source. Throughout the less developed world, the proportion of households that use an unclean drinking water source has declined, but it is extremely unlikely that all households will have a clean drinking water source in the foreseeable future (Mintz et al. 2001).

Accessibility is a criterion for both "basic" and "safely managed" drinking water services. Because the JMP uses travel time as an indicator of accessibility, it is collected routinely in national household surveys and censuses. Accessibility is measured by the time taken to collect water. Nationally, 74 percent of the population reported taking 30 minutes or less to collect drinking water; 19 per cent use a source located on the premises in Ethiopia. The time burden of collection is greater for those using unimproved sources and for residents of rural areas. The burden of collection does not fall equally on all household members – women and younger members of the household spend more time collecting water. (CSAE, 2017)

2.3.3 Affordability

The affordability of water has a significant influence on the use of water and selection of water sources. Households with the lowest levels of access to safe water supply frequently pay more for their water than do households connected to a piped water system. The high cost of water may force households to use alternative sources of water of poorer quality that represent a greater risk to health. Furthermore, high costs of water may reduce the volumes of water used by households, which in turn may influence hygiene practices and increase risks of disease transmission. When assessing affordability, it is important to collect data on the price at the point of purchase. Where households are connected to the drinking-water supplier, this will be the tariff applied. Where water is purchased from public standpipes or from neighbours, the price at the point of purchase may be very different from the drinking-water supplier tariff. Many alternative water sources (notably vendors) also involve costs, and these costs should be included in evaluations of affordability. In addition to recurrent costs, the costs for initial acquisition of a connection should also be considered when evaluating affordability. (WHO, 2017)

2.3.4 Continuity

Interruptions to drinking-water supply, either because of intermittent sources or resulting from engineering inefficiencies, are a major determinant of the access to and quality of drinking water. Any interruption of service is likely to result in degradation of water quality, increased risk of exposure to contaminated water and therefore increased risk of waterborne disease. Daily or weekly discontinuity results in low supply pressure and a consequent risk of in-pipe recontamination. Other consequences include reduced availability and lower volume use, which adversely affect hygiene. Household water storage may be necessary, and this may lead to an increase in the risk of contamination during such storage and associated handling. Seasonal discontinuity often forces users to obtain water from inferior and distant sources. As a consequence, in addition to the obvious reduction in quality and quantity, time is lost in water collection. (WHO, 2017)

2.3.5 Water Quality

There are different physic-chemical and bacteriological elements for water quality standards. The physic-chemical determinants can result naturally from rock types, human exercises like effluent releases/leakage from different sources, agricultural chemical practices with runoff, industrial pollutants and pathogenic contaminations. The level and concentration of these different elements would have a positive or negative health impact and economic effect. Water construction materials damage also ends up with indirect health impacts. Therefore, water quality is one of the service levels factor contributing to a positive public health benefits. (Water Aid Ethiopia, 2014)

Water quality concerns are often the most important component for measuring access to improved water sources. Acceptable quality shows the safety of drinking water in terms of its physical, chemical and bacteriological parameters (WHO, 2004). User communities" perceptions of quality also carry great weight in their drinking water safety. Depending on their perception on taste, odor and appearance, this can lead to having different opinions about the aesthetic values of water quality. Consumer perceptions and aesthetic criteria need to be considered when assessing drinking water supplies even though they may not adversely affect human health (WHO, 2004).

Physical and Aesthetic Aspects

The chemical and physical quality of water may affect its acceptability to consumers. Turbidity, colour, taste, and odour, whether of natural or other origin, affect consumer perceptions and behaviour. In extreme cases, consumers may avoid aesthetically unacceptable but otherwise safe supplies in favour of more pleasant but less wholesome sources of drinking-water. Although guidelines for drinking-water quality are based on the best available public health advice, there is no guarantee that consumers will be satisfied or dissatisfied by water supplies that meet or fail to meet those guidelines. It is therefore wise to be aware of consumer perceptions and to take into account both health-related guidelines and aesthetic criteria when assessing drinking-water supplies.

- Turbidity in excess of 5 NTU (5 JTU) may be noticeable and consequently objectionable to consumers.
- Colour in drinking-water may be due to the presence of organic matter such as humic substances, metals such as iron and manganese, or highly coloured industrial wastes. Experience has shown that consumers may turn to alternative, perhaps unsafe, sources, when their water displays aesthetically displeasing levels of colour, typically exceeding 15 TCU. Drinking-water should ideally be colourless.
- Odour in water is due mainly to the presence of organic substances. Some odours are indicative of increased biological activity, while others may originate from industrial pollution. Sanitary surveys should include investigations of sources of odour when odour problems are identified.

The combined perception of substances detected by the senses of taste and smell is often called "taste". "Taste" problems in drinking-water supplies are often the largest single cause of consumer complaints. Changes in the normal taste of a public water supply may signal changes in the quality of the raw water source or deficiencies in the treatment process. Water should be free of tastes and odours that would be objectionable to the majority of consumers. (WHO, 1997)

Microbiological Aspects

Ideally, drinking-water should not contain any microorganisms known to be pathogenic capable of causing disease or any bacteria indicative of faecal pollution. To ensure that a drinking-water supply satisfies these guidelines, samples should be examined regularly. The detection of *Escherichia coli* provides definite evidence of faecal pollution; in practice, the detection of thermotolerant (faecal) coliform bacteria is an acceptable alternative. (WHO, 1997)

Chemical Aspects

In rural areas of developing countries, the great majority of health-related water quality problems are the result of bacteriological or other biological contamination. Nevertheless, a significant number of very serious problems may occur as a result of the chemical contamination of water resources. Some potentially chronic effects may occur in rural areas where overuse of agrochemicals leads to significant levels of pesticides in water sources.

National Water Quality Standards of Ethiopia

To ensure access to safe drinking water, the Compulsory Ethiopian Standard for Drinking Water Specification (CES58) outlines the physical, chemical, and bacteriological requirements for water for drinking and domestic purposes. Aligned with the new SDG targets, it defines quality and safety standards that conform to all the toxic, bacteriological, and organoleptic requirements.

Ethiopian standard specifies the physical, chemical and bacteriological requirements of water for drinking and domestic purpose for some of the parameters are as indicated in the table 1 below.

Table 2-1**:** Characteristics that affect the palatability of drinking water

Substance or Characteristic	**Maximum Permissible**	**Test Method**
1. Physical Requirements		
Odour	Unobjectionable	ES605
Taste	Unobjectionable	
Turbidity, NTU	5	ES ISO 7887
Colour, TCU	15	ES ISO 7027
2. Chemical Requirements		
Total hardness (as $CaCO_3$)	300	ES 607
Total dissolved solids mg/L, max	1000	ES 609
Total Iron(as Fe) mg/L, max	0.3	ES ISO 6332
Manganese (as Mn) mg/L, max	0.5	ES ISO 7150-2
PH Value	6.5-8.5	ES ISO 10523
Residual, Free chlorine mg/L, max	0.5	ES ISO 7875-1`
3. Bacteriological level		
Total viable organisms, colonies per ml	Must not be detectable	ES ISO 4833
Coliform organisms , number/100ml	Must not be detectable	ES ISO 9308-1
E. Coli, number per 100 ml	Must not be detectable	ES ISO 9308-1

Source: ESA (2013).

2.4 Problems Related to Water Supply Service Provision

Of the 2.1 billion people lacking safely managed drinking water services in 2015, 1.3 billion used basic services, 263 million used limited services, 423 million used unimproved sources and 159 million used surface water**.** (WHO and UNICEF, 2017)

A unique aspect of water as a vehicle for transmitting disease is that a contaminated water supply can rapidly expose a large number of people. When food is contaminated with a pathogen, tens to hundreds of persons are commonly infected. If a large, centralized food-packaging facility is involved, thousands might be infected. However, when drinking water is contaminated with a pathogen, typically hundreds of people are infected and occasionally hundreds of thousands are infected. For example, it is estimated that 500,000 people became ill from contaminated drinking water in the 1993 Milwaukee Cryptosporidium incident (MacKenzie et al., 1994).

As indicated by ADF (2005), over one third of women in some of the regions spent more than two hours for each water collection trip. This fact is aggravated by the poor supply efficiency, resulting from bad condition, which cannot satisfy the entire populations from different villages sharing the same water source and increased queuing time is common during the dry seasons (Admasu et al., 2002). This will ultimately lead to household water insecurity (less water available than is needed for drinking, cooking, and sanitation) in rural areas, especially for those households for which the demand is higher due to large family size (Collick, 2008, as cited by Demeke, 2009). Because of these conditions, it is difficult to think about personal hygiene and sanitation especially for the rural communities. Despite the scarcity of water, many give priority for drinking and cooking purposes. Rural communities use unprotected springs and hand-dug wells commonly for cooking and drinking purposes. Whereas rivers besides their use for washing clothes they also used for drinking purposes.

During the GTP I period of Ethiopia, development and expansion of reliable water supplies to rural and urban areas were undertaken. According to GTP I standard, national potable water supply coverage recorded was 84%, with rural coverage being 82% and urban 91% in 2014/15 (GTP I standard: rural 15 l/c/d within 1.5km radius, urban 20 l/c/d, within 0.5 km radius). However, according GTP II standard (rural; 25 l/c/d within 1km radius, Urban: based on demand categories1 of 100, 80, 60, 50 and 40 l/c/d from the highest to the lowest level, respectively) the rural, urban and national level water supply coverage were estimated as 59%, 51% and 58% respectively. This result shows that the countries water supply access lagged behind. (NPC, 2016)

Water's crucial role in accomplishing the Africa's development goals is widely recognized. Africa faces endemic poverty, food insecurity and pervasive underdevelopment, with almost all countries lacking the human, economic and institutional capacities to effectively develop and manage their water resources sustainably. Thus, a large number of countries on the continent still face huge challenges in attempting to achieve the United Nations water-related Millennium Development Goals (MDGs). Northern Africa and Sub-Saharan Africa even though in one continent, have made different levels of progress towards the Millennium Development Goal on water (Yewondwossen, 2012). North Africa has 92% coverage and is on track to meet its 94% target before 2015. However, Sub-Saharan Africa experiences a contrasting case with 40% of the 783 million people without access to an improved source of drinking water from the region. Sub-Saharan Africa is off track from meeting the MDG on water with just 61% water coverage and with the current pace cannot reach the 75% target set for the region (Richard, 2009).

Additionally, diarrheal disease weakens the immune system leading to higher risk of other diseases as well. There are also a number of other diseases, such as guinea worm, which are transmitted through contact with contaminated water when people use contaminated surface waters for drinking and washing. Further, high frequency of diarrheal episodes in children leads to environmental enteropathy which is the decreased ability of the intestine to absorb nutrients. This leads to malnutrition which has even more implications such as stunting and decreased intelligence (Korpe and Petri 2012). Overall, having access to safe drinking water is a major factor in preventing deaths and improving quality of life for low-income households around the world.

The time taken to collect water, being sick, or looking after those who are sick, puts a huge drain on family resources (Mathew, 2005). Children could spend the time attending school and parents could be spending more time with their families or being more economically productive. Dignity robbed and pain caused by lack of adequate and private sanitation can lead to poor self-esteem, especially for women (Mathew, 2005). These effects can trap people in a cycle of poverty from which it can be difficult to escape.

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

These factors lead to less access to water needed by the household for consumption and forced households to seek out alternate unimproved and unhealthy nearby water sources due to reluctance in using improved sources. It is common that people who are most vulnerable to water-borne diseases are those who use polluted drinking water sources. The WHO (2000) revealed that seventy five percent of all diseases in developing countries arise from polluted drinking water. The lack of access to water also limits sanitation and hygiene practices in many households because of the priority given for drinking and cooking purposes. Water quality concerns are often the most important component for measuring access to improved water sources. Acceptable quality shows the safety of drinking water in terms of its physical, chemical and bacteriological parameters. Depending on their perception on taste, odor and appearance, this can lead to having different opinions about the aesthetic values of water quality. Consumer perceptions and aesthetic criteria need to be considered when assessing drinking water supplies even though they may not adversely affect human health (WHO, 2004).

Strong operations and maintenance (O&M) programmes underpin the effectiveness and sustainability of any drinking-water supply system. Failure to adequately address O&M can bring serious consequences, including operational and/or infrastructural failures, contamination events and economic losses. Despite the critical role of O&M in the provision of safe and adequate drinkingwater supplies, basic O&M functions are often under-resourced – marked by undertrained staff and/or inadequate funding. In a recent global survey, half of the 75 responding countries indicated that tariffs were insufficient1 to recover O&M costs (UN-Water & WHO, 2017).

2.4.1 Iron and Manganese Occurrence in Water

Iron and manganese, which comprise 5% and 0.1% respectively of the earth's crust, are found widely distributed in both surface and ground waters in nearly all geographic areas. Dissolution of these elements occurs by various processes and results in a variety of conditions regarding the concentration and chemical forms in which they are found in water.

Iron and manganese are two common metals found in drinking water that cause aesthetic problems like metallic taste and staining of laundry and fixtures. Iron has never been attributed to health concerns; however recent studies have been conducted linking high manganese intake concentrations in humans to neurological problems. The United States Environmental Protection Agency (EPA) has instituted Secondary Maximum Contaminant Levels (SMCL) for both metals; the SMCL for iron is 0.3 mg/L and the SMCL for manganese is 0.05 mg/L**.**

When ferrous iron oxidizes to ferric iron, it can give a reddish-brown color to the water, which could be aesthetically displeasing (WHO, 2004). Manganese can cause an undesirable taste as well as staining laundry when levels exceed 0.1 mg/liter. The presence of manganese may also lead to the accumulation of deposits in the piping system (WHO, 2004). There is no health-based guideline value set for iron but for manganese it is four times higher than the acceptable threshold of 0.1 mg/liter (WHO, 2004).

In a surface water supply iron and manganese may be present due to their dissolution from the associated geologic formations and/or from the decomposition of organic materials. For example, anaerobic conditions on a reservoir bottom may cause the dissolution of iron and manganese from the bottom sediments. When seasonal overturns occur due to temperature gradients, this dissolved iron and manganese will be distributed throughout the water supply. Although increased levels of iron and manganese may occur during periods associated with overturns, it is also very likely that these elements will be found at objectionable concentrations throughout the year.

Iron is one of the most abundant metals in the Earth's crust. It is found in natural fresh water at levels ranging from 0.5 to 50 mg/litter. Iron may also be present in drinking - water as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status and iron bioavailability and range from about 10 to 50mg/day. (WaterAid, 2014)

Iron and manganese may also combine with organic matter in water to form chemical complexes that are difficult to remove and do not react readily with other chemicals in solution. Combined iron and manganese are often present in both dissolved and oxidized forms and must be detected using a specific laboratory analysis. If household water contains high levels of iron and manganese in both forms, a multistage treatment operation may be necessary. For example, the water supply could be aerated to oxidize the bulk of iron and manganese, then chlorinated to oxidize residual iron and kill iron bacteria, followed by activated carbon filtration to remove excess chlorine and iron and manganese particles.

2.4.2 Effect of High Concentration of Fe and Mn in Drinking Water

Fe and Mn have long been considered to only lead to aesthetic problems, in that they are secondary contaminants that have little or no adverse health effects. However, research conducted by Wasserman et al. (2006) indicated a relationship between increased Mn concentrations in drinking water and reduced intellectual functions of children. Increased levels of Fe and Mn concentrations have been found to be the main cause of drinking water discoloration (Slaats, 2002). Furthermore, discoloured water could also lead to coloured stains on laundries and sinks, increased treatment costs, reduced treatment capacity and increased pumping costs. Water with high concentrations of Fe and Mn has been found to give water an unpleasant metallic taste and vegetables cooked with it become dark and look unappetizing (Herman, 1996).

The causes of water discolouration can be attributed to several factors, most of which are interrelated. These include complex physical, chemical and/or biological processes. Linking the particles found in a WDN to a particular contamination source can be a very difficult task because of the numerous potential sources and the complex layout of a pipe network (Gauthier et al., 1999). There are a number of parameters that influence accumulation process of Fe and Mn. These parameters can be grouped into three categories: (a) chemical parameters representing the chemical reactions within a WDN; (b) biological parameters that aid the accumulation; and (c) physical parameters such as pipe material and network hydraulics.

A study by Seo et al. (1998) showed that the deterioration of drinking water is mainly caused by the corrosion of pipes in WDNs and the dissolved oxygen concentration is the main factor that caused increased corrosion. During corrosion, dissolved oxygen serves as an electron acceptor (eqn. 1), and it oxidises ferrous iron ($Fe2+$) (eqn. 2) or iron scales (eqns. 3 & 4), (McNeill, 2000)

$Fe_{(metal)} + 0.5O_2 + H_2O \rightarrow Fe^{2+} + 2OH^-$ (1)

$Fe^{2+} + 0.25\ O_2 + 0.5H_2O + 2OH^- \rightarrow\ Fe(OH)_{3\,(s)}$ (2)

$3FeCO_{3(s)} + 0.5O_2 \rightarrow Fe_3O_{4(s)} + 3CO_2$ (3)

$4Fe_3O_{4(s)} + O_2 \rightarrow 6Fe_2O_{3(s)}$ (4)

Iron and manganese are problematic in water due to their tendency to oxidize and precipitate as precipitate as insoluble oxides under a variety of conditions, causing both aesthetic and process water problems. In a potable water system iron and manganese frequently result in consumer complaints due to the metallic taste which they often impart to drinking water and beverages, and staining of laundry and porcelain fixtures. Even very low levels of iron may produce favorable conditions for the growth of what are commonly referred to as iron bacteria. These organisms, the most prevalent of which are Gallionella and Crenothrix, utilize energy obtained from the oxidation of ferrous to ferric iron to “fix” dissolved carbon dioxide into organic molecular necessary for their existence. The growth of these organisms, which can occur at phenomenal rates, will result in the formation of a gelatinous mat which may cause pipe encrustations and provide an environment for the production of odor- and taste-causing organisms. In addition, corrosion may occur due to the creation of a galvanic cell and the formation of corrosive by-products (e.g., sulfuric acid and hydrogen sulfide) from associated organisms.

2.4.3 Effect of Distribution System on Water Quality

Although water quality may be acceptable when the water leaves a community treatment plant, transformations can occur as water travels through a distribution system. In the past, water distribution systems were designed and operated mainly on the basis of hydraulic reliability and economics, with little attention paid to the water quality in the distribution system, except when serious problems arose from citizen complaints. This attitude has changed significantly as community water suppliers realize the important influence that time spent in a water distribution system, referenced as resident time, can have on water quality, health concerns, and the conditions of underground water mains.

In developing countries; many water authorities are facing the challenges in providing adequate water supply to the rapidly growing populations’. Thereby, most of the existing water supply systems are unable to meet the various demands of water. Beside to this; infrastructural aging problem, poor management of the existing system components/assets and utilities capacity shortages were increases the level of water losses in the distribution system (Welday, 2005; Jalal, 2008).

2.4.4 Bacteriological Water Quality and Disinfection

E. coli is a recommended indicator of fecal contamination of drinking water. The survey found that E. coli risk varies greatly by drinking water source and location. Nationally, 14 percent of the population gets water from low-risk sources (no detectable E. coli in a 100 mL sample). On the other hand, in Addis Ababa 85 percent of the on premise piped water is low-risk. Similarly, nationally about 42 percent of on premise piped water is low-risk. In general E. coli risk is lower for water from improved sources and in urban areas. The survey also found that E. coli levels are more likely to increase than decrease between collection and consumption within the home. E. coli levels were lower in households that reported treating water and in piped water that had medium or high levels of residual chlorine. In addition, fluoride levels exceeding the national standard (1.5 mg/L) affected 3.8 percent of the population. (CSAE, 2017)

Free chlorine residual was tested for water samples from piped supplies; moderate to high levels usually indicate that water has been adequately treated. Drinking water used by 14 percent of the households with piped water had moderate or high levels of residual chlorine. It was most common in Addis Ababa (28 percent with moderate levels), while no other region had enough moderate or high observations for adequate reporting. Households that had piped water on premises had higher chlorine residual (18 percent combined moderate and high) than other piped water sources. Conversely, an absence of chlorine could reflect water that has never been treated. Almost all household water from piped sources had low residual chlorine (82-97 percent by piped type), as was true for piped water in rural areas (98 percent) and small towns (92 percent). The study showed a reasonably high correlation between moderate to high chlorine levels and low E. coli risk. 75 percent of households using water with moderate and high residual chlorine were also classified as at low risk for E. coli compared to only 33 percent of households with low residual chlorine. Piped water samples with low residual chlorine were about evenly classified as at low, moderate, and high (combining both high and very high) E. coli risk. (CSAE, 2017)

Terminal disinfection is essential for surface waters after treatment and for protected groundwater sources when *E. coli* or thermotolerant (faecal) coliforms are detected. Chlorine in one form or another is the most commonly used disinfectant worldwide. For terminal chlorination, there should be a free chlorine residual of at least 0.5mg/ liter after a minimum contact time of 30 minutes at a pH of less than 8.0, as for inactivation of enteric viruses. When chlorine is used as a disinfectant in a piped distribution system, it is desirable to maintain a free chlorine residual of 0.2–0.5mg/litre throughout, to reduce the risk of microbial regrowth and the health risk of recontamination. In emergencies, e.g. in refugee camps, during outbreaks of potentially waterborne disease, or when faecal contamination of a water supply is detected, the concentration of free chlorine should be increased to greater than 0.5mg/litre throughout the system.(WHO,1997)

2.5 Household Water Treatment and Storage

Where the source of water used by a community is unprotected and/or untreated, or when the water supply is contaminated, household water may require treatment in the home to ensure that it is safe for consumption. Household treatment and hygienic storage can improve the aesthetic quality of water (turbidity, temperature, etc.) and reduce faecal contamination, but its use to improve chemical quality is uncommon. In many situations water must be transported, often carried, from a well, spring, or standpost to households and where the water supply to the household is intermittent, water must be stored in the home to ensure that enough is available when it is needed. Water that is transported or stored unhygienically may be recontaminated, which represents a public health risk; water supplied at the well or standpost may be microbiologically safe but become grossly contaminated with faecal material before consumption because of poor handling. A surveillance programme should therefore include the testing of water stored in the household to establish whether recontamination is occurring. If drinking-water regularly becomes recontaminated, the best remedial action is a hygiene education programme. This should involve all the community but focus particularly on those members with most responsibility for water collection, storage, and treatment (usually women and children). Most recontamination is the result of behavioral patterns; if these can be changed, the health risk can be reduced or eliminated. (WHO, 1997)

A Rapid Assessment of Drinking Water Quality in the Federal Republic of Ethiopia found that 72% of samples from “improved water supplies” were in compliance with the WHO guideline values (GV) and Ethiopia drinking water standards for thermo tolerant coliforms (TTC). Compliance ranged from 88% for utility piped supplies to 43% for protected springs. The water microbiological quality of water is likely to be considerably worse for the 62.7% of the population that relies on unimproved sources. Moreover, at the household level, only 43.6% of samples were in compliance with the WHO Guideline Value and national standard for Thermo tolerant coliform, and more than half of household samples showed post-source contamination. The report provides strong evidence in support of Household Water Treatment, and concludes that "household water quality must be given serious attention". (WaterAid, 2014)

A systematic review of water quality interventions to prevent diarrhea suggests that interventions at the household level (chlorination, filtration, boiling, solar disinfection, flocculation/ disinfection) are about twice as effective in preventing diarrhea as conventional improvements in water supplies (protected wells, boreholes and tap stands). Where local water supplies are known to be contaminated or have not been tested, household treatment should generally be recommended. Faecally contaminated water can be treated by boiling, filtration, chemical disinfection and cloth filtration (to prevent dracunculiasis). (WHO, 1997)

2.6 Water Safety Plan

Water safety plans (WSPs) represent an important opportunity to contribute to the realization of the SDGs and to the human right to water, provided that equity is duly considered. Described in the WHO Guidelines for drinking-water quality as the most effective way to ensure the safety of drinking-water supplies, WSPs have been implemented in at least 93 countries worldwide, with 69 countries reporting to have policy instruments either in place or under development that promote or require WSPs or an equivalent (WHO & IWA, 2017). Water safety planning policy support and practice are expected to continue to grow through the SDG period due to an increased focus on the safe management of water supplies. Water safety plans, therefore, provide a well-established and widely accepted framework that can be applied to ensure social inclusion in the improvement of drinking-water supplies. (WHO, 2019)

Because the Sustainable Development Goal (SDG) indicator "use of safely managed drinking water services" sets a new benchmark for global monitoring, this study sought data to support establishing the baseline for Ethiopia. Safely managed drinking water services consist of improved sources accessible on premises, available when needed, and free from fecal and priority chemical contamination. Using the Joint Monitoring Programme (JMP) methodology, it is estimated from the survey results that, nationally, 13 percent of Ethiopians used safely managed services in 2016.

Water safety planning is a preventative management approach aimed at minimizing the risks posed to drinking water quality and health from catchment to point of use. The purposes of Water Safety Plans (WSPs) are:

• Seek to prevent contamination of water from the source to the point of consumption; and

• Give consumers greater involvement and control over maintaining water quality.

Water Safety Plans can be used for new or existing water supply schemes, both for piped urban utility supplies and rural or peri-urban community supplies. (WaterAid, 2014).

Table 2-2: Comparison of steps in a water safety plan and f Water Aid to assure water quality

Water safety plan steps	**Steps Water Aid promotes**
Establishment of **health based targets** for microbial and chemical water quality	Country program water quality policy identifying high risk contaminants, usually based on national standards informed by health based target
A system assessment to determine whether the water supply chain from catchment to consumer can deliver safe water at the point of consumption	Sanitary inspection of conditions around water points and in households where water is stored before consumption
Effective Operational Monitoring of identified control measures within the water supply chain that provide assurance of safety	Sanitary survey of all points in the water supply chain. Risk-based follow up measures and water quality monitoring
Management and communication plans describing actions to be taken during normal operation or incident conditions which includes feedback and improvement	Communities trained on source protection, safe household storage of water and hygiene. Country programme water quality policy outlines steps to take in event of contamination. Frequency of follow-up monitoring is also outlined.
Health surveillance of water safety	Should be carried out by national institutions

Source: Water AID (2014)

2.7 Models and Software in Evaluating Water Services

2.7.1 Need for Hydraulic Modeling

Most small communities do not have very complex networks as compared to cities; however, they have poor data and records regarding their systems. In such cases, when one has to evaluate the hydraulics and the water quality of the distribution systems, it is advantageous to use computer models. Computer models making use of hydraulic simulation software are capable of mimicking the behavior of a real time system and have the capability of predicting the performance of the same system for future 'what if' scenarios (Haestad Methods, 2003). Some rural water districts that have the capability of maintaining and updating real time models, have used hydraulic simulation models in conjunction with geographic information systems, allowing them to perform criticality studies with greater precision (Zhang, ESRI Users Conference 2009). This can be cost effective as it will provide decision support in operation and maintenance of their systems.

Additionally it has the capability of performing the analysis of the system for the steady state scenarios and for an extended period of any length. The other capabilities of the software are as follows:

WaterCAD V8i (2014) is a hydraulic modeling software package comprised of wide range of functionality includes graphical and profiling advancements, flexibility in data archiving and representations, advancements in GUI and its customization, etc. Many features like hydraulic and water quality analysis, steady state and extended period simulations are also made to function with enhanced capabilities, strong data management along with AutoCAD and GIS integrations. The advantages of WaterCAD V8i over other software's include simplified model building with geospatial modules and tools like Load Builder and TRex, water quality modeling, fire flow analysis, optimization and scenario management, etc. WaterCAD V8i is thus easy to use and versatile water distribution as well as quality modeling software packages accepted for variety of applications. (Nitin, 2015)

WaterGEMS V8i (2014) is a versatile hydraulic modeling software package with the advancements in the interoperability, optimization of networks; model building supported with geospatial tools and asset management tools. WaterGEMS V8i is highly efficient and dynamic modeling software which provides the wide regime of analysis and solutions for fire-flow analysis, water quality modeling, energy and capital cost management, etc. Many of the features and functions are common in WaterCAD V8i and WaterGEMS V8i which are streamlined model building, integration with the GIS and AutoCAD functionalities, optimized model calibration, design and its operations. The best part in the WaterGEMS V8i is the presentation of obtained results which is very attractive and appealing and can be presented with variety of graphical tools include ArcMap visualization, thematic mapping, contouring, profiling with color coding and symbology. With the ever increasing number of users WaterGEMS V8i has proved that WaterGEMS V8i is one of the most popular and user friendly hydraulic modeling and optimization software package. WaterGEMS V8i has strong design algorithm to meet the criteria of accuracy in design of water distribution networks, control of distribution network variables like flow, pressure, and velocity along with their optimization. (Nitin, 2015)

EPANET (2014) is public domain software which can be efficiently used to design any sort of network. It provides variety of advantages like water quality analysis, extended period simulation, residual chlorine calculations for disinfection, etc. It can also be used to renovate or restore the existing water supply systems. It is available as public domain software with the relative nomenclature as EPANET 2.0, EPANET 2d-2w. (Nitin, 2015)

Based on ease of use, Hydraulic elements, CAD& GIS interoperability, Model building tools, Advanced hydraulic features and Technical Support criteria, Water GEMS V8i (2014) more advanced than both EPANET (2014) and WaterCAD V8i (2014). EPANET (2014) lacks most functions related to others like CAD& GIS interoperability, Model building tools, advanced hydraulic features and Technical Support tools almost all in all. Water GEMS V8i (2014) Export to Google Earth and Runs inside of ArcGIS without limitation when compared to WaterCAD V8i (2014). (Nitin, 2015)

2.7.2 Modeling a System Using WaterGEMS V8i (2014)

WaterGEMS V8i is hydraulic simulation software, distributed by Bentley Systems. Once the spatial model is built, the parameters that need to be defined for each model components include:

- **Junction**: Elevations and the base demands
- **Pipes**: Pipe diameters, lengths and pipe type. By default WaterGEMS V8i considers the pipe material as ductile iron having a Hazen William friction coefficient factor of 130.

- **Tanks**: Base Elevation, the minimum and maximum levels, diameter of the tank and initial water level.
- **Pumps**: The most important parameter defining the pump operation is the pump curve. Other input needed is the elevation of the pump.
- **Reservoir**: Elevation

After all the parameters required to run the simulation are entered into the model and calculation methods are selected, the successful simulation run provides solution for the following.

- ✓ Pressure at every single element in the system
- ✓ Flows at every point of time in the system
- ✓ Evaluate the hydraulics for different demands at a single node with varying time patterns
- ✓ Solve for different frictional head losses
- ✓ Determine fire flow capacities for hydrants
- ✓ Model tanks, including those which are not circular
- ✓ Model various valve operations
- ✓ Provides control based operations
- ✓ Perform energy cost calculations
- ✓ Velocities in the pipes
- ✓ Levels in the tanks
- ✓ Water age and constituent concentration.

2.7.3 Nodal Demand Allocation Using MW-Voronoi Diagram (Thiessen Polygons)

Many landscape features are represented as polygons in GIS. Thiessen polygons (or Voronoi diagrams) play four roles in research: As models for spatial processes, as nonparametric techniques in point pattern analysis, as organizing structures for displaying spatial data, and for calculating individual probabilities in point patterns. The MW-Voronoi diagram can be considered a metric in the way that it can define and measure a generator point's region of influence based on its weight. This method is widely used by hydraulics software (e.g

WaterGEMs) for demand allocation when lacking data, and multiplies the original polygons, using population or land use coefficients. (Boots, 1979)

The spatial allocation of the first category was based on the equivalent street length, i.e. each node "received" the proportion of the street's overall water demand based on the ratio of length corresponded to its total length. The allocation of the second category was done by dividing the area's total water demand by the number of its nodes. The demand distribution in the third category was made using both ways in a combined manner. It followed the same distribution of the equivalent road length, except for nodes within the town plan, where correction factors were applied due to the varying population densities met across the street. (Vasilis, 2014)

Based on Papadopoulos (1998) for the calculation of the demand per catchment area three options are developed and implemented considering the commonly available data basis: (A) Values and locations of the demands are given as point features, (B) areas with numbers of the population living there are given as polygon features or (C) building areas are given as polygon features and areas with the population are also given as polygon features. Moreover, option B and C need a constant demand per capita value as input parameter.

Option A) the demand values [volume/time] are accumulated per catchment area by intersecting the catchment areas (polygon features) and the demands (point features) according to the spatial references. Finally, the accumulated demands per catchment area are allocated to the originating nodes.

Option B) The population per catchment area (inhabitants) is determined by intersecting the areas with constant values of the population (polygon features) and the catchment areas (polygon features) according to the spatial reference. To calculate the demand per node (volume/time), the population values (inhabitants) of the catchment area are multiplied with the demand per capita (volume/inhabitant/time).

Option C) the population per building area (inhabitants) is determined by intersecting the areas with constant values of the population (polygon features) and the building areas (polygon features) according to the spatial reference. The building areas, and thus the population, are accumulated per catchment area by intersecting the building areas (polygon features) and the catchment areas (polygon features) according to the spatial references. Finally, the demand per node (volume/time) is calculated by multiplying the Population values of the catchment areas (inhabitants) and the demand per capita (volume/inhabitant/time).

2.8 . Summary

As findings of researches point out that there are problems in access to safe water and service provisions. The access of water supply was global and it is worst in Sub-Saharan Africa countries. As reviewed in this chapter common problems related to this sector are increasing demand of the water due to high rate of urbanization, water quality related problems, operation and maintenance problems and institutional incapability to service providers were most frequent. The effect of Fe and Mn in water sources were also problems to some areas. Generally extent and kinds of problems for different areas were different in water supply service provision and, therefore, it requires examining cases of different areas specifically to solve problems for sustainability of the service provision. Due to this the case for Masha town is not studied and this study was conducted to assess the cause for this specified town.

CHAPTER THREE

3. METHODOLOGY and MATERIALS

3.1 Description of the Study Area

Masha town is found in south western part of Ethiopia. It is one of the reform towns in south nation's nationalities and people region. It is capital of Sheka zone administrational region having city administration consisting of two kebeles named 'Shuni' and 'Yelobayi'.

3.1.1 Climatic Condition and Topography

Masha's climate is classified as warm and temperate. There is a great deal of rainfall in Masha, even in the driest month. In Masha, the average annual temperature is 17.2 °C. The average annual rainfall is 1933 mm. The least amount of rainfall occurs in December. The average in this month is 41 mm. The greatest amount of precipitation occurs in August, with an average of 276 mm. The temperatures are highest on average in March, at around 18.4 °C. The lowest average temperatures in the year occur in July, when it is around 15.8 °C.

3.1.2 Population of the Study Area

Based on figures from the Central Statistical Agency in 2007, Masha has an estimated total population of 6717 of whom, 3404 were men and 3383 were women. As CSA of Ethiopia forecasted total population of the town at the end of 2017 G.C were 14, 440 and based on municipality report of Masha town, total number of population in study year was 20,007. Total numbers of households were 4586 in year 2018 G.C. There were significant disparity between forecast of CSA and Masha town Municipality records because of expansion of town territory and inclusion of surrounding Kebele people in to the town administration after year 2007G.C.

3.1.3 Location of the Study Area

Masha town is administrative town of Sheka zone which is located in south west of Ethiopia with a distance of 676 Km and 951 Km from Addis Ababa and Hawassa via Jimma and Bonga town respectively. This town has a latitude and longitude of 7°44′N 35°29′E to 7.733°N 35.483°E with an average elevation of 2223 meters above sea level. The location map of the town is as shown in fig below.

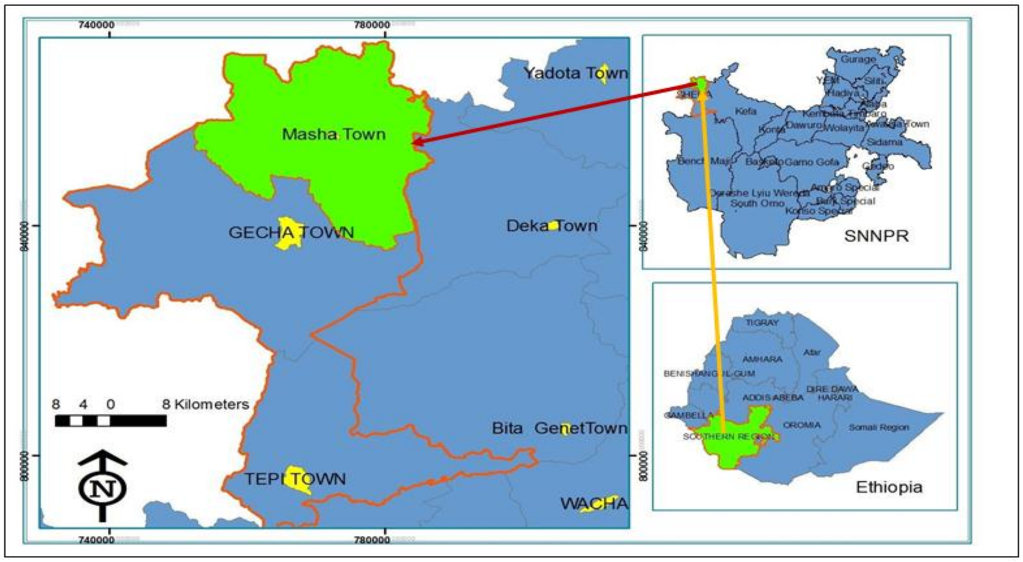


Figure 3-1: Location map of Masha Woreda (Masha Town Municipality)

3.1.4 Background of Improved Water Source of the Town

Design report of Masha Town water supply system and letter from SNNPRG Water, Mines and Energy Office described that initial water supply sources of Masha town were two deep boreholes which had stopped giving service due to failure to fulfill water quality standards of W.H.O and national water quality standard of Ethiopia. Following the failure of borehole's ground water to meet W.H.O standards, the town water supply switched to surface water with a slow sand filter treatment planted along Wonani River. Thus, existing water supply system of the town is motorized scheme that based on river as source with treatment plant. The existing surface water treatment scheme was designed to serve the town for maximum of 15 years. The design discharge of the treatment system was 9.3 l/s and it was proposed to serve the population of the town until the end of year 2022 G.C. The service of this source was official launch by year 2007 G.C in presence of former water and energy ministry minister Ato Asfawu Dingamo (Report from Sheka Zone Water, and Energy Mines Office) and still providing service to Masha town with its limitations.

3.1.5 Intake and Treatment Units

The main water supply source of the town is treated water from Wenani River. The Wenani River originates from highlands of Baro Basin and joins Baro River at the downstream of Upper Baro Bridge. It is currently used as water supply source of the town and has no downstream irrigation and water supply use. It is located about 1.5Km far to west of Masha town. The river is perennial and its catchment area gates high rainfall for long time in year.

The water supply system has weir intake diversion having geographic coordinate of UTM Zone 36; 771757m E, 855718m N, and 2168m. Raw water is conveyed with 4' UPVC pipe to treatment units which are situated at right side of river and about100m far from intake point.

Wonani river treatment plant comprises different treatment components. Sequentially treatment components are cascade aerator, plane sedimentation tank, horizontal roughening filter, slow sand filter, balancing chamber and clear water tank (wet well) from initial to final treatment stages. The image of existing water supply system is as shown in figure below.

Figure 3-2: **Image of existing Masha town water treatment plant, intake and wet well**

3.1.6 Pumping Units, Transmission Main and Reservoirs

The treated water from slow sand filter plant is collected in to 25m3 wet well with a help of gravity and two suction pumps with 3'' GS pipe connected with wet well. The two pump designed to discharge the collected water through Ø 3"GS and 4''GS Pipe. The pumps are connected both with national grid line and 750 HP generators.

Now, there were two pumps operational with estimated discharge of 4.6 l/s and 6.67 l/s. There is also one nonfunctional pump not connected with wet well. However one of the pumps was only connected with national grid line due to malfunctioning of one of the generators. This pump had been idle most of the time because of unavailability of electric power. The pump and reservoirs connected through 1.8Km pressure main line, 4’’ inch GS pipe to town center reservoir and 3’’ inch GS pipe 1.5Km to reservoir site of St. Mary church.

Currently the town has three reservoirs with total capacity of 175m3 in service that are found two at town center 25m3 Sandwich masonry and 100m3 reinforce concrete reservoirs and also at premises of St. Mary church 50m3 sandwich trapezoidal masonry reservoirs. The 25m3 sandwich masonry reservoir situated at center of town is not functional this time.


Figure 3-3: Picture of Reservoirs of the Town

3.1.7 Water Supply Distribution System of the Town

The Masha town distribution system covers about 17.3Km after expansion project in year 2006 E.C and limited only some parts of the town. The existing distribution pipe diameters used are Ø 6’’, 4”, 3”, 2.5”, 2”, 1.5’’ and 1’’ pipes. All the existing distribution pipe lines are GI except 760m Ø 6’’ UPVC pipe lines. The town water supply has also 19 water points for communal service of which fourteen were functional. In the town there are about 1248 water tap users.

Table 3-1: Diameter and Pipe Length of Distribution and Pressure Main

Type	Size (Inch)	Total Length
UPVC	6	1152
GI	4	3159
GI	3	4530
GI	2.5	1705
GI	2	3958
GI	1.5	5787
GI	1	474
TOTAL		**20765**

3.2 Materials Used for Study

For this study, because of unavailability of water supply system layout map, structural map of Masha Town was used as base to identify and made existing water supply distribution systems before conversion to soft copy. In addition to the base map, the following materials were also used in the course of the study:

Table 3-2: Material and apparatuses used in to conduct the study

No.	Materials	Purpose
1.	GPS measuring instrument	To identify ground positions in study
2.	YSI 9300 complete photometer kit with iron and manganese tablets	To measure iron and manganese contents in the system
3	Meter tap	To measure height of reservoirs
4.	Pressure gauge	To measure pressure in the distribution system at appropriate locations
5.	PH meter	To measure PH of water at sample sites
6	Pocket calorimetry Apparatus	To measure free chlorine in supplied water
5	Photo camera	To take pictures at appropriate location for reporting purpose

3.3 Data Types and Sources

3.3.1 Data Types

Both qualitative and quantitative data was collected to counter balance the limitation of the one by the other. These data were collected through questionnaires from the household, interviews of Masha town water utility office, different water source users, field measurements or test and observations. Secondary data like population data, water quality standards, reports of water quality of the town, and design criteria of existing water supply system, existing water tariff and human resource conditions were also collected. Digital topographic map of Masha town, location site and layouts of water supply structures also be used to model existing system. Pressure data also collected at some areas in the system for model calibration. DEMs also be used to extract elevations of strictures in modeling the existing water supply system.

3.3.2 Data Sources

All the necessary data required for the study were obtained from both primary and secondary sources. The major sources of secondary data were from Masha town municipality, Masha town water utility office, Sheka zone water, energy and mines bureau annual and inventory reports, design documents, previous studies, books, digital topographic map of the town and DEM (Digitized Elevation Model). These primary data were collected from sample households, interviews of town water utility officers and different water source users, and field measurements. In addition, water samples, personal observation and measurements were data source for the study.

3.4 Data Collection Techniques

Questionnaire, interview, personal observation, field measurements and testing were employed assess the existing water supply problems in the study area and evaluate water supply services. Prior to the actual collection of data, pre-testing of the materials was made to check its validity and clarity. The pre-testing of the questionnaires actually helped in the administration and implementation of the actual survey and in restructuring the questionnaire format and content.

Questionnaires: - primary data related with the different domestic water sources, services of existing pipe water of the town and about service provision of Masha town water utility office were collected through structured questionnaires. Based on this instrument demand side water use, piped water service and service provision of water utility office was assessed.

Field observation:-It was mainly employed to gather data related with water supply system and structures status and conditions. It was carried out through the help of checklists according to the objectives of the study. In addition based on this method different water source like spring water and hand dug well were visited to know its exact condition where people use it.

Interview: - interview was made mainly to assess water suppliers (Masha town water utility office) capability on providing intended water service to the town. Human resource, logistics, office conditions, laboratories for water quality and operation and maintenance issues were included. Maine problems and measures taken by suppliers were also assessed using interview questions. Water utility offices like manager, human resource department head and pump operators were participated in the interview. Sheka zone water, energy and mines department water quality department head were also participated in study to clarify technical conditions on water quality of existing water supply service of the town. Lastly interviews were implemented to assess reasons and trends of using unprotected water sources in the town that was important and not included in questioner. It was not included in questioner to manage number of questions and reduce complexity of questions.

Field measurements: to locate sampling site and water supply structures GPS instrument reading were used. Existing treatment capacity of Wenani river treatment plant was measured to know the efficiency of the system. Height of reservoir and; pressure in distribution systems were also measured to model the existing water supply system of the town.

3.5 Sampling Techniques

3.5.1 Household Survey Sampling

One of the objectives of this research was to assess water sources of the town for domestic purpose, service adequacy of existing system and the perception of households for existing water sources. To this end to get the representative population and the necessary information accordingly; this research used simple random sampling technique to select from total households of the town. This was because developments of the town in both Kebele were having similar nature, with unique water service providers, single system and the same pipe water source. Mash town was a small town and its total numbers of households were 4586 in year 2018 G.C based on Masha Town Municipality report. The study was conducted by determining appropriate representative sample using simplified formulae for proportions by Yemane (1967).

$$n = \frac{\mathbf{N}}{1+\mathbf{N}(\mathbf{e})^2}$$

Where n is the sample size, N is the population size, and e is the level of precision.

For this study, 90 percent confidence level was accepted since it was manageable with available resources and sample size of the study was computed to be 100 households as follows.

$$n = \frac{\mathbf{4586}}{1+\mathbf{4586}(\mathbf{0.1})^2} = 98 \approx \underline{\underline{\mathbf{100}}}$$

3.5.2 Physiochemical Test Methods

PH, Temperature, Free Chlorine, Total Iron and Total Manganese were tested in the system. Water samples were manually collected from sample locations in properly washed and rinsed appropriate sampling bottles. The pH meter having electrodes were used immediately on spot to measure pH and Temperature on each site. Photometer and tablets were used to measure iron and manganese in the system. Tablets used were iron MR No 1 tables and MR No 2 for iron test and Manganese No 1 tablets and Manganese No 2 tablets to test manganese content in the sample water. Pocket Colorimeter and free chlorine reagents were used to measure free Cl_2 in sampled water. All of the measurement results were digital and directly read from instruments.

3.5.3 Sampling of Water for Test

Water samples were taken from different location of water supply system that was from source to end users from which water quality was expected to be changed. This points includes intake point at weir site, outlet of cascade aerator, at wet well (after filtration), just after pumping, from reservoirs and from different point of water use (public water taps and private taps) in the distribution system. The study water sample GPS locations were indicated in the table below. Water samples were taken from different private taps and public taps at different location from distribution network. Based on this water from 4 public water points, 35 private taps were included in the study. The locations were selected considering pipe line braches, distances from one another and end users. This technique was used to understand sources of chemical elements in the water and its spatial variations in water qualities due to distribution system.

Table 3-3: Location of sampling sites and sample source types

Coordinate		Remark	Coordinate		Remark
latitude(N)	longitude-E		latitude(N)	longitude-E	
7.736171	35.464477	Intake weir	7.74341	35.477594	Public Tap
7.737371	35.46466	Cascade aerator Outlet	7.741883	35.478699	Private Tap
7.738624	35.464234	Wet well	7.745184	35.47943	Private Tap
7.738662	35.464342	Just after pumping	7.745814	35.475903	Private Tap
7.743245	35.475727	Reservoir at Town	7.746546	35.474802	Private Tap
7.745417	35.472583	Reservoir at Church	7.74745	35.475512	Private Tap
7.733861	35.479702	Private Tap	7.748734	35.474594	Public Tap
7.739124	35.482489	Private Tap	7.74847	35.476265	Private Tap
7.739128	35.479791	Public Tap	7.747703	35.47901	Private Tap
7.740767	35.477912	Private Tap	7.747983	35.47778	Private Tap
7.738894	35.479085	Private Tap	7.752389	35.477549	Private Tap
7.740349	35.477362	Private Tap	7.749941	35.474943	Private Tap
7.740818	35.476926	Private Tap	7.751441	35.473012	Private Tap
7.741617	35.474637	Private Tap	7.750794	35.470375	Private Tap
7.742638	35.476312	Public Tap	7.75203	35.476318	Private Tap
7.743095	35.474851	Private Tap	7.754113	35.474477	Private Tap
7.744252	35.474299	Private Tap	7.74341	35.477594	Public Tap
7.744726	35.473532	Private Tap	7.753718	35.474678	Private Tap
7.745644	35.47057	Private Tap	7.754048	35.478803	Private Tap
7.747105	35.47057	Private Tap	7.753392	35.486145	Private Tap
7.748181	35.466739	Private Tap	7.755563	35.479098	Private Tap
7.747535	35.466739	Private Tap	7.758198	35.478111	Private Tap
7.739498	35.468241	Private Tap	7.757928	35.479851	Private Tap
			7.761215	35.476454	Private Tap

Source: Field measurement (March, 2018)

3.5.4 Laboratory Sampling Methods

Manual sampling involves minimal equipment but may be unduly costly and time-consuming for routine or large-scale sampling programs. It requires trained field technicians and is often necessary for regulatory and research investigations for which critical appraisal of field conditions and complex sample collection techniques are essential. In this study manual sampling method was used since it was easily managed by water quality technician of Sheka Zone Water, Energy and Mines Department.

Grab samples technique were applied to single samples collected at a specific spot at a site over a short period of time (typically seconds or minutes). Thus, they represent a ‘‘snapshot’’ in both space and time of a sampling area. Discrete grab samples were taken at a selected location.

Time Interval between Collection and Analysis: In general, the shorter the time that elapses between collection of a sample and its analysis, the more reliable will be the analytical results. For certain constituents and physical values, immediate analysis in the field is required. In the study the test were made in field and time interval was minimum.

3.5.5 Calibration of the Apparatus

The Photometers feature digital electronics and built-in filters. It is lightweight and portable for field or laboratory use. Additionally, the photometers are direct-reading, have automatic blank setting, automatic wavelength selection, and automatic power cut-off.

The calibrations are accessed by entering a unique program number at the start of each test procedure. This enables the instrument to select the appropriate wavelength filter automatically and allows the photodiode response to be converted to a concentration reading. The instrument thus displays a direct reading of the test result. The instrument was calibrated according to instrument manual instructions for each test.

Performing initial calibration with a minimum of three concentrations of standards for linear curves, a minimum of five concentrations of standards for nonlinear curves, or as specified by the method of choice. Choose a lowest concentration at the reporting limit, and highest concentration at the upper end of the calibration range. Ensure that the calibration range encompasses the analytical concentration values expected in the samples or required dilutions. Choose calibration standard concentrations with no more than one order of magnitude between concentrations. If linear regression is used, use the minimum correlation coefficient specified in the method. If the minimum correlation coefficient is not specified, then a minimum value of 0.995 is recommended. However because of unavailability of standard solutions rather than distilled water, the researcher tried to check the instrument using distilled water. Iron and Manganese content of distilled water were tested about three times using the photometer and it reading was “<<” that means result is lower than range: using the result regression was not possible and correlation coefficient were not found.

3.5.6 Testing Procedures

Testing for Fe and Mn were based on the procedures explained in the manufacturer’s manual (YSI, Inc., 2010) and it was clear and easily managed. The manufacturer’s manual procedures are annexed in this thesis.

3.6 Modeling of Existing Water Supply System.

The system was modeled using WaterGEMS V8i. In the MicroStation V8i environment you can create and model your network directly within your primary drafting environment. This gives you access to all of MicroStation's powerful drafting and presentation tools, while still enabling you to perform hydraulic modeling tasks like editing, solving, and data management. This relationship between the two applications enables extremely detailed and accurate mapping of model features, and provides the full array of output and presentation features available in MicroStation V8i. This facility provides the most flexibility and the highest degree of compatibility with other CAD-based applications and drawing data maintained at your organization. WaterGAMs softwer is flexiable, easily understandable, easily available and low cost. WaterGEMS is a comprehensive and easy to use water distribution modeling application.

Inputs to model

- Digital topo map of the town as background for model development and base for pipe line length reference.
- Locating structures based on base map
- Demand for each junction.
- Existing pump characteristic curve
- Height of water tank

- Diameter of water tank
- Elevations of junctions and structures based on TRex tool.
- Actual pressure on distribution systems for model calibration.

Output

- Pressure couture map to know the pressure differences in the town.
- Velocity color-code map to know the velocities differences in the system for existing situation.

3.6.1 Nodal Demand Computation

The impute demand for the software was calculated using weighted thissen polygon technique. Nodal catchment area was delineated using Water GEMS and exported to global mapper software. Then by opening Masha town structural CAD drawing saved by DXF were opened and overplayed on thissen polygon. Under each polygon area of each land use were measured using area measuring tool of global mapper. This measured areas were weighed using housing density and number of houses were calculated to each node. Total population were distributed to number of houses and domestic and commercial demand were calculated. Based on recommended percentage values other demands are calculated. Based on demand fraction of each node currently supplied water were distributed to each node.

3.6.2 Model Setup

Major developed part of Masha town current settlement is mixed spatially for commercial and residential areas. People in the town were conducting their business in area of their dwellings. Therefore separately allocating demand for commercial and domestic demand were difficult.

Water demand for each node was allocated based on Thissen polygon considering its development. Land percales of the town were weighed based on sampled settlement in to well developed, medium and less developed for allocating commercial and domestic water demand for nodes. Housing density of the town was calculate using satellite map of Apple to count housing units and google earth map to locate the percales and structural map of the town to identify land use of the town. Based on analysis housing density of the town was computed as presented in the table below. Well-developed parts of the town are around the center which was built without plan and land holding was also varies. However medium settlement density were more for newly developed town developed based on town development plan. The least developed part of the town are those nearly included in territory of the town with sparsely populated and less development. The value of medium developed house was higher than that of lease standard of the town. This is the result of landholding without development in the town.

Table 3-4: Housing density for different development levels in Masha town

Level of development	Housing Density for Sample blocks		Average
	Block 1	Block 2	
Developed	1 house in 126.7 m^2	1 in 149.9 m^2	1 in 138.3 m^2
Medium	1 in 410.889 m^2	1 in 493.1 m^2	1 in 451.99 m^2
Least	1 in 667.7 m^2	1 in 1122.78 m^2	1 in 895.24 m^2

Source: Computation result of the study

Based on above classification the result of computation was 651.74 housing units for list developed, 2835.43 for medium development and 1129.21housing units in relatively well developed parts of the town. The result shows that the housing units were concentrated in developed parts of the town and large area of the town which is developed least includes only small amount of housing units in it.

Water supply system of different structures were modeled to analyze hydraulic performance of the existing system. The elements in the model were summarized in table below.

Figure 3-4: Model elements of existing water supply system

Elements	Number	Total Length
Pipe	97	20846
Junction	83	
Pumps	2	
Reservoir	1	
Gate valves	8	
Tanker	2	
Check valve	2	

3.6.3 Model Calibration

The model was calibrated using measured pressures at five water points and known boundary condition hydraulic gridlines in both of the reservoirs. The location of this water points are in different directions of the town. Based on the known pressure the software by itself adjusted the roughness coefficients of pipeline significantly.

3.7 Data Analysis

To analyze the data collected a combination of quantitative and qualitative analysis methods were employed. Quantitative data which was generated from household survey were analyzed using simple descriptive statistical tools like frequency, mean, and percentages and they were operated with Micro Soft Excel. The qualitative data collected using interview and personal observation was also analyzed through description, narrating and interpreting the situation contextually so that the town's water supply situation has been properly revealed.

Water quality data were analyzed and evaluated based on water quality standards of Ethiopia and WHO. Water quality data were also analyzed based on the sample location to evaluate source of impurities and treatment efficiencies of treatment plants of existing water supply system. Existing water supply system of the town were also modeled to evaluate pressure differences and velocity of flow based on design standards. Finally based on water quality results, perception of households, and water service utilities capability the service of Masha town water supply was analyzed and concluded.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Introduction

This part of the thesis describes presentation, analysis and interpretation of the data collected from the respondents through questionnaires, interview laboratory test and modeling of existing water supply service. This chapter is broadly classified into sections. The first section focuses on presenting and interpreting existing situation of water supply of the town and households response on water service; the second section describes water quality test result and last portion describes modeling of existing water supply systems.

4.2 . Existing Water Supply Service of Masha Town: Field Observation Results

4.2.1 Status of Treatment Plant and Water Supply Structures

As visited in different system components of water supply, existing weir intake was filled with silt and not properly maintained. In addition, water is passing downstream by eroding left bank of the river at weir site. Conveyance pipe line seriously leaked due to pipe damage as it was lied on surface where there was road in which humans and animals use Seen in figure4-3(a) below. Water from Horizontal roughening filter unit was overtopping and significant amount of conveyed water was lost as shown in figure 4-3(b). As visited in the site, sand filter media was not cleaned and water also lost through overflow due to reduced filtration rate as shown in figure 4-3(c). Generally, part of water diverted to treatment plant was significantly lost due to poor operation and maintenance of the components. These clearly confirm that there is poor operation and maintenance of treatment plan that result in reduced water production and risk of damage of structure.

Figure 4-1: Picture showing water losses in conveyance and treatment units

4.2.2 Management of Existing Water Supply Scheme

Managing water supply of a certain community or town is not a simple task. It needs day to day follow up regarding its operation just from the source to the point of utilization. Mechanical damages and system failures are too often the problems encountered at most water supply systems. The water supply service at Masha town was guided and directed by board of directors having seven members which is chaired by the mayor of the town. The manager of the town water supply service office serves as secretary. Main members include head of zonal water and mines energy bureau though some important stakeholders such as health and education are not included.

The water supply of the town was managed with the water board's scheme management and an implementing water utility office. The water supply utility office has already built office and store but confined to a single office as the office shared with Mayor Office and zonal water resource development.

The region had set a standard regarding number of staffs with qualification to administer water supply of Masha town and similar towns that found in the region. The number of proposed man power with qualification and interview result of the existing staffs was summarized as followed in Table 4-2 below.

As interview result in table indicates that the utility office was providing service with very limited staffs. Currently the staffs serving the water supply office are about 9 that are less than a half of the required man power so as to provide the required service. Most of these staffs were under qualified based on the requirement and lacks major technical staffs like engineers, mechanics, electricians and senior water quality technician. The staffs were not getting successive technical trainings and they were not getting promotions due to limited financial capacity of the office. As a result water supply service provision was inefficient and couldn't assure sustainability. In addition to this the structure for human resource requirements also has limitations since it never assign qualified personnel for same positions like operators.

Table 4-1: Proposed Staff for Masha and Similar Town Water Supply Office

Position	Education and Qualification	Number Required	Current Staff Number
Manager	Bsc in Water resource Engineering, hydraulics, civil, water supply and environmental engineering	1	1 (Delegate)
Finance officers	Diploma or degree in accounting, business management, procurement or economics	3	1
Human resources planning	Business management ,human resources management, public management or economics	1	1
Secretary	Diploma in secretary science	1	1
Electrician	Diploma electro mechanics or electricity	1	0
Plumbers	Diploma in plumber ,general mechanics and others	5	2
Bill workers	Diploma in accounting	6	1
Driver	8th grade	1	0
Operators	6th grade	3	2
Water quality technician	Diploma in Water laboratory, applied chemistry or industrial chemistry	1	0
Total		**23**	**9**

4.2.3 Logistics of Water Utility Office

For effective and efficient water service provision the office needs sufficient logistics like office equipment and vehicles. However, as interview result shows that, the office did not have vehicle except one motor bicycle. Because of limited staffs and unfulfilled logistic, the office not providing timely response for service request and complains.

4.2.4 Water Quality Management

Direct testing of drinking water quality provides an important measure of 'safety', and most countries have national standards aligned with the WHO guidelines for drinking water quality. Water can contain a wide array of constituents that can make people ill and has a unique ability to rapidly transmit disease to large numbers of people.

However as interview result of the study indicates that the enterprise lacks laboratory, equipment and technicians to provide quality controlled service to customers. Quality of water varies from season to season and its quality needs to be inspected in order to know specially disinfection and maintenance requirements.

Disinfection is an essential element of the overall strategy for providing water that is safe to drink. Providing water free from pathogenic organisms is accomplished using several complementary strategies: (1) selecting a water source that is free from microbiological contamination, such as groundwater, (2) protecting surface water sources to minimize microbiological contamination, (3) treating water to remove microorganisms or eliminate their pathogenicity, and (4) preventing recontamination of water as it is delivered to customers through the distribution system. Disinfection is an element of the last two actions. However, as visited in the treatment site, water was distributed most of the time without disinfection. The free chlorine test result in the distribution system also confirmed that the service was provided with improper disinfection. Therefore, water users from pipe source in the town were under risk of water born disease and its consequences.

4.2.5 Operation and Maintenance Water Supply System

Appropriate operation and maintenance of water supply system helps to extend life time of structures and saves overall costs of service provision. However, as site visit shows water supply systems are not well maintained and operated. Electromechanical part of the system requires regular maintenance and safety; however, pump systems were operated with guard men which were unprofessional staffs. Treatment units were also operated with these staffs. As interview from water utility office indicates that there was no schedule for maintenance of treatment units. They also got difficulty in getting appropriate sand for filter media nearby that costs the utility more. Because of this high cost the enterprise was not replacing the filter sand medium even for more than a year. The office tried to prepare locally available sand for filter media but due to unavailability of required sieve they were unable to do so. As the result indicates that the water supply system operation and maintenance was inefficient and the office did not have plan for operation and maintenance of the system.

4.2.6 Demand of Improved Water in the Town

As Masha town municipality report shows that the population of the town in year 2018 was 20,007. CSA estimation of Masha town was 14,440 CSA underestimates the population of current population because of inclusion of parts of surrounding rural Kebeles in to Masha town.

Demand of improved water to Masha town has been inclining due to increasing number of population in the town. Masha town water supply project was designed to fulfill the water demand by year 2022 G.C. As the design report of Masha town water supply project indicates that the capacity of treatment system was 9.3 l/s (803.52m3/day) which were estimated to serve the town at the end of its design period. However, current water demand of the town was analyzed and found to be 1477.44 m3/day (17.1L/s). The estimated amount was exceeded by 673.92m3/day. The analysis result of Masha town water demand was attached on annex 2 in this report document.

4.2.7 Current Operated Capacity of Masha Town Water Supply Systems

As site measurement indicates that the existing water production capacity of Wonani water treatment plant was 3.1 l/s. It takes 2 to 2.5 hours to fill 25m3 wet well. This shows that treatment plant was working with 33.33 percent of its designed capacity. As the intake and treatment component visit shows that the main reasons for reduction of water production were;

1. Reduction of conveyed raw water due to leakages at conveying UPVC pipe line damages.
2. Water lost through overtopping and overflow at horizontal roughing filters because of improper maintenance and placement of gravels in the units after cleaning.
3. Water lost through overflows because of improper maintenance of treatment plants like dirty sand filter Media.

Moreover, because of limited working hours of pump due to very critical power intermittency and only day time operation of pumps, treated water was pumped only five times in a day for two reservoirs of the town. It was pumped once at reservoir at church and four times at reservoir at center of the town. Of daily treated water that was 267.840 m3 only 125 m3 were pumped to central reservoirs. This result shows that only 46.67 percent of treated water was pumped to central reservoirs. Surprisingly water was treated and left freely at wet well site because of power unavailability and not pumping in night time. Treating and disposing water highly increases the cost of water production since it increases operation and maintenance cost without any bill.

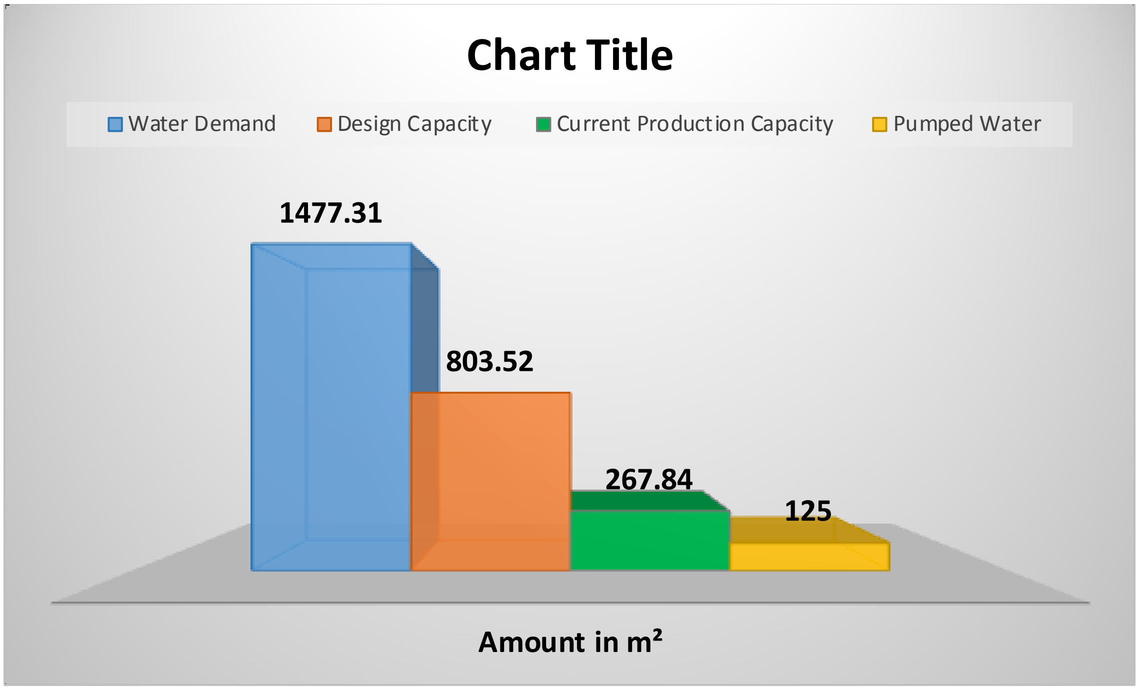


Figure 4-2: Chart describing water demand different performance capacities of WSS

As the study result in chart above presented indicates that existing treatment capacity limitations of Masha town treatment plant to satisfy timely demand of the town was 673.79 m3 in a day. The reason for this problem was underestimation of population growth during study and design stage of Wenani river treatment project. In addition to this, present water production efficiency of treatment systems was found to be only 33.33% due to improper maintenance and operation of system. Pumping efficiency of Masha town water supply system was limited only to 46.67 percent and the problem was caused due to acute intermittency of electric power and limited working hours of pumping. Because of all these reasons only 8.46% of estimated current water demand was pumped to town reservoirs from Wonani river water treatment plants. As the study shows that treatment was serving with its very limited capacity and by improving system operations and maintenance, it has opportunity to increase improved water production. The institutional capacity of water utility limited and even treated water is not fully supplied to the distribution system.

4.2.8 Distribution System of the Town Water Supply System

Distribution system of Masha town waters supply system was limited to some areas and has no equal opportunities to get water for dwellers from the system. Pipe lines were accessed to only some areas of the town. Most households of this study found that initial connection cost for private tap was very high because of this limited pipe line accesses. About five water public fountains out of 19 were not functional. Even most of these operational fountains were concentrated near and around the center of the town where most of private tap users were living. Therefore, people were not using most of the public fountains and even they were not operated most of the time as it was visited.

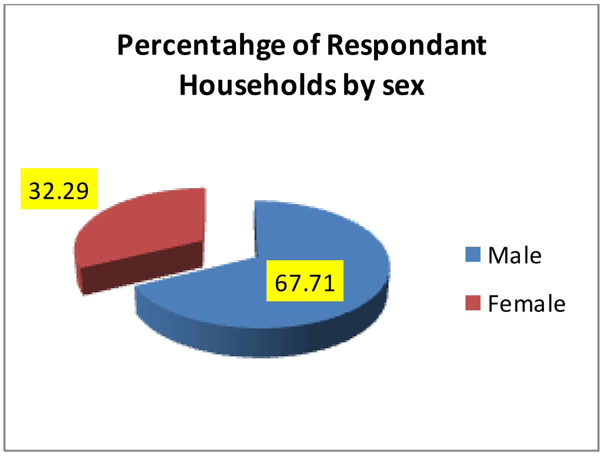
Because of limited water production, manpower and logistic water service enterprise of the town was providing service with shifted base. Each area was supplied with water once in a three day. This intermittent supply of water service has imposed risks of using consumption of easily available unprotected water sources like unprotected hand dug well and springs and declining the capacity of water utility office due to less collection of water sells. The office was under vicious circle where because of less production it was under financial constraints to manage the system and lets it for further weakness.

4.3 Existing Water Supply Service of Masha Town: Household Survey Results

4.3.1 Characteristics of Respondents

In this study the sample size was determined as 100 households but only 96 were filled the questioner and returned back. As indicated in table below from the total sample respondents (96), 79.17% (76) were male and 20.83% (20) female. Both types of gender were participated in the study even though their proportion was not proportional. However, significant numbers of female respondents were included in the study in level that their filling could be addressed in the result.

Age of the respondent household members ranges from 18 to 67 years. Of which 8.33 percent are aged between 18-27, 25 percent are in the age group 28-37 years, 47.92 percent are in the group 38-47 years, 11.46 percent are 48-57 years, and the remained 7.92 percent include 58-67 years age group. Over 80 % of respondents fell between the ages of 18 and 59 years. The implication is that the majority of respondents are in their active stage, thereby requiring more water for domestic use.



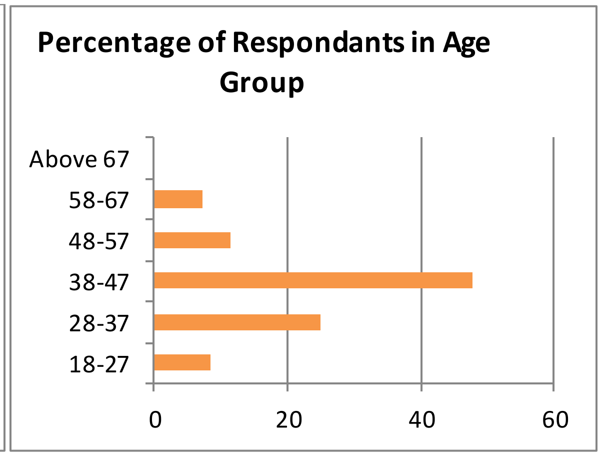


Figure 4-3: Chart Describing Percentage of Respondents' Sex and Age Group

4.3.2 Socio Economic Characteristics

Household Size

Family size here refers to the total number of family members in the household. The average household size of the study area was 4.2. The largest household size in the survey was 11 and the smallest was 1. As indicated in Table 4-2 below more than majority of respondents (more than three fourth) have household size of 3 to 5.

Table 4-3: Household size of Sample respondents

Household size	Frequency	Percentage
1	2	2.08
2	4	4.17
3	24	25.00
4	29	30.21
5	21	21.88
6	12	12.50
7	0	0.00
8	2	2.08
9	1	1.04
10	0	0.00
11	1	1.04
	96	100
4.28		

Household Education Status

The survey result also revealed that 2.13 percent of the sample household heads were no formal education level and 20.21 percent of the respondents have education level of grade 1 to grade 8. Majority of these households are expected that they can read and write. However majority of respondent (77.66 percent) households are above grade 9 educational level. As indicated in the table below the highest percentage (32.98) were covered by those who were completed their secondary education. In the study area there are significant numbers of respondents having educational level of above collage level. This was because there were number of governmental and nongovernmental offices in the town as it is administrative seat for Masha Woreda, Masha town administration and Sheka Zone Administration. High accesses to distance education in the town also have effect on increased educational level of the respondents. Most of respondents were able to understand and answer the questioner easily.

Table 4-4: House Holds Educational status

R. No.	Educational Status	Frequency	Percentage
1	No formal Education	2	2.13
2	Primary (Grade 1-8)	19	20.21
3	Secondary (Grade 9-12)	31	32.98
4	College (level I- VI)	26	27.66
5	University (Degree and above)	16	17.02
Total		94	100

4.3.3 Water Sources for Domestic Consumption

Most national surveys and censuses only collect information about the main source of drinking water used by household members. However, it is well known that households often use multiple sources. This may be due to problems with the main source at certain times of the year, or a matter of convenience, or preference for other sources. Secondary sources may provide a higher or lower level of service, and can be an important way to ensure access to sufficient quantities of water throughout the year. (WHO, 2017)

Based on household response and filed visit, there were different water sources for households in the town. These include municipal pipe water, unprotect hand dug well, unprotected springs, roof catchment, river water and bottled water. Based on study result 70.83 percent of households agreed that they use municipal pipe water was source for their domestic water consumption. In addition, unprotected hand dug well, roof catchment, unprotected spring, river water and bottled water were sources for 87.5, 64.58, 29.17, 6.25, and 3.12 percent of households in the town respectively.

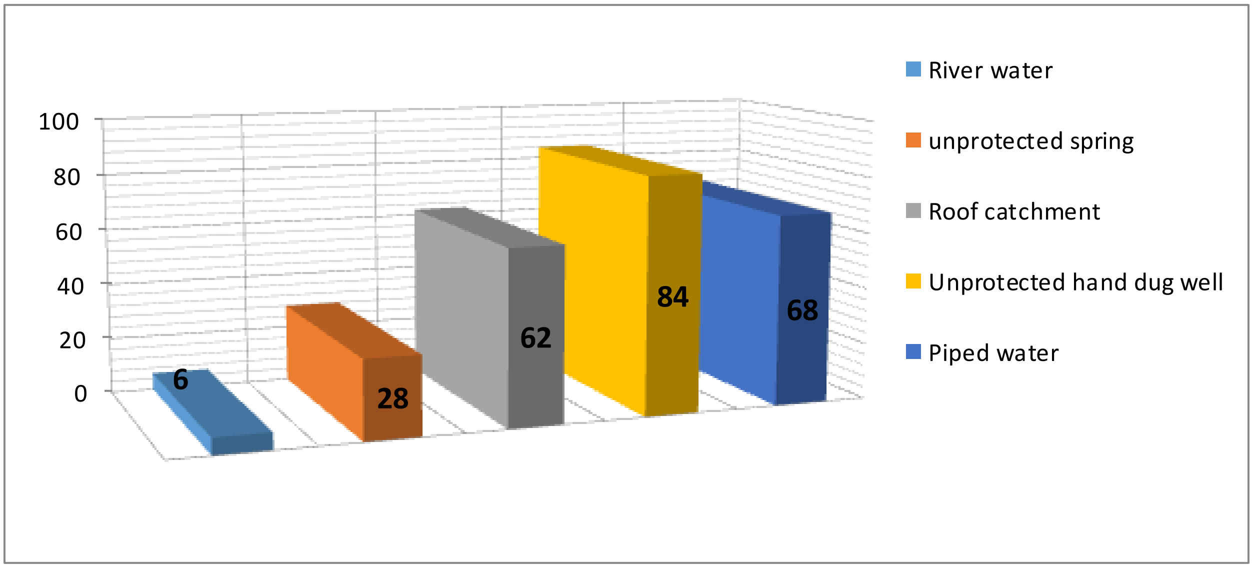


Figure 4-4: Chart describing percentage of households using different water source types

Among these sources hand dug wells are most comment for the households and piped source was the second most common water source for respondents and almost all households use more than one water sources for their domestic consumption.

Hand Dug Well

Based on WHO (1997) open or poorly covered well heads pose the commonest risk to well-water quality, since the water may then be contaminated by the use of inappropriate water-lifting devices by consumers. The most serious source of pollution is contamination by human and animal waste from latrines, septic tanks, and farm manure, resulting in increased levels of microorganisms, including pathogens. Contamination of drinking-water by agrochemicals such as pesticides and nitrates is an additional and increasing problem for small-community supplies. Dug wells are generally the worst groundwater sources in terms of faecal contamination, and bacteriological analysis serves primarily to demonstrate the intensity of contamination and hence the level of the risk to the consumer.

As site visit in Masha town showed hand dug well was common source of domestic water for entire areas of the town except limited areas of the town where construction of wells were impossible due to hard geologic formation. Depth of these wells varies from place to place based on topography of the location and ground water could be reached even at 4 meters depth in some places. In Masha town, most of the time, hand dug well was constructed during house construction as shown in picture below as it needs plenty of water spatially during dry season. Then after it will continue serving as water source for domestic activities. Surprisingly there were water wells aged above 40 years and still serving as water source. The head of these water wells were constructed traditionally from hollow wood as shown in fig 'B' below and not well protected.

Figure 4-5: Image showing appearance of hand dug newly constructed (A) older wells (B)

Spring Water

In the territory of the town there are springs which people use them as source for drinking water. They are unprotected and flow throughout the year. In dry season the discharge of springs are very low and as seen in figure below people are expected to wait for long time to fetch water from this unprotected source. As spring water users indicated that they were waiting for long time to fetch the water because of low flow of springs. Most of water users fetch water in the morning or evening since it was not school time. As shown in the figure the fetch water in small jerry can and their reason was long distance from their home and using only for drinking purpose. In the town people were going distant water sources even though they have nearby pipe water sources.

Figure 4-6: Image showing people fetching water from spring and situation of the spring in the town

4.3.4 Time Spent in Fetching Water from Distant Sources

As information from survey shows that 70.83 percent of households get piped water source at home or vicinity, about 87 percent households get hand dug well at their compound or nearby and only 4.18 percent household's get spring water at their vicinity. However, of spring water users as a water source, 85.71 percent households reported that they fetch spring water from distant and 50 % of river water users were found the source as distant source. Based on survey result time spent to fetch water from these distant sources for households were as presented in the table below. Regarding to this result, more than half of spring water user households spent more than an hour time in a day to fetch water from these distant sources. This reduces time availability for other day to day activity of people in the town. Waiting time length is expected to vary seasonally and times of a day. In dry time the flow discharge of the spring's decreases and waiting time increases. As have seen in the study area more people fetch water in morning and evening when the off school time.

Table 4-5: Time spent to fetch water from distant sources

No.	Time spent to fetch water	Frequency	Percentage
1	Below 30 minutes	6	22.22
2	30 minute to an hour	5	18.52
3	Above an hour	16	59.26
4	Total		100

The result shows that fetching water from the distant sources was mainly the responsibility of female child (about 50 percent). 33.33 percent study household and 16.67 percent households agree that fetching water from distant source was responsibility of male child and adult females respectively. As the result indicates that, responsibility of collecting water from distant source was majorly of female and male child. It is known that females are busy in many household activities and fetching water become an additional burden to them. In the town, among the family members, female were losing more than an hour only for fetching water daily. This becomes additional challenge for their personal development.

4.3.5 Reliability of water in Different Sources

The availability of water in different water sources for domestic consumption in the town varies due to some factors. The degree of availability of different water sources in the town for the survey households are as shown in the chart below.

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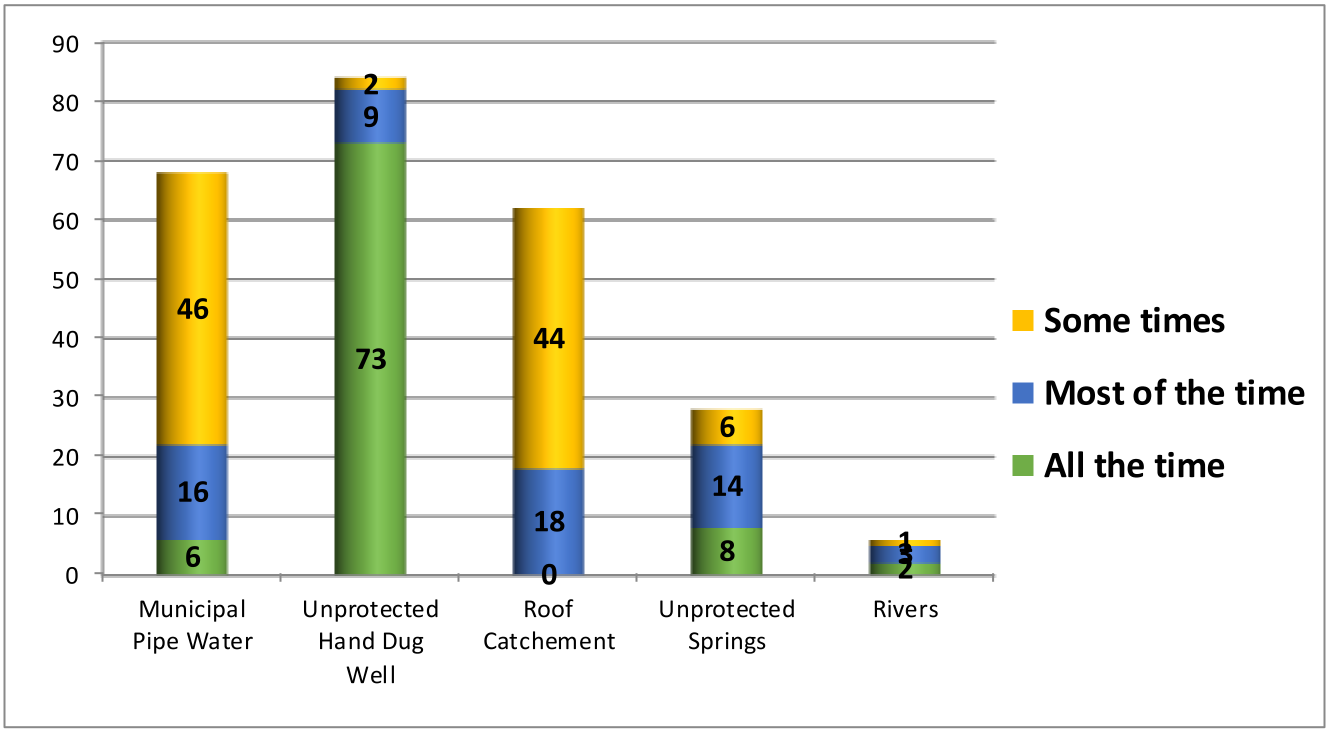

Figure 4-7: Chart Showing Frequency of Degree of water availability for different sources of Households

As presented above in chart, unprotected hand dug well was available all the time for 73 (76.04%) of households, municipal pipe water for 6 (6.25%), unprotected spring water for 8(8.33%) and rivers for 2(2.1%) households. The result points out that availability of unprotected water sources were higher than that of municipal pipe water. Only 6.25 % households replied that they can get water all the time from pipe source and for majority of households it was intermittent. The variation in-service was expected due to location factors, limited supply and operation of the systems. Degree of availability of pipe water can be affected by amount of water required by household and available storages.

As the study shows that, for 16(16.67%) households can get piped water relatively most of the time and about half of resonant households (47.92%) gets relatively sometimes from pipe water source. As the result shows pipe water was unavailable for majority of households that forces them use unprotected sources.

The result indicates that almost all of the dwellers were not getting piped water and they were using unprotected water sources specially hand dug well and spring water sources.

4.3.6 Water Treatments Applied for Different Sources

As respondents reply shows that 95.83 percent of water user household from other sources than piped water were using unprotected water sources without any household treatment or chemical disinfection whereas the remaining 4.17 percent households use water from unprotected by treating using chemicals like chlorine tablets 'Wuha Agar'. The result indicates that home treatment was not common and people were exposed to water contamination.

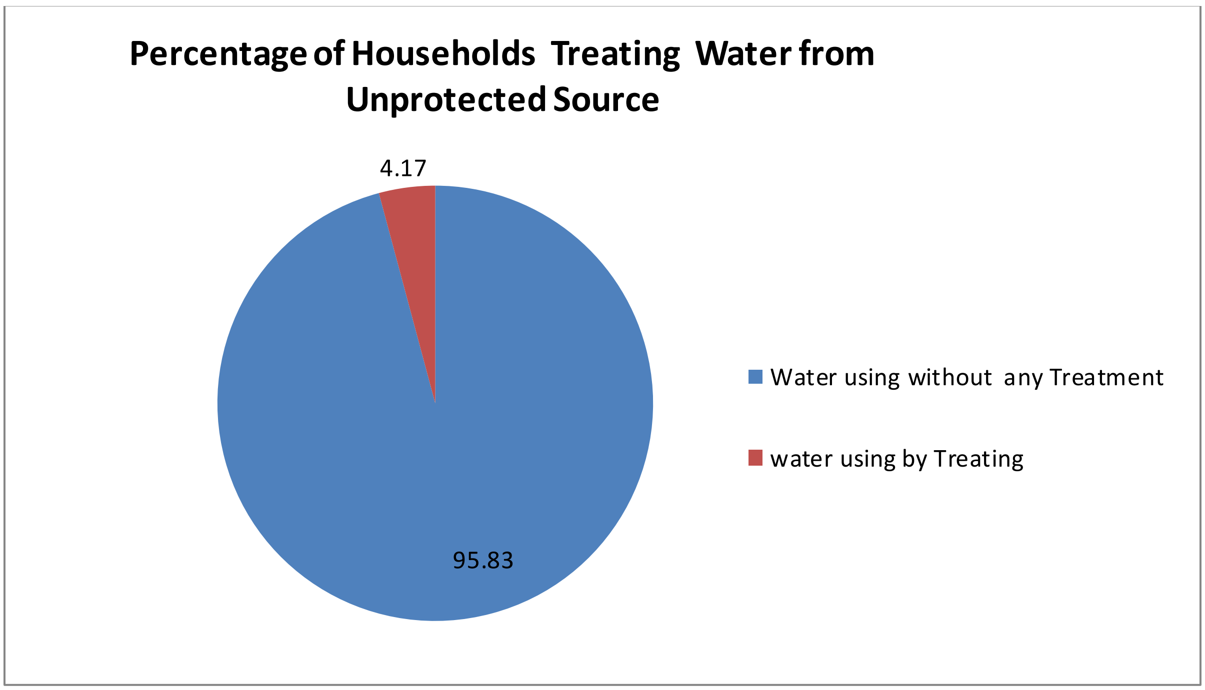

Figure 4-10: Chart describing percentage of households treating water from unprotected sources

4.3.7 State of Municipal Piped Water Service

As the Survey Participant households reply shows that they were using municipal water from different types of connections. These types include connection into dwellings, private tap connection, public taps/fountains and pipe water from vendors. Some of survey respondents use more than one type of piped water source because of intermittent supply and pressure differences in the system. Table blow shows piped water source type for households in the town and majority were using private tap about 33.33% and public tap about and 29.17%. As the figure shows that private pipe users were higher than that of public tape users because of location of public fountains that are concentrated in main parts of the town where most people can get access to different pipe water sources.

Table 4-6: Key aspects of the piped water supply in Masha Town as of the year 2018

No.	Type of piped water connection	Frequency	Percentage of users
1	Piped water into dwelling	2	2.08
2	Piped water to yard/plot	32	33.33
3	Public tap/standpipe	28	29.17
4	piped water from vendor	28	29.17

4.3.8 Availability of Municipal Piped Water Service

As survey shows that municipal pipe water service was unavailable in required amount when the service was needed for all of respondent households. This implies that piped water service is intermittent and there was no water service equity in the town

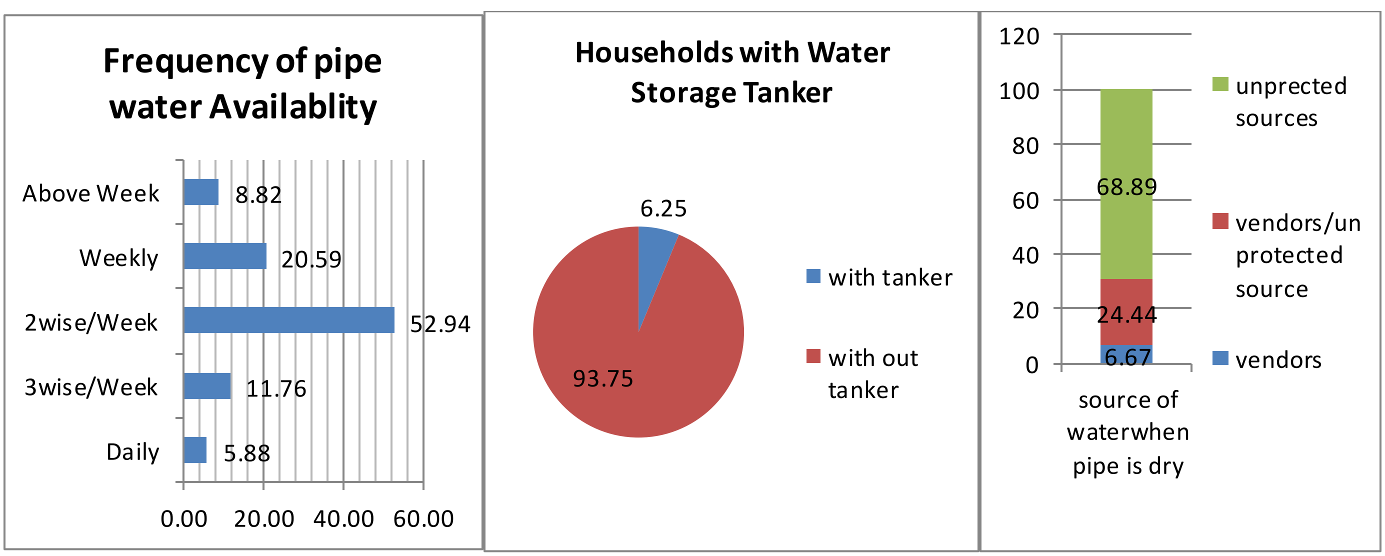

Figure 4-8; Chart showing Pipe water availability, Tanker usage and alternative water sources

With regard to pipe water availability frequency, it was reported that out of respondents, about only 5.88 percent got water daily among pipe water users, 11.76% got three times in a week, majority about 52.94 got two times in a week, and the remaining 29.41 % got water weekly or above week time interval. This result shows the service interruption was series for majority of households and needs coping mechanism to overcome water shortage problem.

Even though, piped water service was intermittent, only 6.25 percent of the households have water tanker for emergency condition of pipe water. The majority about 93.75 percent have no emergency water tanker. This shows that there were other sources of water for domestic activity in which they depend on confidently for these pipe water unavailable days. As the data from survey shows that 68.89 Percent of households use water from unprotected source when the municipal water is unavailable, 6.67 percent use domestic water from water vendors and 24.44 percent use pipe water from either of the sources. Therefore, almost all households in the town are forced to use unprotected water sources or subjected to pay more for water vendors because of unavailability of water sources. Image blow shows women fetching water from unprotected water source as the tap water was unavailable.

In the town there are few residents using water storages equipment except for rain water. This shows that people can get water confidently from other water sources of uncontrolled water safety during interruption of piped water service. This can affect the sustainability of water service by reduced water use and mainly affect the health of people in the town. Therefore, evaluating water supply service of the town and preference of people of water sources is necessary to improve the service and make interventions on water uses to assure the wellbeing of inhabitants of the town by supplying sustainable water service.

Vendors selling water to households or at collection points are common in many parts of the world where scarcity of water or faults in or lack of infrastructure limits access to suitable quantities of drinking-water. Water vendors use a range of modes of transport to carry drinking-water for sale directly to the consumer, including tanker trucks and wheelbarrows or trolleys. There are a number of health concerns associated with water supplied to consumers by water vendors. These include access to adequate volumes and concern regarding inadequate treatment or transport in inappropriate containers, which can result in contamination.

The study result shows that almost all of resonant about 93.75 (those without emergency tankers) were forced to use unprotected water sources or water from vendors in the town.

Figure 4-9:Woman fetching water from Hund dug well while private tap was dry and boy selling piped water for people of the same town

Water Tariff and Cost of Water from Private Connection

The human rights to water and sanitation place obligations on States to ensure that services are affordable.14 this concern is reflected in SDG target 6.1, which calls for universal and equitable access to safe and affordable drinking water for all. Affordability implies that payment for services should not present a barrier to access or prevent people from meeting other basic human needs. While affordability is an important consideration for all households, regardless of service level, there is no commonly agreed-upon way to measure it. (JPM, 2017)

According to the water supply utility office report shows water tariff of Masha town water service was as presented in the table below for different levels of consumptions. A progressive tariff rate with consumption level was applied and the tariff was not revised since 2015.

Table 4-7: Current Water tariffing at Masha town

Consumption level (m^3)	Tariff Rate(Birr/m^3)
Up to 5	5
6 to 10	6
11 to 20	7
21 to 30	8
Above 30	9

Source: Masha Town Water Supply Utility office

The ranges of house hold monthly expense for majority (about 70 percent) of households were from 11 to 20 birr per month. For about 80 percent of households monthly water bill is less than 20 birr. This result indicates that the households were using less than 4 m3 in a month and computed with average family size of households (4.2); water consumption was 15.87l/c/d to 31.75l/c/d. the result indicates that there was low consumption of water from piped water in the town.

The amount of monthly bill is affected by availability of water in the system, preference of water sources and income level of the households. However in Masha town water interruption level was very high and water use from pipe water was limited. Most of private tape users/house connection users, about 88.64, agree that water tariff was fair and the remaining 11.36 find that the tariff was high. Therefore the result shows that water was affordable for majority of households however they were not fully depend on it.

Table 4-8: Amount of average monthly bill of private water users

Average bill/month (Birr)	Frequency	Percentage
Less than 10	4	9.10
11 to 20	31	70.45
21 to 30	6	13.64
31 to 40	2	4.54
41 to 50	1	2.27
Above 50	-	-

Of total respondent 29.17 percent use water from vendors in case of water interruption. The cost of one Jerri cans (20liters water container) water from vendors for households in the towns were different because of distance of pipe water from which water was transported. For 85.71 percent of households using water from vendors the cost of on Jerri can (20liters water container) ranges from 3 to 5 Birr and for 14.29 percent it was from 1 to 3 Birr. Weighted average cost of water vendors was 3.71. The common cost of water from public tap user households for a Jerri can (20liters water container) was 50 cents and comparison of pipe water cost from different water source types were presented in the graph below.

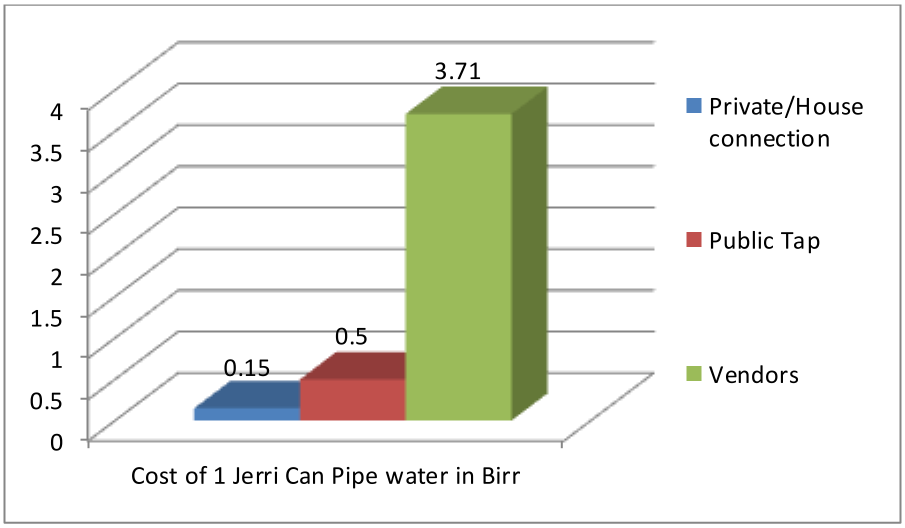

Figure 4-10; Chart describing cost of piped water from different sources

As shown in char above the cost pipe water was highest from vendors and least for households using private water taps or house connections. They pay for vendor for a Jerri can (20 liters) about twenty five fold from that of privet water meter owners. The result shows that water service interruption was highly costing households of the town and it may limit water service from pipe source. These high water venders service cost forces households to consume water from unprotected sources.

Initial cost of private or house pipe connection was high for 28(82.35%) of private water meter owners and fair only for 6(17.65%) of households. This was due to nature of settlement and limited distribution system in the town.

4.3.9 Quality of Pipe Water for Drinking

Regarding to water quality of municipal pipe water, majority of the respondents, out of 68 pipe water service users, about 65 (95.59 percent) were find the quality of pipe water is not good. For 3(4.41%) of household the quality was fair and no respondents find it very good or good quality. As presented in the Chart below, most of study households from pipe water users, about 82.35 %, detected disturbing color, 38.23% find unpleasant taste, 11.76% detected odors and 8.82% detected water is turbid.

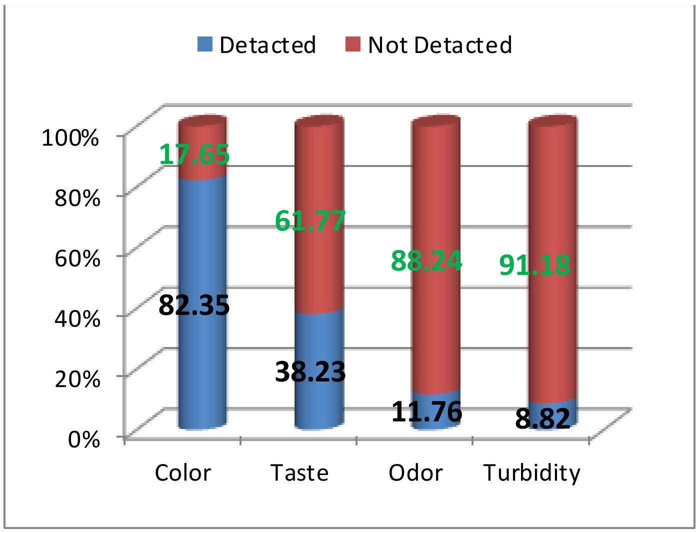

Figure 4-11: chart indicating percentage of households sensed quality problem and image showing comparison of bottled water with piped water

The result shows that the quality of pipe water was not good as it was reported by households and it never fulfils safe water standards. As also observed on site, color of pipe water was detectable using necked eye as in the picture above. Pipe water was having Poor esthetic condition for study household.

4.3.10 Perception of Households about Pipe Water Service

No consensus has been reached on acceptable standards of drinking water quality for communities in rural areas of developing countries. Many studies consider the setting of water quality standards the sole responsibility of experts or planners because of the technical nature of the issue. However, Sheat (1992) has stressed that planners must acknowledge the importance of water quality perception among the water users. He argues that perception may very well become more important than reality, especially when it comes to the quality of drinking water. Among local people, this perception is based on their indigenous knowledge and should be taken seriously. Among rural households, this knowledge is largely abstract, and is usually based on qualitative observations of their daily lives and the surrounding natural environment (Gonzalez 1995). Moreover, the households perceive the knowledge about quality of water through the understanding of their culturally constructed concepts and definitions.

The sample households were asked whether they are satisfied at the current water supply or not? Concerning this, as it is indicated in Table, all of the respondents reported that they were unsatisfied with piped water service of Masha town water. Even, no household was partially satisfied with the service.

Regarding to the causes of dissatisfaction, among 62 household respondents who filled the question properly, the primary reason for their dissatisfaction was service unavailability when required for 41 (66.13%) and inadequate water quality for 21(33.87%) respondents. The secondary reason of dissatisfaction was inadequate quality to 40(64.52%), service unavailability to 18(29.03%) and high initial connection cost to 4(6.45%) study participants. Most of the respondents about 48(77.42%) and 58(93.55%) replayed that the tertiary and least cause for their dissatisfaction of pipe water service was initial connection cost and high water tariff respectively. Therefore, the result clearly shows that the two major causes of dissatisfaction in water services were service unavailability when needed and inadequate water quality. Dissatisfaction in pipe water service degrades water use from the source and increases dependence on water sources of unknown quality.

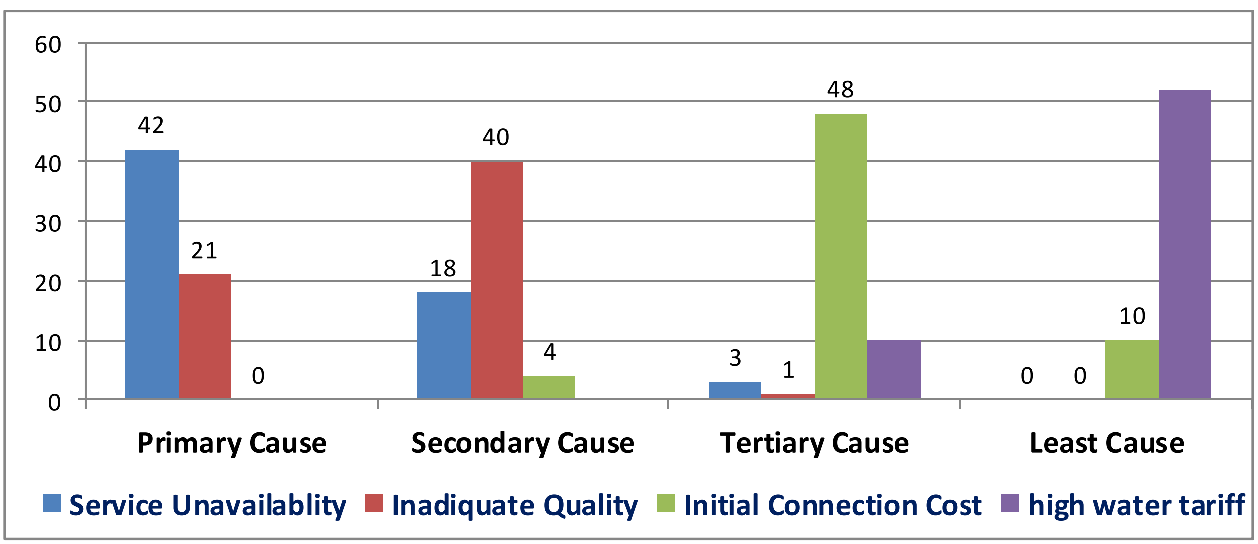

Figure 4-12: Chart showing degree of causes for household dissatisfaction in water service

4.3.11 Effect of Inefficient Piped Water Service

Regarding the effect of poor water service of the town, out of total 96 participants respondents 78 (81.25 percent) of survey households reported that they were forced to depend on unprotected sources, 25 percent reported that they found difficulty in doing economic activities, 79.17 percent reported that they were vulnerability to water born disease and 18.75 percent reported that poor school attendance and performance in education of pupils were effect of limited water service. As the result shows that dependency to unprotected water and vulnerability to water born disease were the main effect of poor water service of Masha town for majority of households.

4.3.12 Efficiency of Masha Town Water Service Enterprise

As Technical Manual for Urban Water Supply and Sewerage Utilities, FDRE Ministry of Water and Energy, March 2003, stated that basically the customers need from the water utilities among others are;

- Provision of adequate water with standard quality and adequate pressure all the time,
- Reasonably affordable service charge for all services (financial, technical and management efficiency),
- Efficient and transparent customers' service, i.e. connection, maintenance, payment,
- Full information on the services of the utility,

As reported by household respondents, 60.29 percent of pipe water users got efficiency and transparency of consumers' service was not good and 22.06 percent got fair efficiency, transparency of consumers' service, 17.65 percent also agreed that efficiency and transparency of consumers' service was good and very good for none of the households. The efficiency and transparency of consumers' service depends on human resources, available logistics, technology they are using, organizational structures, condition of offices (working environment) and skills of workers. The result of the study shows that, efficiency and transparency of consumers' service of the enterprise was not good.

Among pipe water service user households' 33.80 percent have applied for new service or forwarded claims about the service legally to the enterprise. Out of these legal requested 23 respondents only 26.09 Percent of respondents have got timely response, majority 56.52 % got late response and the remaining 17.36 haven't got any response. The result shows that majority of customers are not getting timely response for the new services requested and not getting answers for their claims on water service and service provisions.

As the survey for respondent households shows that 72.06 % percent did not get new information about service and only 27.94 percent households got latest information about the service. These households got information by means of loudspeaker. Even though, the town is not that much big latest information about the service must be available to majority of the customers. Failing to address information affect people when there is conditions like system clearing using hyper chlorination and longtime service unavailability of treatment plant clearing.

4.4 Water Quality Test Result Analysis

4.4.1 Overall Assessment Results in the System

In assessing the quality of drinking-water, consumers rely principally upon their senses. Microbial, chemical and physical water constituents may affect the appearance, odour or taste of the water, and the consumer will evaluate the quality and acceptability of the water on the basis of these criteria. Although these substances may have no direct health effects, water that is highly turbid, is highly coloured or has an objectionable taste or odour may be regarded by consumers as unsafe and may be rejected. In extreme cases, consumers may avoid aesthetically unacceptable but otherwise safe drinking water in favor of more pleasant but potentially unsafe sources. It is there-fore wise to be aware of consumer perceptions and to take into account both health-related guidelines and aesthetic criteria when assessing drinking-water supplies and developing regulations and standards. (WHO, 2006)

Based on water sample test from different locations in the distribution system the test result of Mn, Fe, PH and free chlorine was found as presented in the table below. The concentration of iron and manganese at river source in intake point was found to be 1.88 mg/L and 0.005 mg/L respectively. Existing water supply treatment system incorporates cascade aerator component for iron removal and just after aeration the result of Fe concentration was 1.7 mg/l. The concentration of Mn were 0.005 mg/L and PH were 7.77. Only 9.58 percent of total Fe were removed by cascade aerator oxidation process. After final treatment the concentration of Fe and Mn were found to be 1.06 mg/L and 0.004 mg/L. Only 43.62 percent of total iron from raw water was removed after final treatment. Based on WHO guide line and Ethiopian guide line for drinking water the iron concentration and Mn concentration should be less than 0.3 mg/L and 0.5mg/ L respectively. The result indicates that Fe concentration is far above the recommended values where as both manganese concentration and PH are in line with standard value. Free chlorine was nil in all of the samples tested in the treatment units and distribution system. The test result indicates that there was no disinfection by chlorine or inappropriate chlorination. Therefor the service has high risk on bacteriological contamination in distribution systems and household storages as there was no free chlorine. Nowadays it is comment to hear outbreak of cholera and waterborne diseases in African country and even in our country. Improper disinfection of treated river water can attack hundreds and thousands of people even within a day if water gets contaminated. Below chart indicated that the iron concentration of raw water was not treated to the level required after complete treatment. The final treated quality of water may vary from time to time because of maintenance and clearing of filter sand media and even gravels. However this study was conducted in time where the sand was not clean. In figure 4-15, water quality testing in river source and at private tap was displayed and the color of water sample to be tested after addition of Mn and Fe tablets was seen. In table 4-9 below test result of water sample in different locations were presented and as the result clearly showed that the iron content was high and the cause for water quality degradation that as sensed by most of the households were expected to be high iron in the piped water.

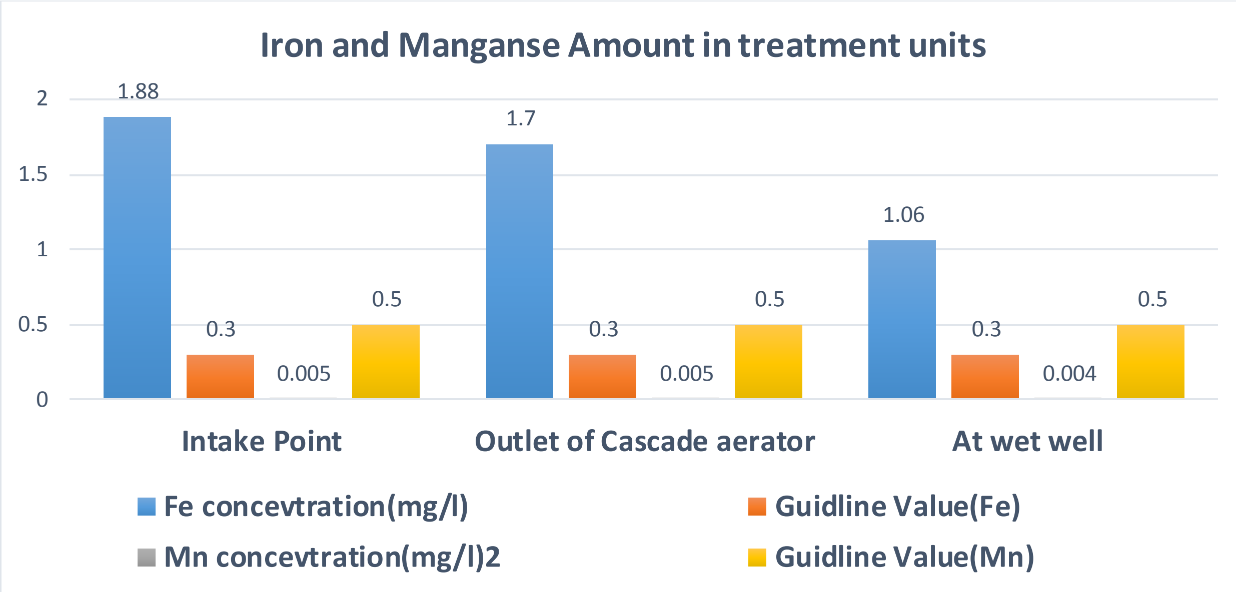

Figure 4-13: Chart describing iron content of raw water and in treatment plant units

Figure 4-14: picture showing water quality testing in the site (Intake Point) at Private Tap

Table 4-9: Test results of Masha town piped water service in March 2019.

Coordinate		Total Iron(mg/L)	Total Manganse (mg/L)	PH	Free Chlorine(mg/L)	Remark
latitude(N)	longitude-E					
7.743245	35.475727	0.97	0.006	7.47	nill	Reserviour at Town
7.745417	35.472583	1.09	0.005	7.25	nill	Reserviour at Church
7.733861	35.479702	1.57	0.003	7.38	nill	Private Tap
7.739124	35.482489	1.67	0.006	7.46	nill	Private Tap
7.739128	35.479791	1.55	0.004	7.33	nill	Puplic Tap
7.740767	35.477912	1.49	0.006	7.39	nill	Private Tap
7.738894	35.479085	1.54	0.006	7.49	nill	Private Tap
7.740349	35.477362	1.52	0.007	7.32	nill	Private Tap
7.740818	35.476926	1.43	0.006	7.71	nill	Private Tap
7.741617	35.474637	1.41	0.005	7.23	nill	Private Tap
7.742638	35.476312	1.27	0.005	7.75	nill	Puplic Tap
7.743095	35.474851	1.38	0.007	7.18	nill	Private Tap
7.744252	35.474299	1.37	0.006	7.34	nill	Private Tap
7.744726	35.473532	1.15	0.007	7.16	nill	Private Tap
7.745644	35.47057	1.45	0.005	7.38	nill	Private Tap
7.747105	35.47057	1.25	0.006	7.19	nill	Private Tap
7.748181	35.466739	1.46	0.005	7.73	nill	Private Tap
7.747535	35.466739	1.47	0.007	7.36	nill	Private Tap
7.739498	35.468241	1.42	0.006	7.36	nill	Private Tap
7.74341	35.477594	1.42	0.005	7.48	nill	Puplic Tap
7.741883	35.478699	1.41	0.005	7.73	nill	Private Tap
7.745184	35.47943	1.44	0.004	7.56	nill	Private Tap
7.745814	35.475903	1.35	0.003	7.38	nill	Private Tap
7.746546	35.474802	1.42	0.006	7.67	nill	Private Tap
7.74745	35.475512	1.46	0.004	7.41	nill	Private Tap
7.748734	35.474594	1.48	0.004	7.43	nill	Puplic Tap
7.74847	35.476265	1.43	0.005	7.75	nill	Private Tap
7.747703	35.47901	1.49	0.005	7.46	nill	Private Tap
7.747983	35.47778	1.35	0.007	7.28	nill	Private Tap
7.752389	35.477549	1.51	0.005	7.86	nill	Private Tap
7.749941	35.474943	1.48	0.004	7.46	nill	Private Tap
7.751441	35.473012	1.54	0.006	7.71	nill	Private Tap
7.750794	35.470375	1.56	0.004	7.48	nill	Private Tap
7.75203	35.476318	1.47	0.006	7.69	nill	Private Tap
7.754113	35.474477	1.53	0.004	7.18	nill	Private Tap
7.753718	35.474678	1.51	0.005	7.64	nill	Private Tap
7.754048	35.478803	1.41	0.007	7.63	nill	Private Tap
7.753392	35.486145	1.56	0.006	7.56	nill	Private Tap
7.755563	35.479098	1.39	0.006	7.65	nill	Private Tap
7.758198	35.478111	1.47	0.004	7.49	nill	Private Tap
7.757928	35.479851	1.58	0.006	7.66	nill	Private Tap
7.761215	35.476454	1.56	0.005	7.67	nill	Private Tap

Source: water quality test result.

As the statistical result of water test shows that the average concentration and ranges of Fe, Mn and PH values at private tap and public fountains were as presented in the table below.

Table 4-10: Range and average concentration of Fe, Mn and PH of pipe water

Statistics	Iron(mg/L)	Manganese (mg/L)	PH	Free chlorine (mg/L)
Average	1.43	0.0053	7.48	Nil
Max	1.67	0.007	7.86	Nil
Min	0.97	0.003	7.16	Nil
Range	0.97-1.67	0.003-0.007	7.16-7.86	

The result of the test conducted showed that there is high concentration of total iron in water supplied to Masha town. Literature in a report by the Central Statistical Agency of Ethiopia in collaboration with the Ministry of Water, Irrigation and Electricity (MoWIE), LSMS, World Bank, UNICEF, WHO, and JMP (2017) classifies chemical and physiochemical risk category as below in table.

Table 4-11: Chemical and Physicochemical Risk Categories

Parameters	Risk category		
	low	Moderate	High
Iron	<0.3 mg/L	0.3-1.0 mg/L	>1.0 mg/L
Chlorine residual	<0.2 mg/L	0.2-0.5 mg/L	>0.5 mg/L

Source: CSAE (2017)

Based on above classification Masha town pipe water is under high risk category in total iron parameter. Residual chlorine amount was nil and it indicates that there is no disinfection or inappropriate disinfection of water that has high health risk for water users. Free chlorine in the water controls further contamination and recommended values is less than 0.5ml/l reduce the effect of residual chlorine. As report from Sheka zone water energy and mines department water quality department showed that bacteriological test were conducted and coliform organisms were detected in tap water. Therefore, water supplied to town was poor quality based on the guide line interims of iron level and chlorine residual.

The free chlorine concentrations at the customer's tap should preferably be in the range of 0.4–0.6 mg/L for aesthetic reasons and always below the health-based guideline value of 5 mg/L.

For effective disinfection, there should be a residual concentration of free chlorine of ≥ 0.5 mg/l after at least 30 min contact time at pH < 8.0. A chlorine residual should be maintained throughout the distribution system. At the point of delivery, the minimum residual concentration of free chlorine should be 0.2 mg/l. (WHO, 2011).

4.4.2 Iron Concentration Variation in Distribution System

In a surface water supply iron and manganese may be present due to their dissolution from the associated geologic formations and/or from the decomposition of organic materials. For example, anaerobic conditions on a reservoir bottom may cause the dissolution of iron and manganese from the bottom sediments. When seasonal overturns occur due to temperature gradients, this dissolved iron and manganese will be distributed throughout the water supply. Although increased levels of iron and manganese may occur during periods associated with overturns, it is also very likely that these elements will be found at objectionable concentrations throughout the year. (John F. and Harold L, 1983)

The cause of deteriorating water quality may be sediments which build up on the inside of pipelines. The research performed has shown that iron sediments may occur inside water supply pipelines at iron concentration of 0.05 mg·dm-3. This leads to an increase in iron concentration despite of good water chemical composition when pumping water into the network. This is caused by picking off sediments due to changes in water flow direction or rate in water distribution network and iron penetration into water by its dissolution. It has been demonstrated that in the latter case an appropriate oxygenation can inhibit the diffusion of Fe (II) from the sediment into tap water [Weber 2010].

A plurality of factors determining drinking water quality causes that the quality is a function of many parameters that have a different and variable contribution in the final microbiological and physicochemical composition. The factors associated with water, hydraulic conditions in the network, pipe material and sealing and network structure play an important role. (Jachimowski A., 2017)

The concentration of Fe and Mn were analyzed based on sampling location from reservoir and the result were presented as in table below.

Table 4-12: Chemical and Physicochemical Risk Categories

Distance from reservoir	Average Fe(mg/l)	Average Mn (mg/l)x100
<500	1.313	0.6
500-1000	1.414	0.5
1001-1500	1.519	0.6
1501-2001	1.473	0.5
>2001	1.567	0.6

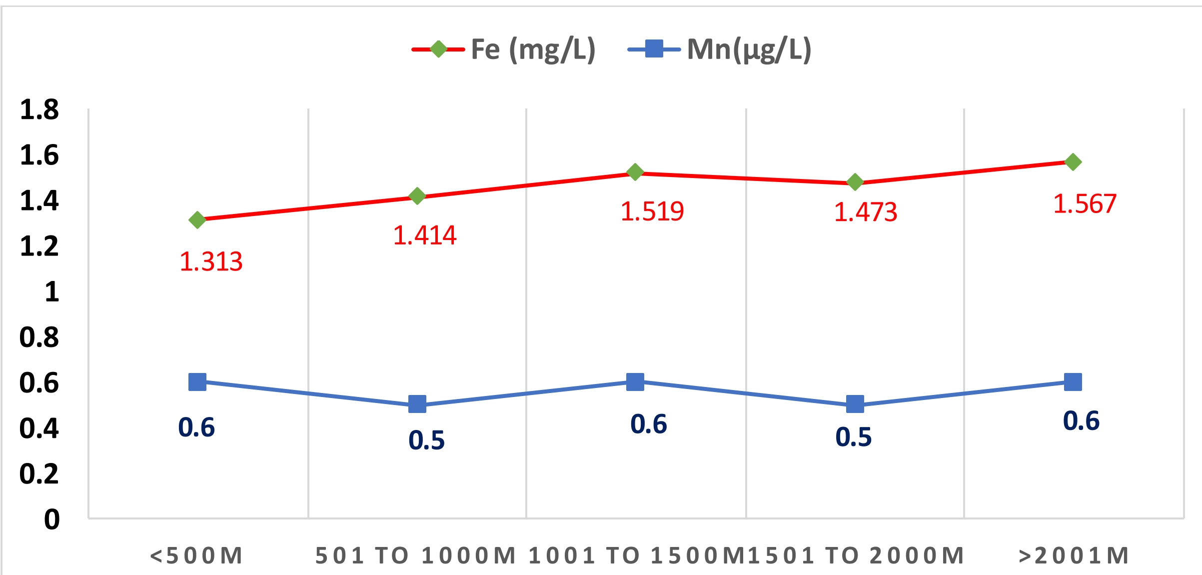

Figure 4-15: Graph showing variation of average Fe& Mn contents in the distribution system with distance from central reservoir

As the result in graph clearly shows that average concentration of Fe increased as sample site gets far from storage reservoir. Average concentration of manganese has no unique trend and it shows fluctuation throughout length of distribution system. The average concentration of iron has declined in distance from 1501 to 2000 meters and this was due to factors affecting concentrations like water pressure. As the result indicates that water users far from reservoir are more affected by high concentration of Iron. Most of newly developed parts of the town were more affected as the end users of water from the system. The increase in iron concentration was due to old iron pipes and highly intermittent supply of the water service in the town that promotes corrosion.

The reason for high concentration of iron in water service were mainly from river source. In addition to this iron concentration was slightly increased in distribution systems due to aged water pipes of the town and sediment deposits as reviewed in literature. This high concentration of iron in the system was cause for poor esthetic of the pipe water in the town.

4.4.3 Microbiological states of Masha town water service

As the very recent biological test result of distributed water at different sources in Masha town indicates that there were detectable microorganisms in distributed water. Sheka zone water, energy and mines department, water quality department, has conducted microbiological taste at different locations in the town from water tap and the test result was as shown in the table below. Based on National Guide line of Ethiopia the acceptable value for both coliform organisms and E-coli is zero. However both coliform organisms and E-coli were detected in the water for all of the samples tested and it is unacceptable based on the guide line value of the country. Test result is attached with this research report.

Based on chemical test result of this study free chlorine in all of the sample site were zero and people were highly exposed to water born disease due to this microorganisms.

4-13: Microbiological test result of piped water of Masha town water service

Sampling site	Total coliform in 100 ml of water	E-coli in 100ml	Remark
Central Reservoir	12	3	
Selam sefer	7	5	
Aroge maremiya	13	6	
Tsehay Gibat	8	6	
Metrologi sefer	7	4	

4.5 Model Based Assessment Results of Existing Water Supply System

4.5.1 Demand of Each Junction

Based on housing density classification mash town existing settlement was evaluated and total number of housing units in town was found to be 4616.39. Based on this the average number of people in a house was 4.33 which is not far from number of people in a household as surveyed in the study by questioner which was 4.2. Based on global mapper software the catchment of demand area of each junction were analyzed by overlaying Thissen polygon and structural map of the town.

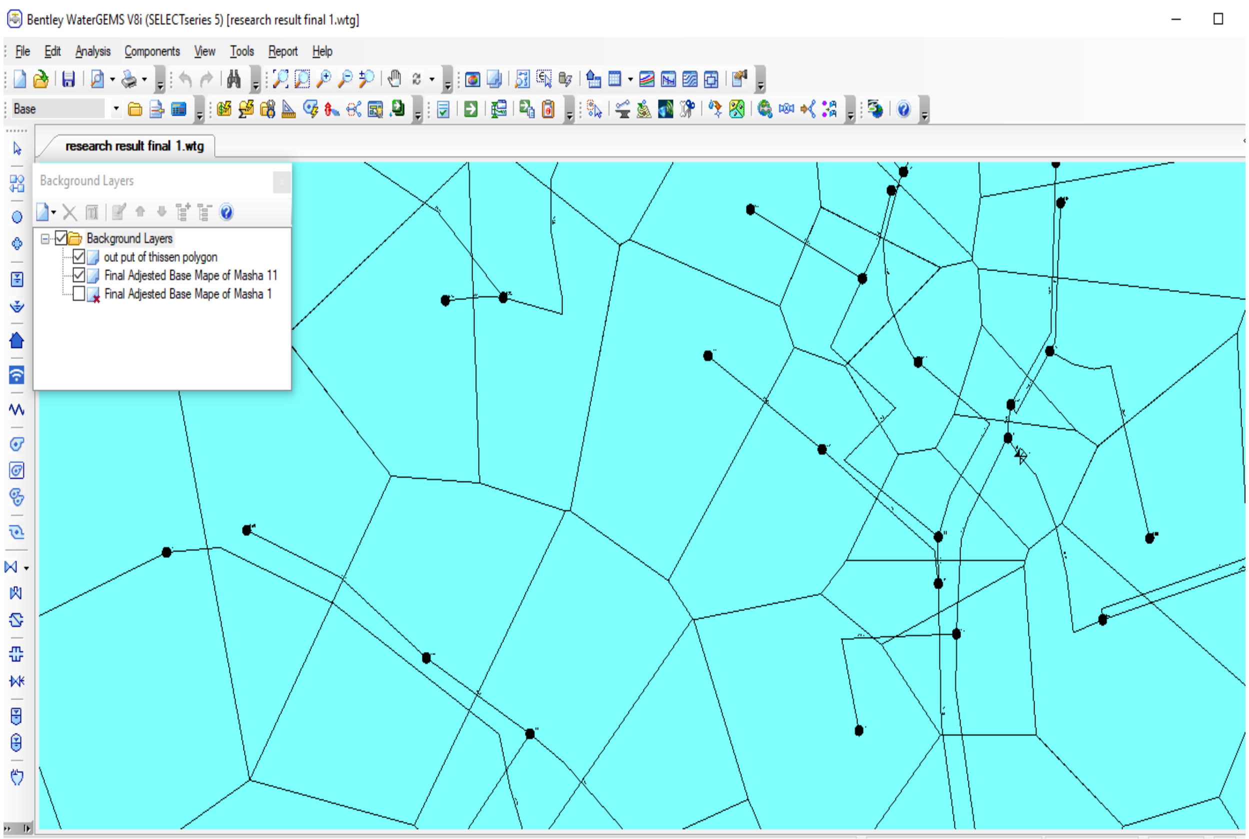

Figure 4-16: Image showing Thissen polygon for Junctions

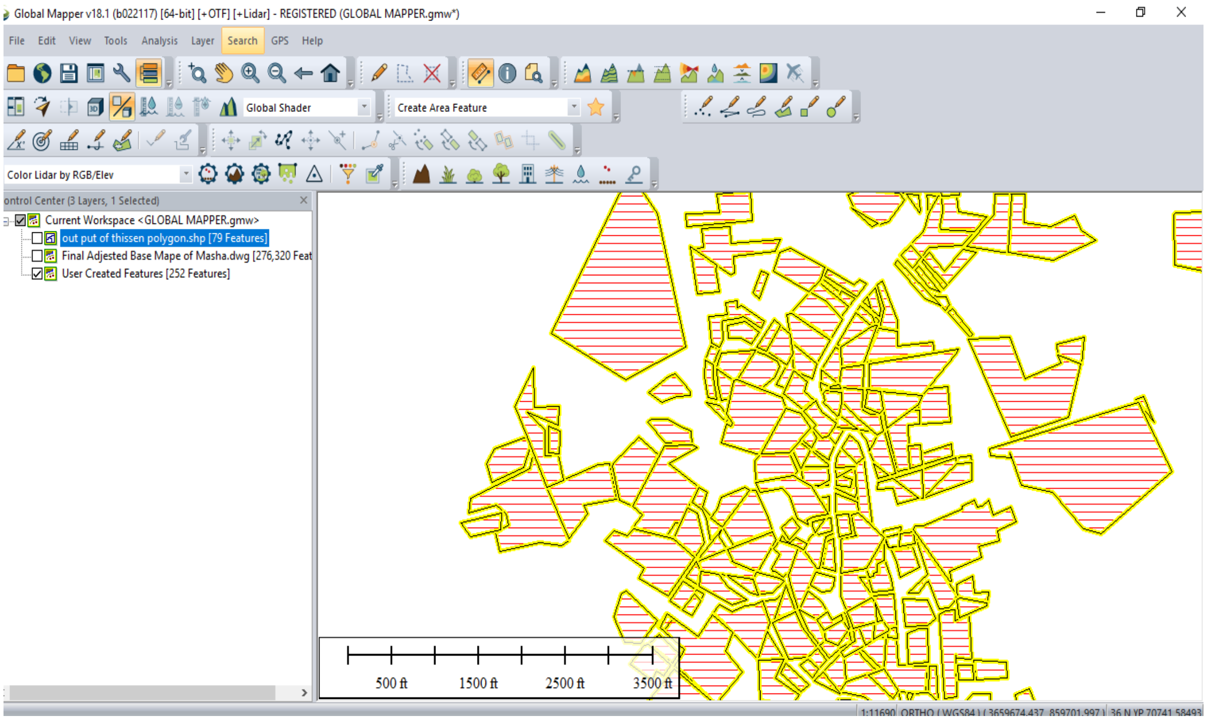

Figure 4-17: Image showing land percales of the town divided for each junction

Based on housing unit weighted Thissen polygon method, number of houses for each junction catchment were detected and corresponding number of people were allocated for each node as values in table attached in annex-3.

To evaluate existing performance distribution system current supply for each node was computed by distributing daily pumped water to nodes in proportion of nodal demand. The last column of annexed table is the result of the computation.

4.5.2 TRex Development for Elevation Data

Using Alaska DEM (12x12 resolution) of the study area contours map of the area was generated and exported in DXF format to use in WaterGEMs software. Then using the software TRex tool the DXF file was selected as data source type and the saved DXF file was used as source file to generate the elevation of elements of model that automatically assigns the value to corresponding elements in Flex table. However the result of this TRex developed was found inifficent and actual elevation from topo map were used as an input for model elements.

4.6 Software Modeling Result and Analysis

The aim of distribution system design is to supply water at adequate pressure and flow. Loss of pressure can allow entrance of contamination and optimize water age in the system. Pressure at any point in the distribution system needs to be maintained within a range to avoid pipe bursts due to high pressure while maintaining minimum flow rates at all expected demands.

The existing system capacity was checked by modelling for different system and operating conditions to know its effects on flow velocity and distribution pressure. Low water pressure in the system affects equity in distribution. Low velocity also affects the quality of water by increasing water ages in the pipe and deposition. In this study different state of operation including peak design flow, minimum design flow, existing water supply condition flow and scheduled flows based on valve operation were analyzed based on World Bank design criteria described below.

Recommended Values (World Bank Water Supply Design Manual)

1. Minimum line pressure = 3 meters

2. Maximum line pressure = 70 meters

3. Maximum velocity of flow in pipes:

a. Transmission Line = 3.0 m/s.

b. Distribution Pipes = 1.5 m/s

4. Minimum flow 0.6m/s

4.6.1 Analysis of distribution system for Designed Flow

Peak Flow Condition

Peak time flow is the flow when most of demand were satisfied and water use from the distribution system was high. Most of the time the pick hour times are in the evening and early in the morning. High flow velocity and low pressure were expected during peak flow time but the system velocity modeled was find below recommended values for most of flows in the pipe lines. However the flow velocity was moderate that is above 0.2m/s for most of the distribution pipe. Water Pressure in the junctions were within recommended values for most of the junctions as shown in figure below. However in central part of the town and some remote areas were with pressure below recommended values. This result indicated that design pipe size were not appropriate and unnecessary large pipes were installed for the distribution system

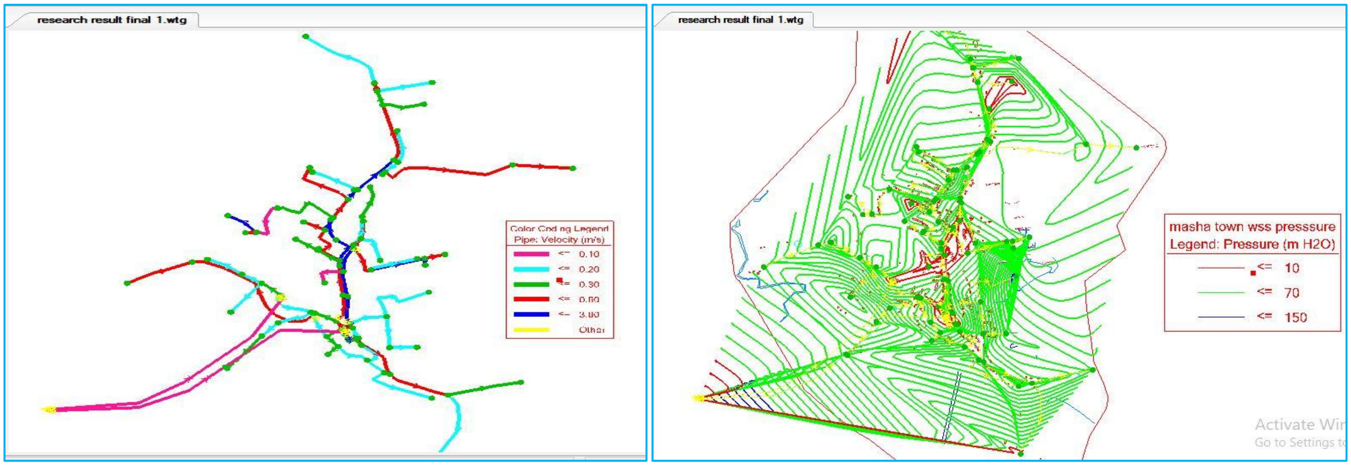

Figure 4-18: Figure showing pressure and Velocity variation in case of peak flow condition

Minimum Flow Conditon

Minimum design flow is the flow when level of water increases and less demand for water is detected. Low flow velocity and high pressure in the system is expected during minimum flow time. In mid night minimum flow is expected. Based on model result velocity of flow for allmost all pipes were low and below recommended value due to inappropritdesign. Supply pressure were almost within recommended values for the junctios. The the centeral part of the town were not getting water with required pressure even in the time of these minimum flow.

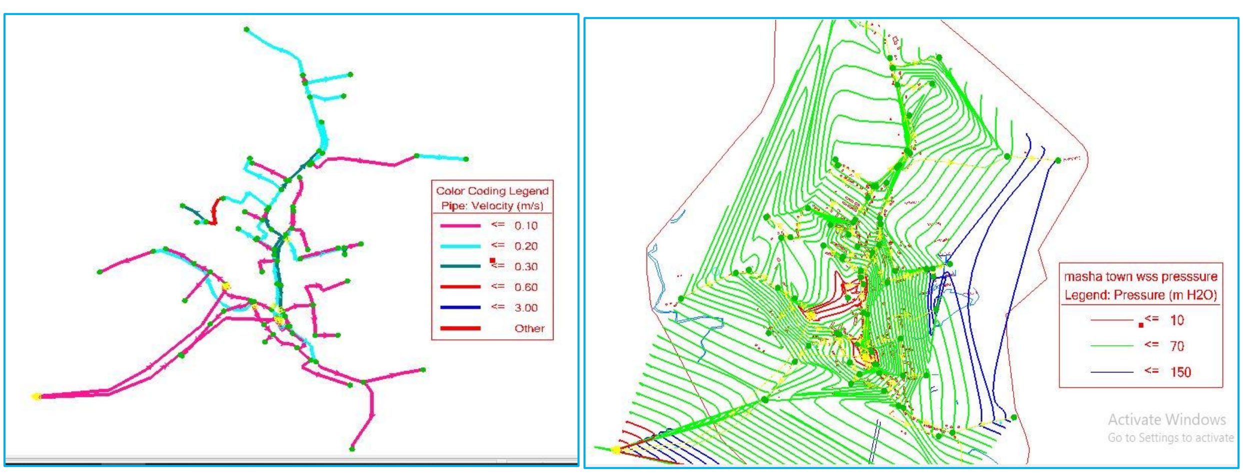

Figure 4-19: Figure showing pressure and Velocity variation in case of minimum flow condition

Flow in Existing Supply Condition

After modeling the existing situation of Masha town water supply distribution system and calibration, out put pressure contour map was reported as shown in figure below. The existing flow rate was below minimum flow that was 2.2 l/s and the velocity of flow were further reduced to nill to some points in the distribution system. As the contour shows that in some parts of the town like in center of the town where the reservoir was situated the system supplies water in low pressure. In central area of the town where high story buildings were under construction water pressure were not adequate to supply houses. Therefor the distribution system cannot deliver sufficient water with adequate pressure for these areas. In some areas of the town pressure was found to be above recommended value as shown in the analysis result. Based on the pressure contour the low pressure junctions were concentrated within limited area and this has opportunity to supply water by zoning this area with special consideration. The analysis result of the model for each junction was annexed in the research report.

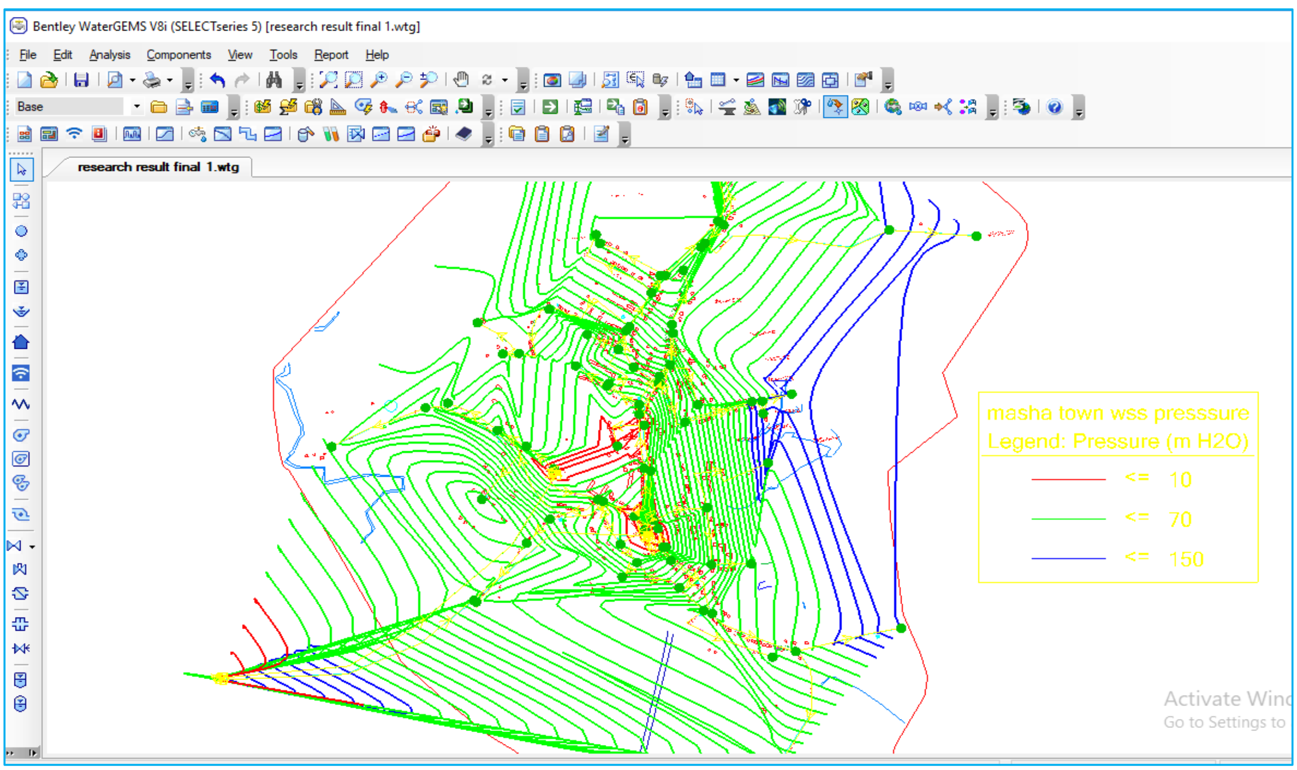

Figure 4-20: Figure showing pressure contour of Masha town based on recommended values

Based on the velocity criteria, existing water distribution model result was coded by color as shown in figure below. All of the velocity were below 0.2 m/s that was below the recommended value of 0.6m/s. The result indicated that distributed water amount was minimum as compared to its designed velocity because of less supplied water and minimum flow rate. This reduced efficiency in water treatment and pumping resulted in low velocity in distribution system that can further degrade the quality of water due to increased water age and deposited. Underutilization of water supply distribution systems can affect the quality of water as in case of Masha town.

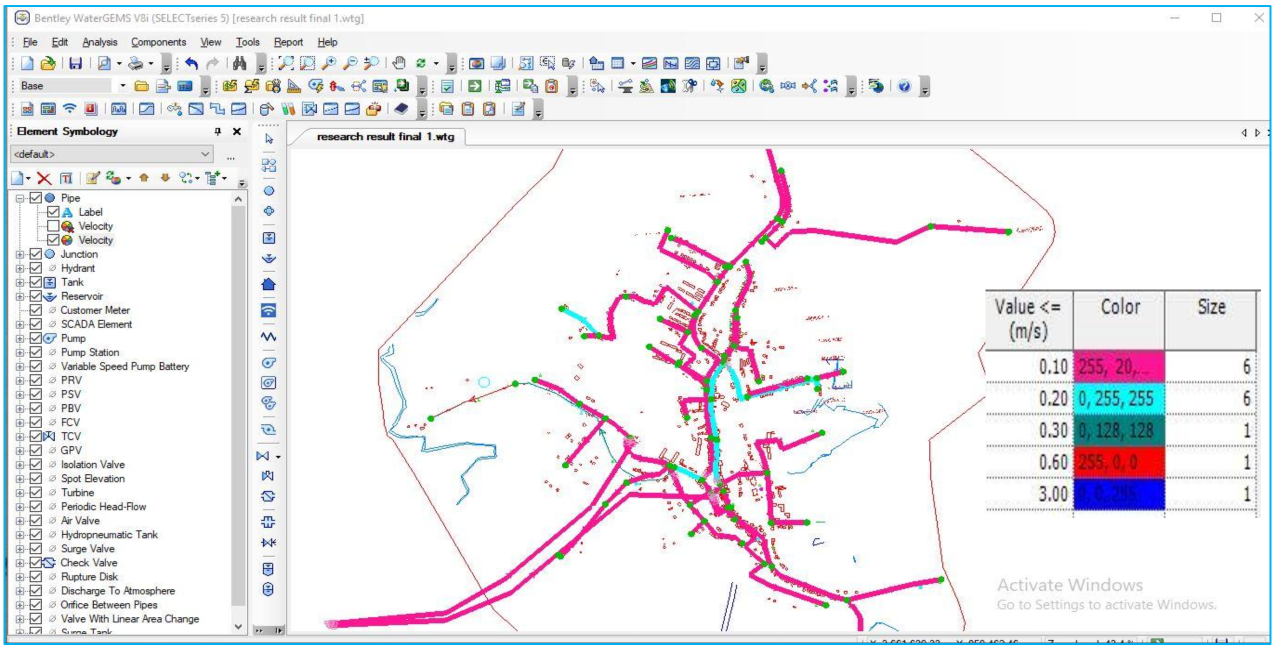

Figure 4-21: Images showing the velocity of the water in the distribution system using color

4.6.2 Modelling of the system based on scheduling

As water production at source was limited, distributing water for entire system at the same time can affect water equity distribution and only some of the areas were benefited from the system based on the available pressure. To improve water distribution efficiency during such limited flow conditions it is recommended to use shift base supply using appropriate placing and operation of control valves. In the model by opening and clothing TCV-3 and TCV-6 in the same time and TCV-7, TCV-9 and TCV-10 in other time the flow condition were analyzed. The shifting time were for a day and full production were supplied for part of the town that increased water distribution equity. TCV-9 and TCV-10 were not actually found in the system and it was proposed to divide the flow for nearly equal demand area in the system. Based on the analysis pressure contours for both schedules were as seen in the figure below.

When TCV-3 and TCV-6 open **When TCV-3 and TCV-6 were clothed**

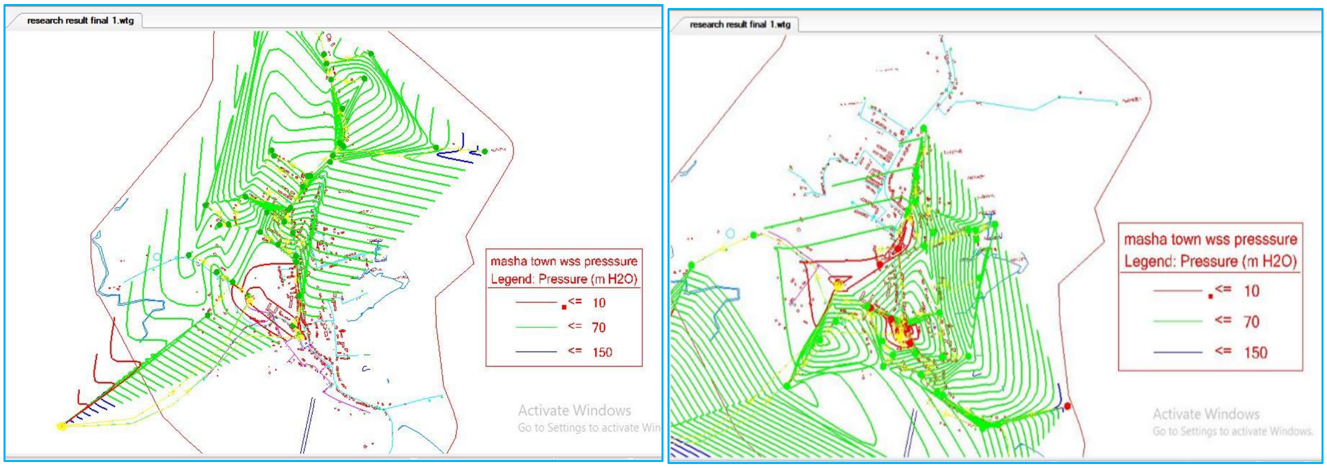

Figure 4-22: Figure showing pressure variation in case of scheduled flow condition

The velocity of flow were improved to some extent by using the shifted schedule. Even though continuous flow were designed to supply water in the town because of this limited production and pumping capacity, shifted distribution significantly improve the water distribution in the town. The variation of velocity in the system were as presented below.

When TCV-3 and TCV-6 open When TCV-3 and TCV-6 were clothed

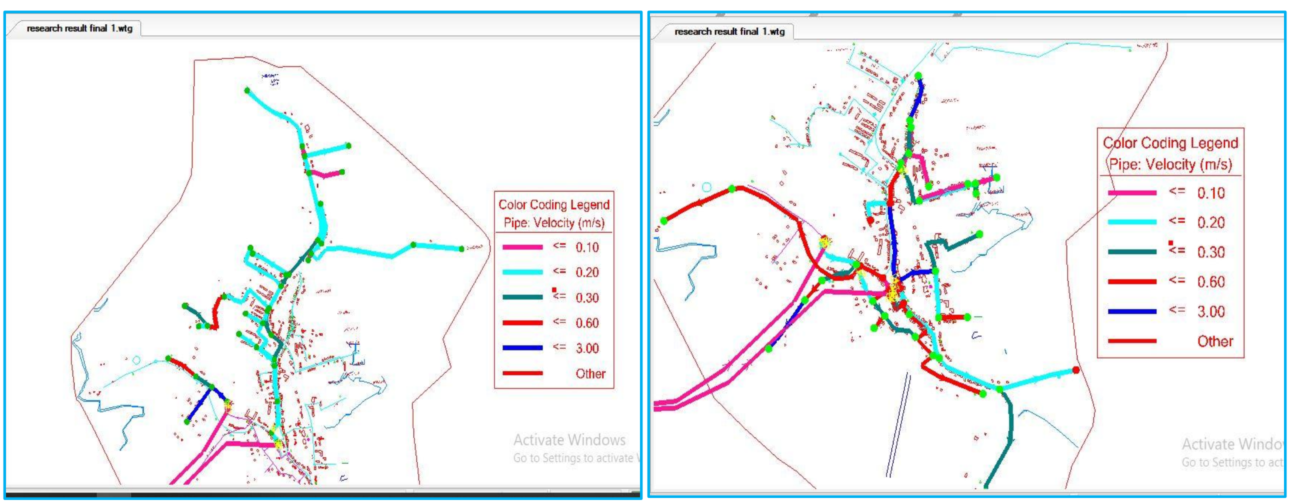

Figure 4-23: Figure showing velocity variation in case of scheduled flow condition

4.6.3 Comparison of Flows in Different Operation Conditions

As presented in the graph peak design flow, minimum design flow, existing supply condition flow and scheduled flows pressure variations in junctions were shown. As the graph result indicates that most of the junctions gate water from distribution system within recommended values at various operation conditions. However J5, J6, J7, J8 and J9 gets water at lower pressure almost all the time. High pressure was not commonly detected in the system. High pressure above recommended values were detected in case of minimum design flow and existing flow conditions where the flow rate was very low. Low pressure below recommended value was relatively high for peak design flow and secondly for scheduled flow.

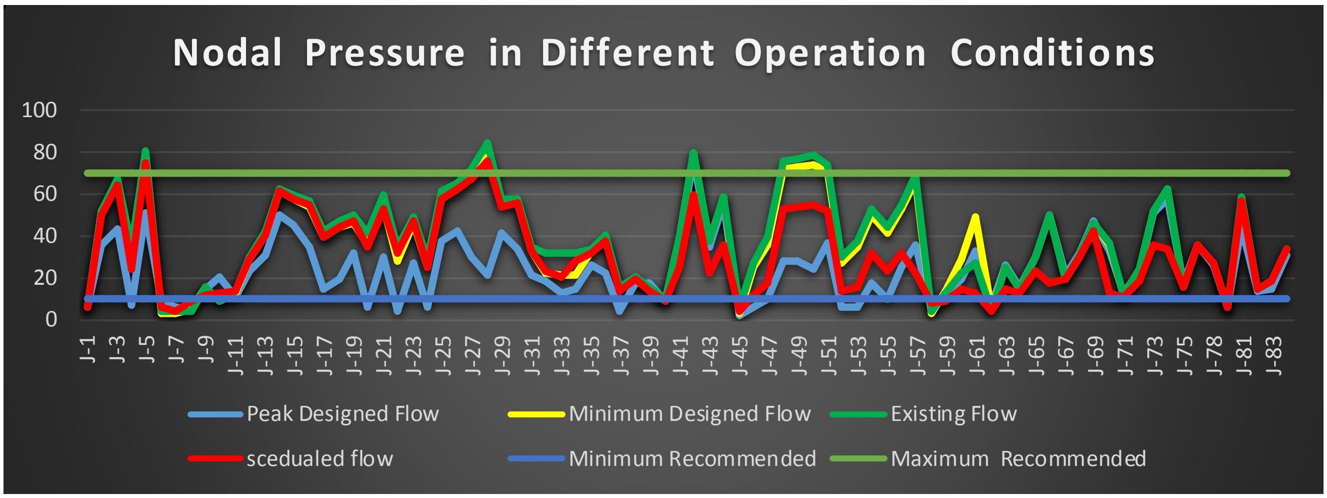

Figure 4-24: Figure showing pressure variation for different flow condition

4.7 Velocity Variations for Different Operation Conditions

In all case the flow velocity were almost below recommended values (0.6m/s) and in case of peak time operation velocity of flow in the pipe were nearer to recommended values. Flow velocity were very low (<1m/s) for existing water operation condition and minimum flow time of designed capacity. In scheduled operation condition the velocity has recovered in some extent. Further it can be improved by improved by scheduling based on once in a three day time but by itself affects the water use trend of the town. In general reduced flow rate due to limited treatment and capacity were affecting the distribution efficiency and water equity in the system. Tabular value for model results were as attached in the annex-6.

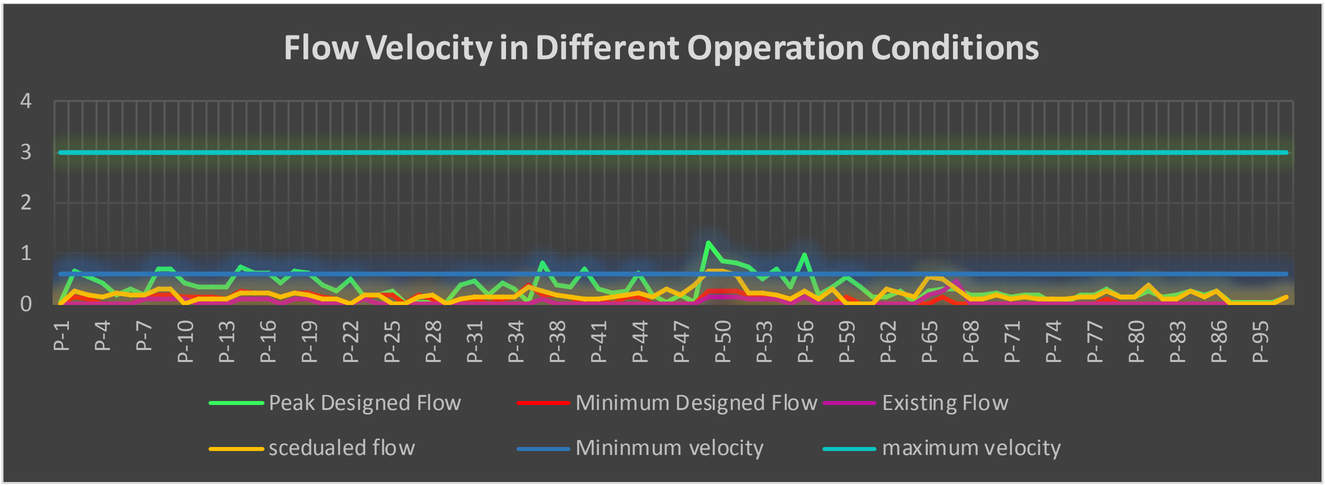

Figure 4-25: Figure showing Velocity variation different system capacity flow condition

4.8 Model Calibration and Validation Employed

Calibration is an iterative procedure of parameter evaluation and adjustment by comparing simulated and observed values.

The Water GEMS Model was calibrated by adjusting sensitive parameter such as Hazen Williams's coefficient. Actual pressure data were collected at public fountains of different locations in the distribution system. Boundary conditions that were water level in the tank by the time of release was known and used to calibrator model.

Model validation is in reality an extension of the calibration process. It is used to assure that the calibrated model properly assesses all the variables and conditions, which can affect model results, and demonstrate the ability to predict field observations different data set.

The hydraulic model calibration parameters that are typically set and adjusted include pipe roughness factors and Control valve setting. In this case actual pressure was used to calibrate the model.

Model Performance Evaluation Criteria

There are many ways to judge on the performance of model calibration. The evaluation were made by calculating the squared relative difference between observed and simulated pressure for each test. The evaluation criteria used was statistical method using correlation coefficient (R2) and Root Mean Square Error (RMS) and graphical method.

Pressure Calibration and Validation

As pressure criteria calibration was 85% of the pressure field test measurements should be within ± 0.5m or ± 5% of the maximum head loss across the system of the simulated pressure, whichever is greater according to (Thomas et al. 2003). According to Thomas (2003), for the smaller water supply system having less than or equal to 600mm diameters, the model should be accurately predict hydraulic grade line (HGL) to within 1.5–3 m depending on size of the system at calibration data points during fire flow tests and to the accuracy of the elevation and pressure data during normal demands. The graph of calibration result of the model is shown below and overall report were annexed in the research report.

However for the calibration result annexed indicates that the pressure variation in between observed and simulated values are as shown in the table below.

Table 4-14: Calibration Result and Checking values

Observed Hydraulic Grade (m)	simulated Hydraulic Grade (m)	Actual observed	Piezometric simulated	Difference
2268.49	2267.89	6.99	6.39	0.6
2266.97	2267.89	58.57	59.49	-0.92
2267.46	2267.85	14.46	14.85	-0.39
2265.29	2267.55	15.79	18.05	-2.26
2269.93	2271.47	32.93	34.47	-1.54

Source: Modeling Result (2019)

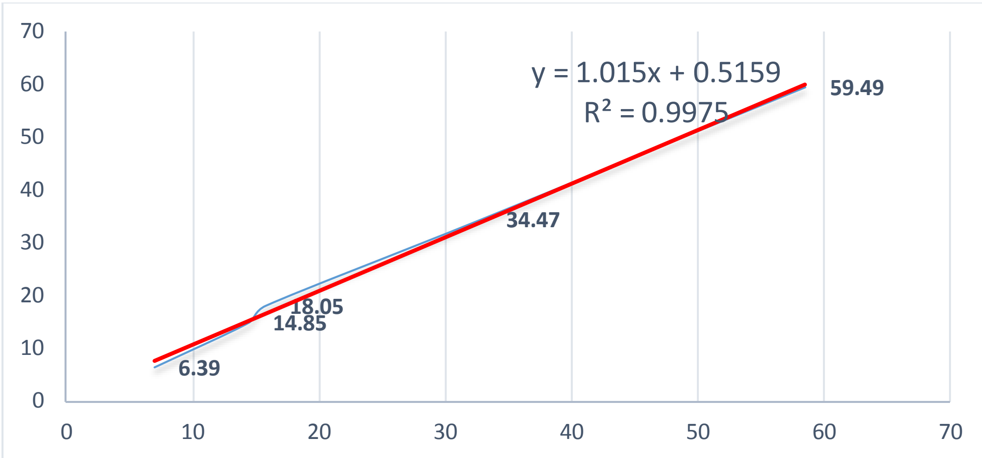

Figure 4-26: Graph of actual verses simulated pressure values for calibration

As presented in the table above all of the pressure deviations were above recommended value by Thomas (2003) that was above ± 0.5m.

Even though the pressure calibrated was not within the recommended value, as shown in graph, there was acceptable correlation of observed pressure and simulated pressure that was above 99.95%. This can improve model representation of real system of Masha town water supply.

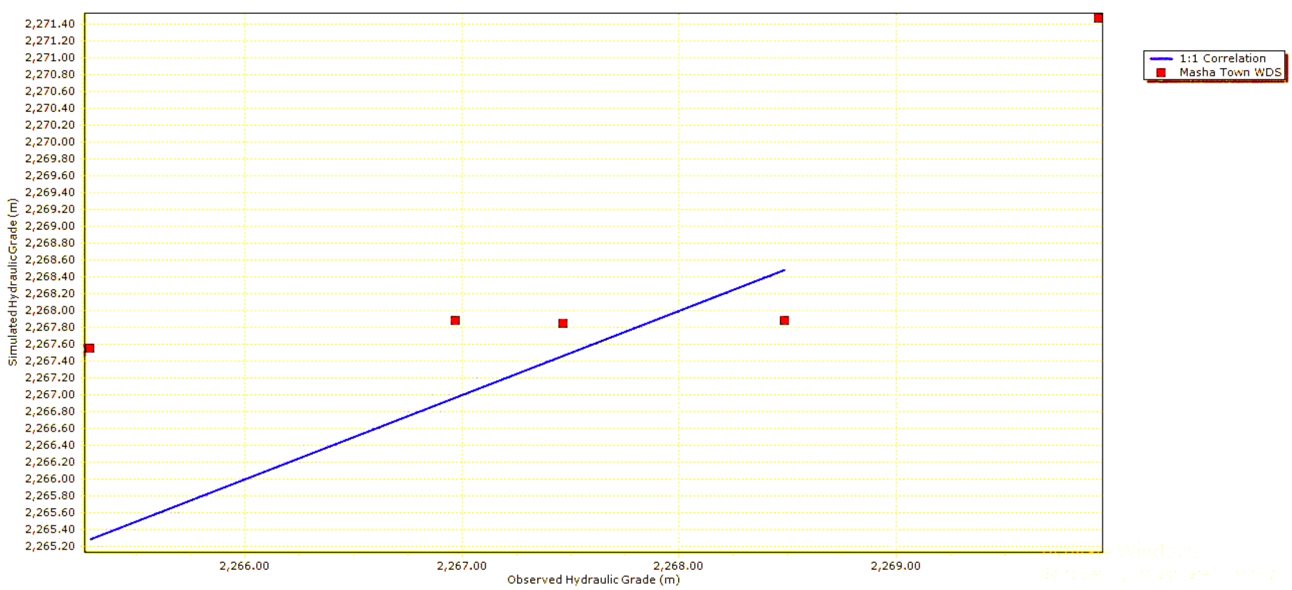

Figure 4-27: Graph showing result of calibration of model

In Masha town water supply was intermittent and there was supply gap in supply during filling of reservoir. Hourly flow was not considered since the supply was intermittent and pipe was dry most hours of a day. By the time water was released all the users tray to fetch water as the supply was very limited in a day that is only 125m^3. In this study peak hourly demand at the time of water released were analyzed. Therefore it was difficult and not logical to analyses hourly demand for hours of the day time and validate the model.

After calibration the model were readjusted using simulated roughness coefficient of pipe lines to represent real situations in existing system. Overall calibration results of the mode was annexed with the research document. As the graph showed that points were not fitted with straight line and this showed that the model has gap in representing the reality. The model calibration needs consideration of other parameters like demand adjustments. However the calibration minimized the error gap.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

Current water demand of the town exceeded the design capacity of existing treatment plant by 673.79 m3/day before its design period ends. Water production capacity of Wonani water treatment plant was reduced to 3.1 l/s which is 33.33 percent of its designed capacity because of water losses in treatment units due to poor operation and maintenance of treatment units and conveyance lines. Moreover, because of limited working hours of water pump only 46.67 percent of treated water was pumped to central reservoirs (125 m3 out of267.840 m3). The cause for this limited pumping hours of pump was found to be acute power intermittency and only day time operation of pumps. In conclusion current institutional capacity of water service utility was incapable of managing and distributing even this limited water produced from treatment plan.

Based on the study municipal water pipe, unprotected hand dug wells, unprotected springs, roof catchments and river water were sources of domestic water consumption in the town. Only 6.67 percent of study households cover their domestic demand from using pipe water alone. Majority of households use unprotected source alone or with pipe water without any treatment at home. Pipe water was available all the time for only 6.67 percent of survey households and unprotected hand dug wells were available to 76.04% all the time. Therefore people were forced to use unprotected water sources of better availability.

Pipe water service intermittency were serious in the town where more than 80 percent of households get water two wise in a week time or even more than once in above a week time. However only 6.67 percent of households have storage tank in their home and the rest were forced to use unprotected water sources or pipe water from vendors in twenty five fold cost from that of privet water meter owners.

Masha town water service is not palatable since majority pipe water users, about 65 (95.59 percent) were perceived that the quality of pipe water were not good for drinking purpose because more than 80 % of household perceived that the water has undesirable color, odor, or test. All of respondents dissatisfied with overall service of Masha town water services. The cause for their satisfaction were primarily due to service unavailability in required time and amount for more than 66 percent households in the town.

Because of poor water service of the town more than three forth of households were commonly forced to use water from unprotected sources and vulnerable for water borne diseases.

Mash town water service utility office service provision in customers service were found inefficient for more than 60 percent of households and the office were not providing timely response for new service requests and claims.

Regarding to water quality test result indicates that average total Fe content of the pipe water in service provision point were found to be 1.43 ml/L which is far above Ethiopian and WHO guide line values for drinking water that is 0.3mg/l. The average concentration of manganese (0.0053ml/L) and range of PH (7.16-7.86) were within acceptable limit of the standards that is less than 0.5mg/l for manganese and range of 6.5 to 8.5 for water PH. Because of this high iron concentration the water is not palatable to households and most of households sensed its effects in pipe water and become among major cause for their dissatisfaction in water service. Amount of Free chlorine in water were found to be nil in all of the sample sites and there is no or inappropriate disinfection of treated water and people were using unsafe water regarding to bacteriological contamination.

Treatment plant was inefficient to remove excess iron concentration from the raw water. Cascade aerator was able to remove only 9.58 percent of initial concentration and overall efficiency of treatment plant efficiency in removing iron was found to be 43.62 percent (reduced to 1.06). the concentration of iron in supplied water was aggravated by aged GI, low velocity of water in distribution system caused by operation in lower capacity and high intermittence of water supply. The concentration of iron was found to be worst for areas where new developments of the town where distance from central reservoir was high.

Water supply system of Masha town was providing water with sufficient pressure (10 to 70m of H_2O) for most areas of the town even with current limited supply capacity because of topographic effect. However some areas of the town especially central part where high raise buildings were constructing were get water with low pressure. The velocity in pipe were found to be below recommended values (0.6m/s to 3m/s) to all of the pipes modeled due to serving of distribution system below design flow. This shows that under operation of design values caused to exposure of water quality degradation by increased water age and deposition of sediment.

5.2. Recommendations

As discussed in the existing water supply states in this the main reason for less treated water production was loss of water in different parts of treatment units. In addition to these supplied water was not satisficing water user because of it high iron content and less pressure in some areas of the town. Supplied water was having high iron content that was above recommended value and the following points needs to be considered in order to improve the limitations.

- Masha Town Water Service Utility office capacity was found critical problem to water service provision and needs improved by implementing Water safety plans (WSPs) that can contribute to improve operation and maintenance by supporting the systematic assessment, prioritization and management of risks from catchment to consumer, including those related to inadequate operation and maintenance. The management approach was conducted in different countries and based on WHO & IWA (2018) report by adopting WSPs implementation Bhutan improved operator capacity, more effective treatment and better microbial water quality; India reduced raw and treated water losses, less treatment plant down time and better water quality and The Philippines (Manila Water) increased Operational efficiencies and significant reductions in annual O&M costs and hence it can be adopted as best practice to solve problem of the same kind.
- Basically design period of existing water supply come to an end after two years but current water demand exceeded the design capacity of existing structure and hence expansion projects or new project has to be considered. In these projects treatment of high iron content of the raw water has to be carefully considered and appropriate treatment systems has to be designed.
- Filter medium of slow sand filter need to be cleaned and refilled based on the design arrangement and size. Even though there was high water loss in conveyance pipe line and horizontal roughening filter, water was also lost at this unit through overflow pipe because of clogged (muddy) sand. This problem was also critical since the treating capacity of slow sand filter was even below that of water reached in the unit. As described by water utility office the sand were transported from very long distance that was from Adama. This imposes high cost for the utility office and water utility office should prepare appropriate sand size from local

available sand based on sieve analysis value of design value. This can enable the utility office timely change filter sand and make sustainable supply.

- As seen in the site water was overtopping horizontal roughening filter unity and significant amount of water was lost in the compartment. The reason was clogging of the voids spaces by dirty matter and moreover the arrangement of gravels were distorted during cleaning and refilling. Three different sized gravels were filled in the horizontal roughening filter separately in three subdivided units by mesh wire. The arrangement were from smaller to higher gravel size along water flow direction but because of mixing each other the entropy of gravel arrangement has increased and voids become decreased. This resulted in low flow area and leads to overtopping as the designed area was lost. Therefore, the gravel in the unit needs to be cleaned and refilled based on the design arrangement.
- Conveyance UPVC pipe line were laid over ground surface where there was access road where people and animals were crossing the site. The formation of the area is difficult to lay it below ground surface and needs to be changed by steel pipe. Water lost in this line was very significant and affected in reduction of amount conveyed.
- As detected from water quality teste result, iron content of raw water as well as treated water was far above recommended values of palatable water and hence cascade aerator has to be modified in order to efficiently oxidase iron and manganese in the raw water. As the number and size of cascade aerator increases the exposure of water to air in surface area and contact time increases and leads to increased efficiency in aeration. Design of cascade aerator was based on experiment and it helps to decide on the angle, loading and size of steps of the unit. It is highly dependent on water temperature and dissolved oxygen content of the raw water. Additionally PH and the combined form of iron in the water determines the oxidation rate. Therefore detailed study based on experiment is required on the appropriate design of aeration system and improve treated water quality to acceptable level.
- As the modelling result pointed that water supply distribution system design was not appropriate since the velocity of water even in peak flow time was below recommended value that is 3m/s. The reason was large pipe size leading to low velocity. Inappropriate large pipe size is uneconomical to install and beyond that it affects the quality of water by increasing water age and sediment deposits in the system. Moreover in existing less water production capacity of treatment plan distributed water was with low flow velocity becomes stagnant most of the time.

Therefore to improve water supply efficiency and equity operation of get valves must be scheduled. Based on this study the areas of the town were divided in to two using valve control system and evaluated its efficiency. This can increase the portion of demand supplied by the system and increases the system efficiency for such large pipes due to increased flow rate.

- Central part of the town was getting water with limited pressure in all cases of operation and hence elevated tank is required at minimum height of 8m above the ground near the site of reservoir. The model was checked for raised tank elevation and all areas will get minimum recommended pressure value. However for few high raised buildings under development booster pump should be installed.

- Home treatment like boiling and using chlorine tablets should be exercised in the town for piped water and other source by teaching and advocating its importance in improving water use.
- In central limited parts of the town where low water pressure was detected, water pressure can be easily improved by constricting elevated tanks. The pump head capacity of the existing system is high and constructing elevated tank near the central reservoir can be advantageous to lift the water using existing pumps and pressure mains to the system.
- Microbiological water quality of the supplied water has to be improved by continuous and appropriate disinfection of treated water.
- While designing water supply systems, the effect of easily availability of unprotected water sources and custom of water use in study area, like in case of Masha town, has to be researched and considered in design. If managed and improved these alternative sources can cover part of water consumed rather than drinking.

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APPENDICES

Annex-1: Iron and Manganese Test Procedure

IRON MR Test Procedure

Method

In the YSI Iron MR method iron is reduced to the ferrous form and then reacted with 1, 10-phenanthroline to form an orange colored complex. A decomplexing agent is incorporated into the reagent system in order to break down complexed forms of iron. The test is simply carried out by adding tablet reagents to a sample of the water under test.

The intensity of the color produced is proportional to the iron concentration and is measured using a YSI Photometer.

Interference can occur in industrial waters treated with molybdate and nitrite based treatment products. A supplementary reagent can be used to prevent this interference.

Reagents and Equipment

YSI Iron MR No 1 Tablets

YSI Iron MR No 2 Tablets

YSI Citrate IR Tablets

YSI 9300 or 9500 Photometer

Round Test Tubes, 10 ml glass (PT 595)

Test Procedure

1. Fill the test tube with sample to the 10 ml mark.
2. Add one Iron MR No 1 tablet, crush and mix to dissolve.
3. Add one Iron MR No 2 tablet, crush and mix to dissolve.
4. Stand for 10 minutes to allow full color development.
5. Select Phot 39 on photometer.
6. Take photometer reading in usual manner (see photometer instructions).
7. The result is displayed as mg/l Fe.

Manganese Test Procedure

Method

Manganese may occur in water in various different valency states. In the first stage of the YSI method, manganese in lower valency states is oxidised to form permanganate by the action of an oxidising agent. In the second stage the permanganate formed is further reacted with leucomalachite green to form an intense turquoise colored complex. Catalysts and inhibitors are incorporated into the tablet reagents to ensure that the color reaction proceeds correctly and interferences are eliminated.

The intensity of color produced in the test is proportional to the total manganese concentration and is measured using a YSI Photometer.

Test Procedure

1. Fill test tube with sample to the 10 ml mark (see Note 1).
2. Add one Manganese No 1 tablet, crush and mix to dissolve.
3. Add one Manganese No 2 tablet, crush and mix to dissolve then cap the tube.
4. Stand for 20 minutes to allow color development (see Note 2).
5. Select Phot 20 on photometer.
6. Take photometer reading in usual manner (see photometer instructions).
7. The result is displayed as mg/l Mn.

Annex -2 Water demand computation report for Masha town for year 2018.

S.N	Description	Unit	Year 2018
1	***Population***	No	20,007
2	***Domestic Water Demand***		
	Mood of Connection %		
	House Connection	%	2
	Yard Connection	%	32
	Public Fountains	%	66
	Mood of Connection by users		
	House Connection	No	400
	Yard Connection	No	6402
	Public Fountains	No	13205
	Per Capital Water demand by Mood of Connection		
	House Connection	l/c/d	50
	Yard Connection	l/c/d	35
	Public Fountains	l/c/d	30
	Water Demand by Mood of Service		
	House Connection	m3/day	20
	Yard Connection	m3/day	224.07
	Public Fountains	m3/day	396.15
	Average Domestic Water Demand	m3/day	**640.22**
	Non Domestic Water Demand		
	Public, Institutional Commercial (ADWD 30%)	m3/day	192.07
	Livestock demand (7% ADWD)	m3/day	44.82
	Industrial demand(5% ADWD)	m3/day	32.01
	Total Non-Domestic Water Demand (TNDWD)	m3/day	268.89
	Total Water Demand	m3/day	909.11
4	***Un- Accounted Water Demand*** (30% TWD)	m3/day	272.73

	Average Day Demand	m3/day	1181.85
	Max day factor	%	1.25
	Max Day Demand	m3/day	1477.31
6		l/s	17.10

Annex – 3 Number of houses allocated to each Junction

Junction ID	High Dense	Medium	Low Dense	Nodal House
J20	4.56	247.69	0.00	252.25
J19	2.09	126.12	0.00	128.21
J18	8.73	0.00	0.00	8.73
J21	1.84	18.14	0.00	19.98
J17	0.83	58.19	0.00	59.02
j22	1.86	24.01	0.00	25.87
J30	2.54	191.41	0.00	193.95
J24	20.73	51.26	0.00	71.99
J16	2.74	31.10	0.00	33.84
J23	19.38	72.57	0.00	91.94
J27	5.85	69.30	0.00	75.14
J28	1.38	0.00	0.00	1.38
J25	8.01	5.83	0.00	13.84
J26	4.02	0.00	0.00	4.02
J57	2.90	12.20	0.00	15.10
J15	4.62	0.00	26.97	31.59
j14	11.38	0.00	0.00	11.38
j13	19.85	0.00	0.00	19.85
j36	7.74	0.00	0.00	7.74
j29	17.69	0.00	0.00	17.69
J56	9.91	28.80	0.00	38.71
J54	6.10	61.03	0.00	67.13
J49	0.00	450.51	0.00	450.51
J48	0.00	2.59	0.00	2.59
J51	11.77	24.08	0.00	35.85
J50	8.29	0.00	0.00	8.29
J55	26.24	0.00	21.55	47.79
J47	16.10	0.00	0.00	16.10
J45	3.34	0.00	35.97	39.31
J10	0.00	0.00	44.74	44.74
J11	0.00	0.00	63.59	63.59
J46	0.00	0.00	49.57	49.57
J52	0.00	0.00	38.05	38.05
J53	0.00	0.00	159.81	159.81
J37	6.63	0.00	0.00	6.63
J31	1.81	51.30	0.00	53.11
J33	0.00	367.82	0.00	367.82

Junction ID	High Dense	Medium	Low Dense	Nodal House
J34	0.00	33.36	0.00	33.36
J32	3.77	0.00	0.00	3.77
J39	0.00	0.00	0.00	0.00
J38	13.67	5.86	0.00	19.54
J35	7.33	0.65	74.22	82.20
J61	14.32	111.49	0.00	125.80
J60	25.50	62.49	0.00	87.99
J65	0.00	43.67	0.00	43.67
J64	0.00	83.88	0.00	83.88
J63	5.06	21.13	0.00	26.18
J62	3.78	0.00	0.00	3.78
T2	10.59	0.00	0.00	10.59
J67	8.58	0.00	45.66	54.24
J59	0.00	0.00	99.21	99.21
J8	5.38	0.00	26.49	31.86
J40	0.00	0.00	73.61	73.61
J41	21.58	0.00	21.79	43.36
J42	5.07	94.89	0.00	99.95
J9	26.67	6.26	0.00	32.93
J58	17.82	0.00	10.39	28.21
J66	55.00	4.46	0.00	59.45
J68	8.71	40.58	18.08	67.38
J71	14.42	0.00	0.00	14.42
J75	6.40	4.58	0.00	10.98
J72	7.24	0.00	37.86	45.10
J43	15.91	0.00	0.00	15.91
J44	26.62	13.56	20.02	60.21
J5	0.00	131.26	0.00	131.26
J3	4.98	72.29	34.86	112.14
J74	17.68	0.00	38.70	56.38
J2	18.03	0.00	74.16	92.19
J73	3.66	21.49	2.68	27.83
J76	27.38	0.00	29.82	57.20
J70	0.00	100.21	0.00	100.21
J1	2.79	0.00	30.07	32.87
T1	0.00	0.00	29.39	29.39
J6	6.89	0.00	4.36	11.25
J7	0.00	0.00	17.60	17.60
	651.74	2835.43065	1129.21772	4616.39

Nodal Demand and Corresponding Supply

Junction ID	Domestic+ Commercial	Institutional/ Public	Industrial	Livestock	Total Demanded	Currently Supplied
J20	1.023	0.163	0.000	0.074	1.260	0.107
J19	0.520	0.205	0.000	0.037	0.762	0.065
J18	0.035	0.036	0.000	0.005	0.076	0.006
J21	0.081	0.287	0.150	0.006	0.524	0.044
J17	0.239	0.000	0.000	0.017	0.257	0.022
j22	0.105	0.000	0.000	0.008	0.113	0.010
J30	0.787	0.000	0.000	0.056	0.843	0.071
J24	0.292	0.065	0.000	0.026	0.383	0.032
J16	0.137	0.000	0.000	0.010	0.148	0.013
J23	0.373	0.000	0.000	0.032	0.405	0.034
J27	0.305	0.000	0.000	0.023	0.328	0.028
J28	0.006	0.421	0.000	0.001	0.427	0.036
J25	0.056	0.000	0.000	0.006	0.062	0.005
J26	0.016	0.000	0.000	0.002	0.019	0.002
J57	0.061	0.000	0.000	0.005	0.066	0.006
J15	0.128	0.021	0.000	0.005	0.154	0.013
j14	0.046	0.000	0.000	0.006	0.053	0.004
j13	0.081	0.172	0.000	0.011	0.264	0.022
j36	0.031	0.000	0.000	0.004	0.036	0.003
j29	0.072	0.000	0.000	0.010	0.082	0.007
J56	0.157	0.000	0.000	0.014	0.171	0.014
J54	0.272	0.000	0.000	0.021	0.293	0.025
J49	1.827	0.000	0.000	0.129	1.956	0.166
J48	0.010	0.000	0.000	0.001	0.011	0.001
J51	0.145	0.000	0.000	0.014	0.159	0.013
J50	0.034	0.000	0.000	0.005	0.038	0.003
J55	0.194	0.000	0.000	0.017	0.211	0.018
J47	0.065	0.000	0.000	0.009	0.074	0.006
J45	0.159	0.020	0.000	0.005	0.184	0.016
J10	0.181	0.000	0.000	0.004	0.185	0.016
J11	0.258	0.000	0.000	0.006	0.263	0.022
J46	0.201	0.000	0.000	0.004	0.205	0.017
J52	0.154	0.000	0.000	0.003	0.158	0.013
J53	0.648	0.000	0.000	0.014	0.662	0.056
J37	0.027	0.249	0.000	0.004	0.280	0.024
J31	0.215	0.109	0.000	0.016	0.340	0.029
J33	1.492	0.000	0.000	0.105	1.597	0.135

J34	0.135	0.000	0.000	0.010	0.145	0.012
J32	0.015	0.075	0.000	0.002	0.092	0.008
J39	0.000	0.496	0.000	0.000	0.496	0.042
J38	0.079	0.194	0.000	0.009	0.283	0.024
J35	0.333	0.000	0.000	0.011	0.344	0.029
J61	0.510	0.091	0.000	0.040	0.642	0.054
J60	0.357	0.043	0.000	0.032	0.433	0.037
J65	0.177	0.000	0.000	0.013	0.190	0.016
J64	0.340	0.000	0.000	0.024	0.364	0.031
J63	0.106	0.100	0.000	0.009	0.215	0.018
J62	0.015	0.292	0.000	0.002	0.309	0.026
T2	0.043	0.166	0.000	0.006	0.215	0.018
J67	0.220	0.000	0.000	0.009	0.229	0.019
J59	0.402	0.000	0.000	0.009	0.411	0.035
J8	0.129	0.000	0.000	0.005	0.135	0.011
J40	0.299	0.013	0.000	0.006	0.318	0.027
J41	0.176	0.200	0.154	0.014	0.544	0.046
J42	0.405	0.000	0.000	0.030	0.435	0.037
J9	0.134	0.026	0.000	0.017	0.177	0.015
J58	0.114	0.032	0.000	0.011	0.158	0.013
J66	0.241	0.013	0.060	0.032	0.346	0.029
J68	0.273	0.000	0.007	0.018	0.298	0.025
J71	0.059	0.000	0.000	0.008	0.067	0.006
J75	0.045	0.000	0.029	0.005	0.078	0.007
J72	0.183	0.000	0.005	0.007	0.195	0.017
J43	0.065	0.110	0.000	0.009	0.183	0.016
J44	0.244	0.000	0.150	0.021	0.415	0.035
J5	0.532	0.000	0.000	0.038	0.570	0.048
J3	0.455	0.000	0.070	0.027	0.551	0.047
J74	0.229	0.000	0.106	0.013	0.348	0.029
J2	0.374	0.000	0.036	0.017	0.427	0.036
J73	0.113	0.000	0.000	0.008	0.121	0.010
J76	0.232	0.000	0.000	0.018	0.250	0.021
J78	0.113	0.027	0.000	0.016	0.156	0.013
J69	0.363	0.000	0.083	0.026	0.471	0.040
J70	0.406	0.000	0.065	0.029	0.500	0.042
J1	0.133	0.028	0.000	0.004	0.165	0.014
T1	0.119	0.000	0.000	0.003	0.122	0.010
J6	0.046	0.008	0.000	0.004	0.058	0.005
J7	0.071	0.000	0.000	0.002	0.073	0.006
Total	18.725	3.661	0.915	1.281	23.301	1.281

Annex-4: Water system modeling results of velocity and head loss and Pressure at Each Junction

ID	Label	Length (m)	Diameter (in)	Material	C	Flow (L/s)	Velocity (m/s)	Head loss (m/m)
32	P-1	16	6	GI	60	0.164392	0.01	0
34	P-2	93	2	GI	60	0.164	0.08	0.001
36	P-3	338	2	GI	60	0.135	0.07	0.001
38	P-4	356	2	GI	60	0.099	0.05	0
40	P-5	549	1.5	GI	60	0.004	0	0
42	P-6		1.5	GI	60	0.048	0.04	0
44	P-7	75	2	GI	60	0.005	0	0
46	P-8	14	6	PVC	75	2.248177	0.12	0
48	P-9	10	6	PVC	60	2.247784	0.12	0.001
50	P-10	70	6	PVC	75	1.563392	0.09	0
52	P-11	28	6	PVC	60	0.942392	0.05	0
54	P-12	175	6	PVC	75	0.942	0.05	0
56	P-13	215	6	PVC	75	0.907	0.05	0
58	P-14	40	4	GI	60	0.805	0.1	0.001
60	P-15	202	4	GI	60	0.727	0.09	0.001
62	P-16	174	4	GI	60	0.723	0.09	0.001
64	P-17	157	4	GI	60	0.517	0.06	0
66	P-18	87	3	GI	60	0.442	0.1	0.001
68	P-19	293	3	GI	60	0.412	0.09	0.001
70	P-20	416	3	GI	60	0.245	0.05	0
72	P-21	106	3	GI	60	0.213	0.05	0
74	P-22	62	3	GI	60	0.163	0.04	0
76	P-23	535	1.5	GI	60	0.098	0.09	0.002
78	P-24	306	1.5	GI	60	0.044	0.04	0
80	P-25	232	1.5	GI	60	0.01	0.01	0
82	P-26	27	6	GI	60	0.154	0.01	0
84	P-27	237	2	GI	60	0.032	0.02	0
86	P-28	101	3	GI	60	0.088	0.02	0
88	P-29	23	3	GI	60	0.019	0	0
90	P-30	762	1.5	GI	60	0.064	0.06	0.001
92	P-31	330	1	GI	60	0.036	0.07	0.002
94	P-32	278	1.5	GI	60	0.007	0.01	0
96	P-33	379	1.5	GI	60	0.071	0.06	0.001
98	P-34	402	3	GI	60	0.184	0.04	0
102	P-36	289	6	GI	60	0.155	0.01	0
104	P-37	200	1.5	GI	60	0.135	0.12	0.003
106	P-38	61	1.5	GI	60	0.012	0.01	0

ID	Label	Length (m)	Diameter (in)	Material	C	Flow (L/s)	Velocity (m/s)	Head loss (m/m)
108	P-39	339	2	GI	60	0.056	0.03	0
110	P-40	81	2	GI	60	0.003	0	0
112	P-41	131	2	GI	60	0.024	0.01	0
114	P-42	174	2	GI	60	0.086	0.04	0
116	P-43	143	1	GI	60	0.042	0.08	0.003
118	P-44	68	4	GI	60	0.678392	0.08	0.001
120	P-45	212	4	GI	60	0.132	0.02	0
122	P-46	469	3	GI	60	0.035	0.01	0
124	P-47	225	3	GI	60	0.051	0.01	0
126	P-48	150	2	GI	60	0.035	0.02	0
128	P-49	16	2.5	GI	60	0.519392	0.16	0.003
130	P-50	367	2.5	GI	60	0.519392	0.16	0.003
132	P-51	179	2.5	GI	60	0.490392	0.15	0.003
134	P-52	20	2.5	GI	60	0.342392	0.11	0.001
136	P-53	196	2.5	GI	60	0.342	0.11	0.001
138	P-54	304	2.5	GI	60	0.333	0.11	0.001
140	P-55	115	2.5	GI	60	0.166	0.05	0
142	P-56	49	1.5	GI	60	0.166	0.15	0.004
144	P-57	273	1.5	GI	60	0.003	0	0
146	P-58	29	2.5	GI	60	0.131	0.04	0
148	P-59	73	1.5	GI	60	0.094	0.08	0.002
150	P-60	128	1.5	GI	60	0.056	0.05	0.001
152	P-61	218	2	GI	60	0.025	0.01	0
154	P-62	218	2.5	GI	60	0.024	0.01	0
156	P-63	231	1.5	GI	60	0.006	0.01	0
158	P-64	200	1.5	GI	60	0.013	0.01	0
160	P-65	131	2.5	GI	60	0.61	0.19	0.004
162	P-66	899	2	GI	60	0.575	0.28	0.011
164	P-67	388	1.5	GI	60	0.54	0.47	0.039
167	P-68	12	6	GI	75	0.388428	0.02	0
169	P-69	14	6	GI	75	0.388428	0.02	0
171	P-70	137	3	GI	60	0.094	0.02	0
173	P-71	126	3	GI	60	0.047	0.01	0
175	P-72	219	2	GI	60	0.016	0.01	0
177	P-73	269	2	GI	60	0.029	0.01	0
179	P-74	23	6	PVC	75	0.268428	0.01	0
181	P-75	233	6	GI	60	0.268428	0.01	0
183	P-76	201	3	GI	60	0.1473	0.03	0
185	P-77	131	2.5	GI	60	0.1223	0.04	0

ID	Label	Length (m)	Diameter (in)	Material	C	Flow (L/s)	Velocity (m/s)	Head loss (m/m)
187	P-78	301	1.5	GI	60	0.0823	0.07	0.001
189	P-79	51	4	GI	60	0.102128	0.01	0
191	P-80	146	4	GI	60	0.101735	0.01	0
193	P-81	302	4	GI	60	0.0555	0.01	0
195	P-82	301	3	GI	60	0.039	0.01	0
197	P-83	433	1.5	GI	60	0.029	0.03	0
199	P-84	95	2	GI	60	0.040635	0.02	0
201	P-85	203	2	GI	60	0.021	0.01	0
204	P-86	80	2	GI	60	0.013	0.01	0
207	P-87	8	4	GI	60	3.39E-05	0	0
209	P-88	12	6	GI	60	5.97E-05	0	0
210	P-89	1,582	3	GI	60	5.95E-05	0	0
213	P-90	5	4	GI	60	5.91E-05	0	0
215	P-91	15	6	GI	60	5.92E-05	0	0
216	P-92	1,794	4	GI	60	5.94E-05	0	0
228	P-93	12	0.75	GI	60	0.01	0.04	0.001
231	P-94	19	0.75	GI	60	0.01	0.04	0.001
233	P-95	26	0.75	GI	60	0.02	0.07	0.003
235	P-96	12	0.75	GI	60	0.02	0.07	0.003
239	P-97	12	0.75	GI	60	0.04	0.14	0.009

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic gread line (m)	Pressure (m H2O)
47	J-7	2,264.10	0.006	2,268.09	4
43	J-6	2,263.60	0.005	2,268.00	4
157	J-58	2,262.10	0.013	2,266.88	5
168	J-62	2,267.00	0.026	2,272.00	5
49	J-8	2,262.70	0.011	2,268.07	5
129	J-45	2,260.80	0.016000001	2,266.89	6
33	J-1	2,261.60	0.014	2,268.00	6
227	J-79	2,261.50	0.01	2,267.99	6
55	J-10	2,258.70	0.016000001	2,268.04	9
117	J-40	2,257.90	0.027	2,268.05	10
190	J-71	2,260.20	0.0056	2,271.99	12
159	J-59	2,254.30	0.034999999	2,267.54	13
57	J-11	2,254.20	0.022	2,268.01	14
172	J-64	2,257.10	0.031	2,271.99	15
232	J-82	2,253.00	0.020000001	2,267.99	15
115	J-39	2,251.70	0.042000003	2,267.62	16
198	J-75	2,256.00	0.006635	2,271.99	16
53	J-9	2,252.00	0.014999999	2,268.05	16
111	J-37	2,251.70	0.024	2,267.96	16
234	J-83	2,249.50	0.020000001	2,267.95	18
180	J-67	2,253.10	0.019	2,272.00	19
113	J-38	2,248.00	0.024	2,267.98	20
161	J-60	2,236.00	0.034999999	2,257.73	22
192	J-72	2,248.00	0.016499999	2,271.99	24
170	J-63	2,247.00	0.017999999	2,271.99	25
203	J-78	2,245.20	0.013	2,271.99	27
131	J-46	2,238.90	0.017	2,266.40	27
163	J-61	2,214.90	0.539999947	2,242.44	27
83	J-24	2,238.20	0.032000002	2,267.41	29
145	J-52	2,236.80	0.013	2,266.39	30
174	J-65	2,242.30	0.016000001	2,271.99	30
59	J-12	2,238.00	0.004	2,267.89	30
182	J-68	2,241.40	0.025000001	2,271.97	31
103	J-33	2,235.40	0.134999987	2,267.11	32
105	J-34	2,236.00	0.012	2,267.72	32
101	J-32	2,236.00	0.008000001	2,267.72	32
107	J-35	2,234.00	0.029	2,267.96	34
238	J-84	2,237.00	0.040000001	2,271.47	34
79	J-22	2,232.60	0.01	2,267.29	35

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic gread line (m)	Pressure (m H2O)
39	J-4	2,232.80	0.004	2,267.60	35
97	J-31	2,232.80	0.029	2,267.72	35
200	J-76	2,235.60	0.021000001	2,271.98	36
186	J-70	2,235.00	0.042300002	2,271.58	37
147	J-53	2,228.70	0.013	2,266.28	38
123	J-43	2,230.00	0.016000001	2,268.04	38
135	J-47	2,227.10	0.006	2,266.09	39
119	J-41	2,228.70	0.045999998	2,268.05	39
109	J-36	2,227.40	0.003	2,267.96	40
75	J-20	2,225.00	0.097999997	2,266.37	41
61	J-13	2,226.20	0.022	2,267.79	42
69	J-17	2,225.00	0.022	2,267.30	42
151	J-55	2,221.90	0.025000001	2,266.27	44
184	J-69	2,226.00	0.040000001	2,271.94	46
71	J-18	2,219.80	0.006	2,267.27	47
81	J-23	2,218.00	0.034	2,267.43	49
73	J-19	2,217.50	0.064999996	2,267.26	50
176	J-66	2,221.50	0.029	2,271.98	50
194	J-73	2,219.80	0.01	2,271.99	52
35	J-2	2,215.50	0.035999998	2,267.75	52
149	J-54	2,212.80	0.055999999	2,266.20	53
153	J-56	2,211.00	0.017999999	2,266.39	55
67	J-16	2,210.00	0.013	2,267.43	57
93	J-29	2,210.00	0.007	2,267.66	58
95	J-30	2,209.00	0.070999997	2,267.40	58
230	J-81	2,208.40	0.01	2,267.65	59
125	J-44	2,208.60	0.034999999	2,268.03	59
77	J-21	2,207.20	0.044	2,267.15	60
65	J-15	2,207.40	0.013	2,267.67	60
85	J-25	2,206.20	0.005	2,267.42	61
63	J-14	2,205.60	0.004	2,267.75	62
196	J-74	2,209.70	0.029	2,271.91	62
87	J-26	2,202.00	0.019	2,267.42	65
37	J-3	2,200.80	0.047000001	2,267.60	67
155	J-57	2,197.60	0.006	2,266.39	69
89	J-27	2,194.30	0.027999999	2,266.84	72
143	J-51	2,191.90	0.003	2,266.09	74
137	J-48	2,189.80	0.001	2,265.69	76
139	J-49	2,188.60	0.165999998	2,265.64	77

ID	Label	Elevation (m)	Demand (L/s)	Hydraulic gread line (m)	Pressure (m H2O)
141	J-50	2,186.70	0.165999998	2,265.47	79
121	J-42	2,188.00	0.034999999	2,268.04	80
41	J-5	2,186.00	0.048	2,267.42	81
91	J-28	2,182.40	0.035999998	2,266.22	84

Annex-5: Model output of Pressure and Velocity for different operation conditions

label	Peak Designed Flow	Minimum Designed Flow	Existing Flow	scheduled flow
J-1	6	6	6	6
J-2	36	52	52	50
J-3	43	66	67	64
J-4	7	34	35	24
J-5	51	80	81	75
J-6	9	4	4	6
J-7	34	4	4	4
J-8	5	5	5	9
J-9	15	16	16	12
J-10	20	9	9	13
J-11	11	13	14	14
J-12	23	29	30	29
J-13	31	40	42	40
J-14	50	61	62	61
J-15	45	58	60	58
J-16	35	54	57	55
J-17	15	39	42	39
J-18	19	44	47	44
J-19	32	46	50	47
J-20	6	36	41	35
J-21	30	54	60	53
J-22	4	28	35	32
J-23	27	46	49	47
J-24	6	25	29	25
J-25	38	58	61	58
J-26	42	62	65	62

label	Peak Designed Flow	Minimum Designed Flow	Existing Flow	scheduled flow
J-27	30	68	72	67
J-28	21	78	84	76
J-29	41	56	58	54
J-30	34	56	58	56
J-31	21	33	35	33
J-32	18	22	32	23
J-33	13	21	32	20
J-34	15	21	32	28
J-35	26	33	34	32
J-36	22	39	40	38
J-37	4	15	16	14
J-38	17	20	20	19
J-39	17	15	16	14
J-40	9	10	10	9
J-41	37	39	39	25
J-42	77	80	80	60
J-43	35	38	38	22
J-44	56	59	59	36
J-45	2	4	6	5
J-46	6	25	27	12
J-47	10	36	39	17
J-48	28	72	76	53
J-49	28	73	77	54
J-50	24	74	79	55
J-51	37	71	74	52
J-52	6	27	30	14
J-53	6	35	38	16
J-54	17	50	53	32

label	Peak Designed Flow	Minimum Designed Flow	Existing Flow	scheduled flow
J-55	10	41	44	23
J-56	25	53	55	32
J-57	36	66	69	22
J-58	5	3	5	8
J-59	12	14	13	9
J-60	19	29	22	15
J-61	33	49	27	13
J-62	7	5	5	5
J-63	26	25	25	15
J-64	16	15	15	13
J-65	30	30	30	23
J-66	50	50	50	17
J-67	21	19	19	19
J-68	32	30	31	30
J-69	47	46	46	42
J-70	33	36	37	13
J-71	13	12	12	11
J-72	23	24	24	18
J-73	51	52	52	36
J-74	58	62	62	34
J-75	17	16	16	16
J-76	36	36	36	36
J-78	26	27	27	27
J-79	6	6	6	6
J-81	44	57	59	57
J-82	14	15	15	15
J-83	15	18	18	18
J-84	31	34	34	34

Model output of velocity and pressure for different operation conditions

label	Peak Designed	Minimum Designed Flow	Existing	scheduled flow
P-1	0.07	0.01	0.01	0.03
P-2	0.64	0.13	0.08	0.25
P-3	0.54	0.11	0.07	0.17
P-4	0.42	0.08	0.05	0.14
P-5	0.18	0.01	0.01	0.22
P-6	0.29	0.07	0.04	0.17
P-7	0.2	0.1	0.1	0.2
P-8	0.68	0.2	0.12	0.32
P-9	0.68	0.2	0.12	0.32
P-10	0.42	0.14	0.09	0.06
P-11	0.36	0.13	0.05	0.12
P-12	0.36	0.13	0.05	0.12
P-13	0.36	0.12	0.05	0.12
P-14	0.73	0.26	0.1	0.24
P-15	0.63	0.22	0.09	0.22
P-16	0.62	0.22	0.09	0.22
P-17	0.44	0.15	0.06	0.15
P-18	0.67	0.24	0.1	0.23
P-19	0.6	0.23	0.09	0.2
P-20	0.38	0.14	0.05	0.12
P-21	0.28	0.11	0.05	0.1
P-22	0.51	0.06	0.04	0.08
P-23	0.13	0.15	0.09	0.19
P-24	0.18	0.18	0.04	0.19
P-25	0.26	0.2	0.01	0.02
P-26	0.05	0.02	0.01	0.08

label	Peak Designed	Minimum Designed Flow	Existing	scheduled flow
P-27	0.11	0.18	0.02	0.14
P-28	0.11	0.11	0.02	0.19
P-29	0.06	0.01	0.01	0.01
P-30	0.38	0.1	0.06	0.12
P-31	0.47	0.12	0.07	0.16
P-32	0.18	0.01	0.01	0.16
P-33	0.42	0.11	0.06	0.14
P-34	0.3	0.15	0.04	0.15
P-36	0.06	0.38	0.01	0.36
P-37	0.8	0.2	0.12	0.26
P-38	0.39	0.18	0.01	0.2
P-39	0.35	0.13	0.03	0.15
P-40	0.69	0.01	0.02	0.12
P-41	0.32	0.1	0.01	0.1
P-42	0.23	0.06	0.04	0.13
P-43	0.25	0.14	0.08	0.18
P-44	0.6	0.14	0.08	0.23
P-45	0.17	0.03	0.02	0.16
P-46	0.12	0.01	0.01	0.3
P-47	0.17	0.02	0.01	0.2
P-48	0.12	0.03	0.02	0.39
P-49	1.22	0.27	0.16	0.67
P-50	0.85	0.27	0.16	0.67
P-51	0.8	0.26	0.15	0.57
P-52	0.75	0.18	0.11	0.23
P-53	0.52	0.18	0.11	0.23
P-54	0.71	0.18	0.11	0.2
P-55	0.35	0.09	0.05	0.1

label	Peak Designed	Minimum Designed Flow	Existing	scheduled flow
P-56	0.98	0.25	0.15	0.26
P-57	0.2	0.01	0.05	0.09
P-58	0.36	0.07	0.04	0.32
P-59	0.56	0.13	0.08	0.06
P-60	0.33	0.08	0.05	0.01
P-61	0.15	0.02	0.01	0.04
P-62	0.13	0.01	0.01	0.29
P-63	0.26	0.01	0.01	0.24
P-64	0.08	0.02	0.01	0.15
P-65	0.27	0.07	0.19	0.54
P-66	0.31	0.13	0.28	0.51
P-67	0.32	0.08	0.47	0.3
P-68	0.17	0.03	0.02	0.12
P-69	0.17	0.03	0.02	0.12
P-70	0.21	0.04	0.02	0.2
P-71	0.13	0.02	0.01	0.1
P-72	0.2	0.03	0.01	0.15
P-73	0.18	0.02	0.01	0.1
P-74	0.11	0.02	0.01	0.1
P-75	0.11	0.02	0.01	0.1
P-76	0.17	0.05	0.03	0.15
P-77	0.19	0.06	0.04	0.14
P-78	0.29	0.1	0.07	0.25
P-79	0.13	0.02	0.01	0.16
P-80	0.13	0.02	0.01	0.16
P-81	0.25	0.01	0.01	0.38
P-82	0.13	0.02	0.01	0.1
P-83	0.18	0.04	0.03	0.1

label	Peak Designed	Minimum Designed Flow	Existing	scheduled flow
P-84	0.27	0.02	0.02	0.25
P-85	0.18	0.01	0.01	0.15
P-86	0.26	0.01	0.01	0.25
P-93	0.04	0.04	0.04	0.04
P-94	0.04	0.04	0.04	0.04
P-95	0.07	0.05	0.01	0.06
P-96	0.07	0.01	0.01	0.01
P-97	0.14	0.01	0.02	0.06

Annex 6: Demand for scheduled flow based on existing water supply

Label	Existing Supply	schedal-1	schedal-2	schedual-1	schedual-2
J-1	0.013961186			0.000	0.025
J-2	0.036136924			0.000	0.066
J-3	0.046650106			0.000	0.085
J-4	0.004230662			0.000	0.008
J-5	0.048231165			0.000	0.088
J-6	0.004900224			0.000	0.009
J-7	0.006169776			0.000	0.011
J-8	0.01139059			0.000	0.021
J-9	0.014955319			0.033	0.000
J-10	0.015685825			0.035	0.000
J-11	0.022294959			0.049	0.000
J-12	0.004230662			0.009	0.000
J-13	0.021999445			0.049	0.000
J-14	0.00445327			0.010	0.000
J-15	0.01303545			0.029	0.000
J-16	0.012500606			0.028	0.000
J-17	0.021706753			0.048	0.000
J-18	0.006426446			0.014	0.000
J-19	0.06451253			0.143	0.000
J-20	0.09815137			0.217	0.000
J-21	0.044323643			0.098	0.000

Label	Existing Supply	schedal-1	schedal-2	schedual-1	schedual-2
J-22	0.009551872			0.021	0.000
J-23	0.034244488			0.076	0.000
J-24	0.032442037			0.072	0.000
J-25	0.005276633			0.012	0.000
J-26	0.001573077			0.003	0.000
J-27	0.027750299			0.061	0.000
J-28	0.036122467			0.080	0.000
J-29	0.006920365			0.015	0.000
J-30	0.071326156			0.158	0.000
J-31	0.028774462			0.064	0.000
J-32	0.007815876			0.017	0.000
J-33	0.135153435			0.299	0.000
J-34	0.012256966			0.027	0.000
J-35	0.029128512			0.064	0.000
J-36	0.003027988			0.007	0.000
J-37	0.023672579			0.052	0.000
J-38	0.023908376			0.053	0.000
J-39	0.041979784			0.093	0.000
J-40	0.026913217			0.000	0.049
J-41	0.046032291			0.000	0.084
J-42	0.036848816			0.000	0.067
J-43	0.015525872			0.000	0.028

Label	Existing Supply	schedal-1	schedal-2	schedual-1	schedual-2
J-44	0.035128642			0.000	0.064
J-45	0.015599372			0.000	0.028
J-46	0.017379623			0.000	0.032
J-47	0.006298162			0.000	0.011
J-48	0.00095051			0.000	0.002
J-49	0.165537736			0.000	0.302
J-50	0.165537736			0.000	0.302
J-51	0.003244129			0.000	0.006
J-52	0.013453624			0.000	0.025
J-53	0.013341736			0.000	0.024
J-54	0.056031741			0.000	0.102
J-55	0.024810373			0.000	0.045
J-56	0.017823056			0.000	0.033
J-57	0.005615857			0.000	0.010
J-58	0.013350968			0.000	0.024
J-59	0.034785106			0.000	0.063
J-60	0.036600011			0.000	0.067
J-61	0.054306758			0.000	0.099
J-62	0.02615052			0.058	0.000
J-63	0.01820966			0.040	0.000
J-64	0.030822485			0.068	0.000
J-65	0.016046976			0.035	0.000

Label	Existing Supply	schedal-1	schedal-2	schedual-1	schedual-2
J-66	0.029272779			0.065	0.000
J-67	0.019365997			0.000	0.035
J-68	0.025254074			0.000	0.046
J-69	0.039887619			0.000	0.073
J-70	0.042337745			0.000	0.077
J-71	0.005642571			0.000	0.010
J-72	0.016506627			0.000	0.030
J-73	0.010267			0.000	0.019
J-74	0.02945193			0.000	0.054
J-75	0.006634525			0.000	0.012
J-76	0.02116558			0.000	0.039
J-78	0.013196382			0.000	0.024
	2.202200092			2.202200092	2.202200092

Annex-7: Calibration Result and Information Report

Darwin Calibrator (research result final 1.wtg): New Optimized Run - 2

Demand Adjustment Values

Adjustment Group	Demand Adjustment Factor	Emitter Coefficient (L/s/(m H2O)^n)	Number of Leakage Nodes

Roughness Adjustment Values

Adjustment Group	Hazen-Williams C
New Roughness Group - 1	0.5

Demands

Adjustment Group	Node	Original Demand (L/s)	Adjusted Demand (L/s)	Original Emitter Coefficient (L/s/(m H2O)^n)	Adjusted Emitter Coefficient (L/s/(m H2O)^n)

Roughness's

Adjustment Group	Link	Original Roughness	Adjusted Roughness
New Roughness Group - 1	P-1	120.000	60.000
New Roughness Group - 1	P-2	120.000	60.000
New Roughness Group - 1	P-3	120.000	60.000
New Roughness Group - 1	P-4	120.000	60.000
New Roughness Group - 1	P-5	120.000	60.000
New Roughness Group - 1	P-6	120.000	60.000
New Roughness Group - 1	P-7	120.000	60.000
New Roughness Group - 1	P-8	150.000	75.000
New Roughness	P-9	120.000	60.000

Group - 1				
New Roughness Group - 1	P-10	150.000	75.000	
New Roughness Group - 1	P-11	120.000	60.000	
New Roughness Group - 1	P-12	150.000	75.000	
New Roughness Group - 1	P-13	150.000	75.000	
New Roughness Group - 1	P-14	120.000	60.000	
New Roughness Group - 1	P-15	120.000	60.000	
New Roughness Group - 1	P-16	120.000	60.000	
New Roughness Group - 1	P-17	120.000	60.000	
New Roughness Group - 1	P-18	120.000	60.000	
New Roughness Group - 1	P-19	120.000	60.000	
New Roughness Group - 1	P-20	120.000	60.000	
New Roughness Group - 1	P-21	120.000	60.000	
New Roughness Group - 1	P-22	120.000	60.000	
New Roughness Group - 1	P-23	120.000	60.000	
New Roughness Group - 1	P-24	120.000	60.000	
New Roughness Group - 1	P-25	120.000	60.000	
New Roughness Group - 1	P-26	120.000	60.000	
New Roughness Group - 1	P-27	120.000	60.000	
New Roughness Group - 1	P-28	120.000	60.000	
New Roughness Group - 1	P-29	120.000	60.000	

New Roughness Group - 1	P-30	120.000	60.000	
New Roughness Group - 1	P-31	120.000	60.000	
New Roughness Group - 1	P-32	120.000	60.000	
New Roughness Group - 1	P-33	120.000	60.000	
New Roughness Group - 1	P-34	120.000	60.000	
New Roughness Group - 1	P-36	120.000	60.000	
New Roughness Group - 1	P-37	120.000	60.000	
New Roughness Group - 1	P-38	120.000	60.000	
New Roughness Group - 1	P-39	120.000	60.000	
New Roughness Group - 1	P-40	120.000	60.000	
New Roughness Group - 1	P-41	120.000	60.000	
New Roughness Group - 1	P-42	120.000	60.000	
New Roughness Group - 1	P-43	120.000	60.000	
New Roughness Group - 1	P-44	120.000	60.000	
New Roughness Group - 1	P-45	120.000	60.000	
New Roughness Group - 1	P-46	120.000	60.000	
New Roughness Group - 1	P-47	120.000	60.000	
New Roughness Group - 1	P-48	120.000	60.000	
New Roughness Group - 1	P-49	120.000	60.000	
New Roughness Group - 1	P-50	120.000	60.000	
New Roughness Group - 1	P-51	120.000	60.000	

New Roughness Group - 1	P-52	120.000	60.000	
New Roughness Group - 1	P-53	120.000	60.000	
New Roughness Group - 1	P-54	120.000	60.000	
New Roughness Group - 1	P-55	120.000	60.000	
New Roughness Group - 1	P-56	120.000	60.000	
New Roughness Group - 1	P-57	120.000	60.000	
New Roughness Group - 1	P-58	120.000	60.000	
New Roughness Group - 1	P-59	120.000	60.000	
New Roughness Group - 1	P-60	120.000	60.000	
New Roughness Group - 1	P-61	120.000	60.000	
New Roughness Group - 1	P-62	120.000	60.000	
New Roughness Group - 1	P-63	120.000	60.000	
New Roughness Group - 1	P-64	120.000	60.000	
New Roughness Group - 1	P-65	120.000	60.000	
New Roughness Group - 1	P-66	120.000	60.000	
New Roughness Group - 1	P-67	120.000	60.000	
New Roughness Group - 1	P-68	150.000	75.000	
New Roughness Group - 1	P-69	150.000	75.000	
New Roughness Group - 1	P-70	120.000	60.000	
New Roughness Group - 1	P-71	120.000	60.000	
New Roughness Group - 1	P-72	120.000	60.000	

New Roughness Group - 1	P-73	120.000	60.000	
New Roughness Group - 1	P-74	150.000	75.000	
New Roughness Group - 1	P-75	120.000	60.000	
New Roughness Group - 1	P-76	120.000	60.000	
New Roughness Group - 1	P-77	120.000	60.000	
New Roughness Group - 1	P-78	120.000	60.000	
New Roughness Group - 1	P-79	120.000	60.000	
New Roughness Group - 1	P-80	120.000	60.000	
New Roughness Group - 1	P-81	120.000	60.000	
New Roughness Group - 1	P-82	120.000	60.000	
New Roughness Group - 1	P-83	120.000	60.000	
New Roughness Group - 1	P-84	120.000	60.000	
New Roughness Group - 1	P-85	120.000	60.000	
New Roughness Group - 1	P-86	120.000	60.000	
New Roughness Group - 1	P-87	120.000	60.000	
New Roughness Group - 1	P-88	120.000	60.000	
New Roughness Group - 1	P-89	120.000	60.000	
New Roughness Group - 1	P-90	120.000	60.000	
New Roughness Group - 1	P-91	120.000	60.000	
New Roughness Group - 1	P-92	120.000	60.000	

New Roughness Group - 1	P-93	120.000	60.000
New Roughness Group - 1	P-94	120.000	60.000
New Roughness Group - 1	P-95	120.000	60.000
New Roughness Group - 1	P-96	120.000	60.000
New Roughness Group - 1	P-97	120.000	60.000

Statuses

Link	Original Status	Adjusted Status

Hydraulic Grade RMSE's

Snapshot	Hydraulic Grade RMSE (m)
Masha Town WDS	1.33

Flow RMSE's

Snapshot	Flow RMSE (L/s)

Flows

Field Data Snapshot	Pipe	Observed Flow (L/s)	Simulated Flow (L/s)	Difference (L/s)

Hydraulic Grades

Field Data Snapshot	Junction	Observed Hydraulic Grade (m)	Simulated Hydraulic Grade (m)
Masha Town WDS	J-79	2,268.49	2,267.89
Masha Town WDS	J-82	2,266.97	2,267.89
Masha Town WDS	J-83	2,267.46	2,267.85
Masha Town WDS	J-81	2,265.29	2,267.55
Masha Town WDS	J-84	2,269.93	2,271.47

Difference (m)						
-0.59						
0.91						
0.39						
2.27						
1.54						

research result final 1.wtg 4/3/2019	Bentley Systems, Inc. Haestad Methods Solution Center 27 Siemon Company Drive Suite 200 W Watertown, CT 06795 USA +1-203-755-1666	Bentley WaterGEMS V8i (SELECTseries 5) [08.11.05.61] Page 1 of 1

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Comparison of drinking water quality Guideline.

ተ.ቁ	መለኪያዎች	[illegible] WHO Guideline	[illegible] E.DWQ Guideline	[illegible]	[illegible] Source
1	Total coliform in 100mL	0	0	12	[illegible]
	E.coli in 100mL	0	0	3	
2	Total coliform in 100mL	0	0	9	[illegible]
	E.coli in 100mL	0	0	6	
3	Total coliform in 100mL	0	0	5	[illegible]
	E.coli in 100mL	0	0	7	
4	Total coliform in 100mL	0	0	13	[illegible]
	E.coli in 100mL	0	0	6	
5	Total coliform in 100mL	0	0	8	[illegible]
	E.coli in 100mL	0	0	6	
6	Total coliform in 100mL	0	0	7	[illegible] Estadium [illegible]
	E.coli in 100mL	0	0	4	

[illegible]