HYDRAULIC PERFORMANCE ASSESSMENT OF KOFELE TOWN WATER SUPPLY DISTRIBUTION SYSTEM

M.Sc. THESIS

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HYDRAULIC PERFORMANCE ASSESSMENT OF THE WATER DISTRIBUTION NETWORK OF KOFALE TOWN WATER SUPPLY SYSTEM

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We, the undersigned members of the board of examiners of the final open defense "Hydraulic Performance Assessment of The Water Distribution Network of Kofele Town Water Supply System" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree master of science.

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This is to certify that the thesis entitled "**Hydraulic Performance Assessment of the Water Distribution Network of Kofele Town Water Supply System**" submitted in the partial fulfillment of the requirements for the degree of **Master's** with specialization In Hydraulic Engineering, the Graduate Program of the Department of Hydraulic & Water Resource Engineering, and has been carried out by **Awol Hassen Mohammed ID.No. GPHydrR/003/11,** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Tewodros Assefa (PhD)	________________	________________
Name of Major Advisor	Signature	Date
Gemedo Gelgalu (MSc.)	________________	________________
Name of Co-Advisor	Signature	Date

DECLARATION

I undersigned and declared that this MSc thesis entitled "Hydraulic Performance Assessment of The Water Distribution Network of Kofele Town Water Supply System'' is my original work prepared under the guidance of Tewodros Assefa (Ph.D.) and Gemedo Gelgalu(MSc). All sources of materials used for this thesis have been properly acknowledged and this is not presented by any other party for any purpose.

Name ------------------------------------

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

This M.Sc.thesis has been submitted for examination with my approval as thesis advisor

Name ------------------------------------

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

Place and Date Submission date---------------------------

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LIST OF ABBREVIATIONS AND ACRONYMS

CIWD	Commercial and Institutional Water Demand
CSA	Central Statistical Agency
EPA	Environmental Protection Agency
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphic Use Inter-phase
HCU	House Connection Users
MoWR	Ministry of Water Resources
NGO	Non-Governmental Organizations
OWWDSE	Oromia Water Works Design and Supervision Enterprise
PTU	Public Tap Users
UFWUN	Accounted for Water
UNICEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International Development
UTM	Universal Transverse Mercator
WDS	Water Distribution System
YC	Yard Connection

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ABSTRACT

Knowledge about actual network performance during different operating situations is a key tool to control and manage the existing water supply systems or design new networks. This study was conducted in Kofele Town to assess the hydraulic performance of the water supply distribution system. Both secondary and primary data sources were used for this study. To analyze the existing water distribution system using Water GEMS V8i software. The model can be used to identify the zone of higher and lower pressure junctions and velocity through the pipe. The current total domestic water demand in town was 400 m^3 /day, and the average per capita domestic water consumption was 12.45 lit/person/day. The water flowing from the source to the system is not enough and low system efficiency was observed to satisfy the user community. According to simulated results; the maximum and and a minimum pressures were 119m and 2m respectively. The water loss of the town was 31.125% from the total water production. Hence, the water distribution network was faced frequent pipe bursts and failures during low demand times and exposed to a large volume of water loss. The average amount of water, which reached the consumers accounts only 68.875% of the total water produced and it is less than 75%..Generally the result of the analysis shows that the overall hydraulic performance of water distribution of the town was poor, which is reflected by low water production rate, low water consumption, and high level of Non-revenue water, low service coverage. Therefore, it is significant to rehabilitate and improve the water distribution system capacities, establishing pressure zone, increase pumping rate and drilling additional borehole. In addition providing more attention to water losses reduction policies and strategies are vital for remedial measures.

Keywords: WaterGEMSV8i; Hydraulic Performance Assessment; Kofele Town Water Supply.

1. INTRODUCTION

1.1. Background

Access to water supply and sanitation is a fundamental need and a human right. It is vital for the dignity and health of all people (Liu, 1996). Providing sufficient water of appropriate quality and quantity has been one of the most important issues in human history. Most ancient civilizations were initiated near water sources. People began to transport water from other locations to their communities. Today, a water supply system consists of infrastructure that collects, treats, stores, and distributes water between water sources and consumers. Limited new natural water sources and rapidly increasing population has led to the need for innovative methods to manage a water supply system (Adeosun, 2014). Most problems that occurred in developing countries are intermittent, inequalities in service provision between the rich and the poor, high rate of water losses from the distribution systems, Population growth and urbanization, growing urban water demand, infrastructure is aging and deteriorating (Jalal, 2008).

According to WHO/UNICEF, (2019) estimated that 57% of Ethiopian households have access to improved drinking water sources 93% in urban areas and 49% in rural areas. As a result, most of the rural population rely on unimproved water sources, such as rivers, lakes, ponds, streams, rainwater, unprotected springs and wells, irrigation water from canals and dams, as a source of water for drinking and other domestic uses.

Problems with access to sufficient water are most happening in the developing world due to either the intermittent nature of the system or the poor operational practice in continuous supplies. According to the global water supply and sanitation assessment report in 2000, 1.1

billion people of the world population were without access to an improved water supply. The majority of these people live in Asia and Africa, where two out of five Africans lack improved water supply. In Sub- Saharan Africa, 748 million people were relying on unsafe drinking water sources in 2012 of which 173 million obtained their drinking water straight from rivers, streams and ponds. The remaining population relied on unprotected, open wells or poorly protected natural springs (Ott, 2014).

Water distribution systems are designed to satisfy the water requirements for domestic, commercial, industrial, and fire-fighting purposes. The system should be capable of meeting the demands and pressures at each node within the distribution system at all times. The Water distribution networks play an important role in modern societies being their proper operation directly related to the population’s well-being. However, water supply activities tend to be natural monopolies, so to guarantee good service levels in a sustainable way the water supply systems' performance must be evaluated (Muranho et al., 2014). This research is conducted to assess the hydraulic performance of the water distribution network of the Kofele Town water supply system.

1.2. Statement of the Problem

The primary goal of all water distribution systems is the delivery of water from the source or treatment facilities to its consumers to meet the demands with quantity and pressure.

Unfortunately, as a water distribution system ages, its ability to transport water diminishes and the demands placed upon it increases. In addition to the unsatisfactory performance of a deteriorated network, there are direct economic impacts of a failing system (Hickey, 2008).

Growing populations and lack of available cost-effective supply augmentation options make reliable estimates of residential water demand important for policymaking (Dharmaratna et al, 2010). Problems of providing safe water supply to the urban poor in developing countries are increasing with the increase in population. On average towns are growing fast. They are doubling in population every 15-20 years. As a result, urban water supply is complex as compared to rural water supply in terms of study, design, operation &maintenance, management, and implementation (MoWRE, 2011).

To ensure the availability of sufficient quantities of to the increased population of the country, it becomes imperative, to evaluate the technical performance of existing schemes by using computer software WATERGEMS V8*i* that can be used in hydraulic and water quality modeling application for water distribution systems. Even though the software can help to evaluate the performance of water distribution networks and water quality modeling, this research will focus only on the performance evaluation of the water distribution network. Therefore, the scope of this research is limited to hydraulic performance assessment of water supply distribution networks and water demand prediction.

Kofele is a town that is getting fast development and growing population. The rapid extension of the urban areas in the town necessitates revising the existing water supply scheme and other important infrastructure to provide the required services and to protect the health and environment of the concerned population.

Like in many developing cities of Ethiopia a rapid population growth and high rural-urban migration pose many social and environmental challenges for the Kofele town. One of these is a water supply system. The situation of insufficient and unsafe water, especially the community using unprotected river/spring in rural areas and poor urban areas that have no enough yard or community tap because of the shortage of supply.

Less water for drinking, bathing, washing, and sanitation resulted in poor hygiene and health situation. Water has not reached areas around public taps and water sources. This is because the existing water supply is not enough for the town.

Therefore, this research work was prepared to assess the Kofele Town water distribution network by assessing demand and production of water, loss of water, and hydraulic parameter.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of this study was to evaluate the hydraulic performance of the Kofele Town water supply distribution system.

1.3.2. Specific objectives

The specific objectives of this study were:-

1.To identify problems of existing water supply and demand

2. To estimate water losses of the existing water distribution system

3. To evaluate hydraulic parameters of the existing distribution system

1.4. Research Questions

1. What are the problems of existing water supply of Kofele Town?

2. How much water is lost in the system comparing with system production?

3. How do the hydraulic performance of the distribution system evaluated?

1.5. Significance of the Study

The poor performance of the water supply distribution network is the main problem in the whole world predominantly in poor countries like Ethiopia. Many sectors of water distribution systems in most parts of Kofele Town suffer from the deficiency of water supply quantities and sharp deficiency in the pressure so that to achieve the consumer demand at satisfactory levels, it must be improved and increased the efficiencies of the water distribution operating and management systems.

The study shows the existing water supply situation of the urban dwellers by investigating the water demand, water losses, and identifying factors that affect the performance of the water distribution network. It will provide insight to policymakers, NGOs, community-based organizations, and other stakeholders who are concerned with urban water supply problems. This paper will be a significant input for the Kofele Town Water Supply and Sanitation Office and also for Kofele Woreda Water Resources Development and Energy Office to reconsider their system and take any necessary measures during the upgrading & rehabilitation of the system. This research also adds to the literature on urban water supply issues, which are currently a global challenge. Still, no research was conducted in the area on the assessment of the hydraulic performance of the distribution network and evaluate demand and supply. Therefore, this study will initiate to contribute a research idea by filling this gap. It will also serve as the baseline for other researchers who will be interested in the area.

1.6. Scope of the Study

The scope of the research focuses on the performance of the water supply distribution system of the urban places of Ethiopia, particularly in the Kofele town. This study primarily focuses on evaluating the performance of the water supply distribution system in terms of pressure, flow or velocity, demand meeting (not included livestock water demand and industrial demand), and water loss. This research was used hydraulic network analysis software Bentley WaterGEMSV8i. The performance of the system was observed under peak consumption and minimum time consumption and its performance was evaluated based on hydraulic conditions not including water quality.

2. LITERATURE REVIEW

Water is at the centre of economic and social development; it is vital to maintain health, grow food, manage the environment, and create jobs. According to World Bank (2020), despite water's importance, Some 2.2 billion people around the world do not have safely drink water services, 4.2 billion people do not have safely managed sanitation services, and 3 billion lack basic handwashing facilities (World Health Organization, 2020). Safe drinking water is the birth right of all humankind as much a birth right as clean air ,while access to clean water can be considered as one of the basic needs and rights of a human being. The health of people and dignified life is based on access to clean water (Hutton & Bartram, 2008). Water Supply Systems are characterized by a large variety and complexity providing a huge opportunity to act in the economic and/or energetic efficiency improvement (Coelho & Andrade-Campos, 2014). In developing countries like Ethiopia, the gap in supply and demand for water is increasing and predominant. The existing system of water supply is facing problems like a higher rate of leakage, poor maintenance, poor customer service, and poor quality of water (Paneria and Bhatt, 2017).

A water supply system is a set of structures, facilities, and services that produces and distributes water to consumers (Vilanova and Balestieri, 2014). Water supply systems are crucial strategic systems that have physical complexity in their construction, installation, operation, with enormous economic concerns and environmental implications(MoWR, 2006) They also contribute significantly to public health.

Despite this, design and operational challenges have often been underestimated by professionals and engineers and their direct or indirect impacts, although often considered separately, have seldom been investigated comprehensively (Taylor, 2018). The most common challenges for the water industry include water quality degradation, capacity shortages, infrastructure aging and deterioration, demand increases, and their ever-increasing energy consumption coupled to the global energy crisis (Jalal, 2008). Water supply system, infrastructure for the collection, transmission, treatment, storage, and distribution of water for homes, commercial establishments, industry, and irrigation, as well as for such public needs as firefighting and street flushing. Of all municipal services, the provision of potable water is perhaps the most vital. People depend on water for drinking, cooking, washing, carrying away wastes, and other domestic needs. Water supply systems must also meet requirements for public, commercial, and industrial activities. In all cases, the water must fulfill both quality and quantity requirements (Nathanson, 2020).

2.1. Basic Principles of Water Distribution System

Water distribution networks play an important role in modern societies being their proper operation directly related to the population's well-being.

However, water supply activities tend to be natural monopolies, so to guarantee good service levels in a sustainable way the water supply systems performance must be evaluated incorporation of performance assessment methodologies in the management practices creates competitiveness mechanisms that lead to the culture of efficiency and the pursuit of continuous improvement (Muranhoa, 2013).

The objective of water distribution systems is to deliver water of suitable quality to individual users in an adequate amount and at satisfactory pressure. It should be capable of delivering the maximum instantaneous design flow at a satisfactory pressure. The water distribution networks should meet demands for potable water. If designed correctly, the network of interconnected pipes, storage tanks, pumps, and regulating valves provides adequate pressures, adequate supply, and good water quality throughout the system. If incorrectly designed, some areas may have low pressures, poor fire protection, and even health risks (Adeosun, 2014). The water distribution network, which is typically the most expensive component of water the supply system is continuously subject to environmental and operational stresses which lead to its deterioration. Increased operation and maintenance costs, water losses, reduction in the quality of service, and reduction in the quality of water are typical outcomes of this deterioration (Kleiner et al., 2001).

2.2. Water Supply Distribution Network

Water distribution systems are designed to adequately satisfy the water requirements for a combination of domestic, commercial, industrial, and firefighting purposes. The system should be capable of meeting the demands placed on it at all times and the satisfactory hydraulic performance (Zyoud, 2003).

Water distribution networks are very important lifeline infrastructure systems, where failures are inevitable. A typical WDNs consist of a network of pipes, nodes linking the pipes, storage tanks, reservoirs, pumps, additional appurtenances like valves.

Water distribution systems represent a major portion of the investment in urban infrastructure and a critical component of public works. The main goal is to design water distribution systems to deliver potable water over spatially extensive areas in required quantities and under satisfactory pressures (Nyende-Byakika, 2012). The design of water distribution systems, in general, is based on the assumption of continuous supply. However, in most developing countries, the water supply system is not continuous but intermittent (Khatri, 2007). A well-planned water distribution network is very essential in the development of urban areas. The network is built to satisfy various consumer demands while meeting minimum pressure requirements at certain nodes (Adeosun, 2014). To provide this, the service area is divided into different pressure zones. One of the main criteria determining the number of zones is the topology. A system serving a highly elevated hilly area has more pressure zones than a relatively flat area (Misirdali, 2003).

2.3. Problems of the Water Distribution System

Water flow is a function of several things, including the size and shape of the opening, and the pressure at the opening (Rossman et al, 2003). Typically, city water supplies are at 40 to 70m, (static pressure). Older private systems are set to maintain water pressure between 20m and 40m, which is too low for some lifestyles; plumbers can set systems higher if the pump is capable of delivering higher pressure (MoWR, 2006).

Gravity is another source of pressure loss in a residential plumbing system. Energy is required to push the water uphill. For every 0.305m of elevation increase in a pipe, approximately 0.434 m is lost. With no water flowing, the static pressure available at the street main maybe 42 m, but the static pressure at the second-floor basin would be 52 m (Ilesenim, 2006).

2.4. Population Forecasting

The design population is estimated due to all factors governing the future growth and development of the project area in the industrial, commercial, educational, social, and administrative spheres. Design of water supply and sanitation scheme is based on the projected population of a particular City or Town. Also estimateion of the design period of the components of all structures of water supply and sanitation are depend © on the projection of population. Changes in the population of the City over the years occur, and the system should be designed taking into account the population at the end of the design period (Nuru et al., 2020).

2.4.1. Methods of population forecasting

According to Nuru et al.,(2020), there are four methods of population forecasting of future population those are: -Arithmetic progressive method, Incremental increase method, Geometric method. Arithmetic progressive method is the average rate of increase in population is assumed to be constant from decade to decade. The average increase per decade is found out from the previously available census data. The product of this amount obtained and the number of decades for which the population is to be worked out is added to the present population of the subjected area to get the approximate population after n decades. By using the formula given below the future population is worked out progression method, and Exponential growth methods.

The geometric increase method is based on the assumption that the percentage increase in population from decade to decade remains constant. In this method the average percentage of growth of the last few decades is determined; the population forecasting is done on the basis that the percentage increase per decade will be the same. The average percentage increase per decade is found out from the previously available census data.

The incremental increase method is an improvement over the above two methods. The average increase in the population is determined by the arithmetical method and to this is added the average of the net incremental increase once for each future decade.

The Exponential increase method is the best method of population forecasting based on past information. This method tends to give a higher estimate than other methods normal since it behaves exponentially. It is more accurately describes the continuous and cumulative nature of the population growth rate. This method is used by the central statistics Authority of Ethiopia.

Common Causes of Low Water Pressure

According to Roote, (2021), there are several reasons for the loss of water pressure. Some of them are listed below.

Too Much Demand on Water In some homes, having multiple plumbing fixtures on at once can place too high of a demand on the water supply for proper water pressure to be maintained in every fixture. With a little coordination, this issue can usually be avoided. Faulty Fixtures Fixtures themselves, such as showerheads or faucets, can become faulty or clogged over time. In some cases, simply cleaning out the screen or aerator is enough to fix the issue, but at other times, an entire fixture may need to be replaced.

issue, but at other times, an entire fixture may need to be replaced.Broken Pressure RegulatorWater pressure regulators are designed to help stabilize water pressure in the home, keeping it within a certain range. When these regulators go bad, water pressure can either become too high or too low.Closed Valves water supply can be shut off by two different valves. If either of these valves is not fully open, then it can affect the water pressure.Clogged Pipes If pipes become clogged, these blockages can disrupt water flow through pipes. With the flow disrupted, water pressure will also go down. Pipes need to be cleaned out or replaced to address the issue.

Corroded Plumbing Clogs can be fixed by cleaning out or replacing small sections of piping. Over time, though, the entire system of piping can become corroded, which can have a negative effect on the water pressure.

2.5. Performance Evaluation of Water Distribution System

The performance of a water distribution network can be defined as its ability to deliver a required quantity of water under sufficient pressure and an acceptable level of quality during different normal and abnormal operational situations (Tabesh and Dolatkahi, 2006). Evaluating the performance of water supply systems is important for the water industry to deliver competent levels of service. A good distribution system should be capable of supplying water at all intended places within the city with reasonably sufficient pressure heads and the requisite amount of water for various types of demand. The performance of an urban water supply scheme can be evaluated based on four performance measures: Hydraulic, Structural, Water Quality, and Customer perception (Dighade et al., 2014).

2.5.1. Hydraulic performance

The hydraulic performance of a water distribution system is the ability to provide a reliable water supply at an acceptable level of service that is, meeting all demands placed upon the system with provisions for adequate pressure, fire protection, and reliability of uninterrupted supply (Tabesh and Doulakhah, 2006). Thus, hydraulic simulation modeling is nowadays the most common tool used by water supply engineers and managers.

2.5.2. Structural performance

The physical performance of the water supply system is the ability of the distribution system to act as a physical barrier that prevents external contamination from affecting the quality of the internal, drinking water supply (Tabesh and Dolatkahi, 2006).

The most obvious indication of the physical deterioration and failure of the pipe network is leakage. Analysis of a pipe network is essential to evaluate a physical system of water supply systems. The annual volume of water lost is an important indicator of water distribution efficiency, both in individual years and as a trend over years. High and increasing water losses are an indicator of ineffective planning and construction, and low operational maintenance activities. The other indicator is the volumetric efficiency which is the ratio of the registered volume and the total supplied volume during a certain reference period a value above 75% is considered to be acceptable (Mckenzi et al, 2006).

2.5.3. Water quality

Water quality deteriorates as it travels through a drinking water distribution system (DWDS). Parameters and reactions that are considered of interest include disinfectant residual and the disinfectant by-product formation, nitrification, bacterial re-growth, corrosion, sedimentation, temperature, and taste and odor.

2.5.4. Customer perception

It is important to maintain the public's confidence in the quality of drinking water and the services provided by a utility. Satisfied customers will pay their bills promptly and will provide political support for necessary rate increases or bond issues. To evaluate a WDS, it would be ideal to identify all major customers with their preferences, expectations, needs, and requirements and then to explore the ways of meeting their expectations with consideration to associated consequences. Major customers may need those facilities that constitute a significant portion of supply-demand in a region (e.g., residential, Industrial, and firefighting users, public health officials). An ideal approach might be to investigate the quantity of water needed for each customer, the period they need water for, and the appropriate level of water quality that is suitable for their need. The estimation of the quantity of water should reflect customer preferences and expectations efficiently. The more closely customer needs are met, the higher the level of satisfaction for customers, and the better the water utility is managed (Jalal, 2008).

2.6. Water Supply Mode in the Distribution System

According to Kelkar, (2007) a critical appraisal of selected water distribution networks was made under two modes of operation, intermittent water supply, and continuous water supply.

2.6.1. Continuous Water Supply system

In the continuous supply systems, water is directly conveyed through the distribution network continuously without interruptions. Consumers use water at any time without any need for an individual roof (Abu-Madi & Trifunovic, 2013). The main factors required to achieve continuous water supply system are summarized as follows:-

Enough water at the source: to meet consumer’s requirements for water.

A good and reliable distribution network: to guarantee enough water with acceptable pressure to all consumers.

Effective system parameters: capable pump stations and suitable pipe diameters

Successful monitoring policy: to discover any interruption, and to detect damaged pipes early as possible, to reduce leakage

The water distribution network in the continuous supply systems should be designed to with stands the range of pressures corresponding to the minimum and maximum supply conditions

2.6.2. Intermittent supply system

The distribution system is usually designed as a continuous system based on the assumption of continuous supply. However, in most developing countries water supply is not continuous but intermittent. A serious problem arising from intermittent supplies, which is generally ignored, is the associated high levels of contamination. This occurs in networks where there are prolonged periods of interruption of supply due to negligible or zero pressures in the system. During the Supply period, the water is stored in all sorts of vessels for use in non-supply hours and when the supply is resumed, the stored water is wasted and freshwater again stored. During non-supply hours, polluted water may enter the supply mains through leaking joints, pollute the supplies, and create a health-related problem. Intermittent systems, which require frequent valve operations, are likely to affect equitable distribution of water mostly due to operator negligence. Intermittency generates inequitable water distribution due to pressure-dependent flow conditions, with obvious disadvantages for consumers located far away from the supplying points or at higher altitudes in the area (Totsuka et al, 2004).

There are no dead ends in this type of distribution network. The maintenance operation does not affect the interruption of the system as in the branching system (Lines, 2021).

2.7. Methods of Distribution

According to Kumar et al., (2015) there are three methods of distribution systems: (i) Gravity system (ii) Pumping system (iii) Combined gravity and pumping system

2.7.1. Gravity distribution

When the ground level of water source/storage is sufficiently raised than the core village/town area, such a system can be utilized for distribution. The water in the distribution pipeline flow due to gravity and no pumping is required. Such a system is highly reliable and economical

2.7.2. Distribution using pumps with storage

In such a system, water is supplied by continuous pumping. Treated water is directly pumped into the distribution main with constant pressure without intermediate storage. Supply can be affected during power failure and breakdown of pumps(Guyer, 2012).

2.7.3. Combined gravity and pumping system

In such a system, both gravity as well pumping systems are used. Such systems are used where there are variations in topography in town/village

2.8. Principles of Pipe Network Hydraulics

Flow in a pipe network satisfies two basic principles, conservation of mass, and conservation of energy (Izinyon & Anyata, 2009).

2.8.1. Conservation of mass

For steady-state conditions, Conservation of mass states that the flow into and out of the system must be the same. It is assumed that water is incompressible (M. Hopkins, 2012).

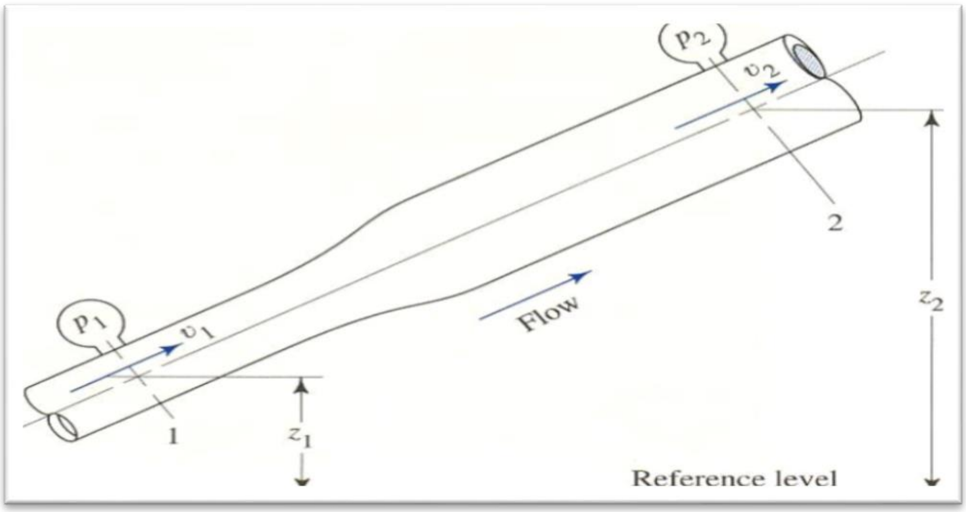


Figure 2.1: Continuity diagram (conservation of mass) (Source: Belay, 2012)

Mass of fluid at section 1 = Mass of fluid at section 2

Principle of conservation of mass

A1V1=A2V2=Q1=Q2 …………………………………….. ……………………………. (2.5)

Where, V = average velocity (m/sec); A = cross-sectional area (m^2) and Q = Discharge (m^3 /sec).

2.8.2. Conservation of energy

The principle of conservation of energy states energy can neither created nor destroyed. Thus, the energy difference between the two points is the same regardless of the path taken. The energy in pipe flow is typically described in terms of the head. The energy at any point in a distribution system is the sum of three components, pressure head, velocity head, and elevation head (Walski et al., 2006)

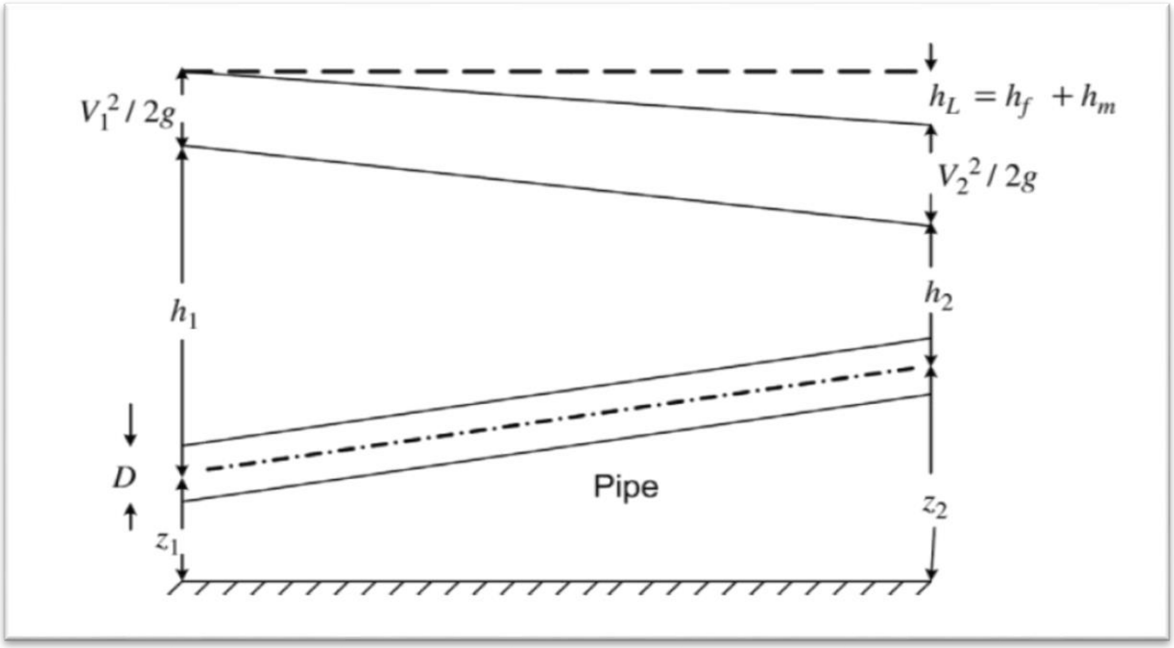


Figure 2.2: Diagram of conservation of Energy (Source: Swamee, 2008)

$$P1/\Upsilon + V12/2g + z1 = P2/\Upsilon + V22/2g + z2 + HL \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2.6)$$

Where, P = Pressure (Pa); V = Velocity (m /s); z = Elevation; g = gravitational acceleration constant (9.8 m /sec2); γ = Specific weight of water (N /m.) and hl = Head losses (m).

2.9. Head Losses

Different factors cause energy losses. The main reason for the energy loss is due to internal friction between fluid particles traveling at different velocities (Zyoud, 2003).

Major and minor losses in the flow of any fluid are important factors to consider when designing a system to move a fluid from one point to another, and doing it efficiently. Applications such as pump sizing are factored heavily on these losses. Major losses are head losses due to friction factor and pipe diameter and can vary depending on the type of pipe used. Minor losses are small losses due mainly to bends or valves that disrupt a smooth steady flow. Most minor losses are quantified as K values, loss coefficients, and for many types of fittings such as elbows, tee's, contraction/expansion fittings, and valves such as a globe, ball, and check valves, are readily produced (Bud Bliss, 2014).

$$hl = 10.7(Q/C)^{1.85} * L/(D)^{4.87} \quad \text{……………………………………………………...} \quad (2.7)$$

Where C =Roughness coefficient, D = Pipe diameter = Flow Rate, hl = pipe friction loss

L = Riser pipe and head work pipe length

2.10. Water Demand

Water demand is the volume of water requested by users to satisfy their needs. In a simplified way, it is often considered equal to water consumption, although the two terms conceptually do not have the same meaning (Wallingford, 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use (Berhe, 2005). (Maher Abu-Madi, 2013) Noted that, water demand is the algebraic sum of the quantity of water utilized by a consumer and the amount of water physically lost from the system.

It is usually expressed as per capita demand. Per capita, water usage varies widely due to the differences in climatic conditions, the standard of living, population growth, type of commercial and industrial activity, and water pricing. Water demand increases with time due mainly to population growth. Therefore, new water resources ought to be developed to meet the increasing water demand at present and in the future. It is usual to classify water demand in various sorts depending on the characteristics of the consumers'. The most common types are domestic, commercial, industrial, firefighting, and unaccounted for water demand (Abdo, 2009).

2.10.1. Domestic water demand

Domestic demand includes the water required in the private building for drinking, cooking, bathing, flushing, and washing clothes (WHO, 2008) indicated that domestic consumption varies according to the living conditions of the consumers, economic status of the community, climatic condition, mode of service and affordability and accessibility of the service. Daily per capita water consumption in Ethiopia is generally very low throughout the country. DWD is suppressed in almost all towns in the country because of supply shortages. Actual demand is expected to be greater than present consumption if greater supplies were available to the community (Ministry of Water & Energy, 2011).

2.10.2. Non-domestic water demand

According to Van Zyl et al., (2021) non-domestic demand comprises Industrial, Commercial, and Institutional, Firefighting demands, Unaccounted Water Demand (UWD).

Industrial water demand represents the amounts of water demand required by industries and factories in the cities.

According to MoWRE,(2011) the ordinary per capita consumption of industries is 50l/c/d. but due to the modernization of technology in reusing wastewater the amount of water required for an industry getting reduced.

Commercial And Institutional Water Demand (CIWD**)** In addition to those of household consumers, the water requirements of towns include the needs of such commercial and institutional consumers as public schools, clinics, hospitals, offices, shops, bars, restaurants, and hotels. CIWD is usually linked directly to population size. For medium towns, the CIWD estimate is taken as 10 percent of DWD.

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

2.11. Water Losses in The Distribution System

There are two types of water losses in the distribution system according to Dighade et al., (2014). These are real losses and apparent losses. Real losses consist of water lost through burst pipes, leaking joints, fittings, service pipes, and connections, whereas apparent losses result from illegal connections, under-registration of customers‟ meters inaccurate meters, bypassing meters, billing errors, inadequate meter reading policy, bribery, and corruption of meter readers.

Real losses increase the water utility production costs and water resource since they represent water that is extracted and treated but never reaches beneficial use. It is recommended as a standard practice to split water losses into real and apparent losses when studying water losses (Hamilton et al., 2006).

2.11.1. Real losses

Real losses are “the annual volumes lost from transmission and distribution system through all types of leaks, bursts and overflows on mains, service reservoirs and service connections up to the point of customer metering”. Real losses are attributed to varying pressure, inefficient leak detection systems, poor workmanship, and maintenance of the distribution network (Kumar et al., 2015).

2.11.2. Apparent losses

Apparent loss is the quantity of water lost due to the mechanical errors in meters at the source, at various points in the water supply system, and at the consumers' connections, which are recording a lesser quantity of water than the actual quantity of flow. Human errors in reading or recording the meter reading lesser than the actual quantity, and Flow through illegal connections, which are not accounted for and billed for apparent loss of water is considered as the loss of revenue (Motiee et al., 2007). According to Lambert and Alegre et al.,(2016), the assessment of apparent losses has a direct impact on real losses and therefore it is important to pay attention to both components of water loss.

2.11.3. Causes for leakage

Leakage occurs in all distribution networks - the degree of leakage varying widely from one country to another, and between the regions of a country.

It is important to distinguish between total water loss (sometimes referred to as 'unaccounted-for water' (UFW) and leakage. Total water loss describes the difference between the amount of water produced and the amount which is billed or consumed. Leakage is one of the components of the total water lost in a network, and comprises the reallosses from pipes, joints, and fittings, and also from overflowing service reservoirs. These losses can be severe and may be undetected for months or even years. The larger losses are usually from burst pipes, or the sudden rupture of a joint, whereas smaller losses are from leaking or "weeping" joints, fittings, service pipes, and connections. The volume lost will depend largely on the pressure in the system, and on the "awareness" time, i.e. how quickly the loss is noticed and dealt with. This in turn depends on whether the soil type allows water to be visible at the surface. It also depends on the leak detection and repair policy of the water supply company. The other components of total water loss are non-physical losses, e.g. meter under-registration, illegal connections, and illegal or unknown use (World Health Organization, 2020).

Water distribution system (WDS) losses may be classified as due to background losses (e.g., from joints, fittings, and small cracks), reported bursts, and unreported bursts. Bursts are intended as major water outflow events that are usually reported to water utilities and repaired since they are likely to produce major service disruptions. For this reason, bursts are commonly considered accidents whose impact on WDS can be limited by improving active leakage control and the efficiency of detection and repair actions (Bildirisi et al., 2018) .

The causes of the leakage in the pipeline are:- The use of sub-standard pipes and fittings leads to imperfect jointing, causing leakage in joints. Selection of pipe material without considering the corrosives of the soil in which the pipes are to be laid and the quality of water the pipe has to carry, which eventually may lead to corrosion of the pipes and fittings.

Lack of quality control in the jointing of pipes while installation, which may result in leaks in joints when there is the settlement of the supporting soil. On-conducting or improper conducting of hydraulic pressure testing of pipelines and joints at the time of installation. Soil movement particularly when the pipes are laid in swelling soils like clay, due to change of moisture content, which may cause disturbance to the pipes and joints ultimately resulting in leakage. Water hammer pressure disturbs the joints resulting in leakage. Not detecting and rectifying the badly leaking joints regularly. Even in a properly maintained system, at any time 10% of the joints will be seeping joints (with the loss of water of 1 to 3 Lph / joint), and 1% of the total joints will be badly leaking joints (with the loss of water of 90 to 200 Lph / joint) (Erickson et al., 2020).

According to Hamilton et al., (2006) classification and descriptions of water losses as acceptable, if the loss is <10%, intermediate, if the loss is 10-25%, and matter of concern if the loss is>25%.

Table 2.1 Classifications and description of water losses

Water losses	Levels and action needed
< 10%	Acceptable, Monitoring and control
10-25%	Intermediate, could be reduced
> 25	A matter of concern, reduction needed

(Source: Hamilton) et al., (2006)

2.11.4. Reduction in carrying capacity of the pipeline

The carrying capacity of the pipeline depends on the diameter and the Hazen-Williams C-value, which is proportional to the smoothness of the interior surface of the pipe. Due to the deposition of solids with time, the interior surface may be deteriorated and incrusted; in effect, the diameter of the pipe and the Hazen-Williams C-value get reduced. The reduction in diameter and C-value causes an increase in frictional loss and is reflected in the gradual reduction in the carrying capacity of the pipeline and reduction in tail end pressures (Erickson et al., 2020).

3. MATERIAL AND METHODS

3.1. Description of the Study Area

Project area location:- Kofele Town is the capital of Kofele Woreda in the West Arsi Zone of Oromia National Regional State. The Town is located at a distance of 275km southeast of Addis Ababa and 25km east of the zonal capital, Shashemene. Kofele is entirely accessed by asphalt road on the way to Bale Robe. The Town is found between grid coordinates of 474496m to 488112m easting; and 780476m to 783294m northing using projection of Universal Transverse Mercator (UTM) at Adindan datum in zone 37.The Town lies on flat terrain between the water shade of Wabe and Rift Valley with an elevation ranging between 2680 and 2740m. a.s.l.

Population:-The present projected population of the Town is about 31,579 according to the 2007 population and housing census of Ethiopia and the average household size of Kofele is 6116.

Climate:-The Town has an average altitude of 2700m a.s.l. According to the traditional climate classification of the country based on altitude and temperature, the Kofele area is categorized under 'Dega' or temperate climate as its altitude range is between 2500m to 3000ma.s.l. The study area has bimodal rainfall with mean annual precipitation of 1170mm and, the mean annual potential evapotranspiration and actual evapotranspiration of the study area are 1279.3mm and 1008.6mm respectively. The mean monthly maximum and minimum temperatures are between 17ºc to 22ºc and 6ºc to 10ºc, respectively.

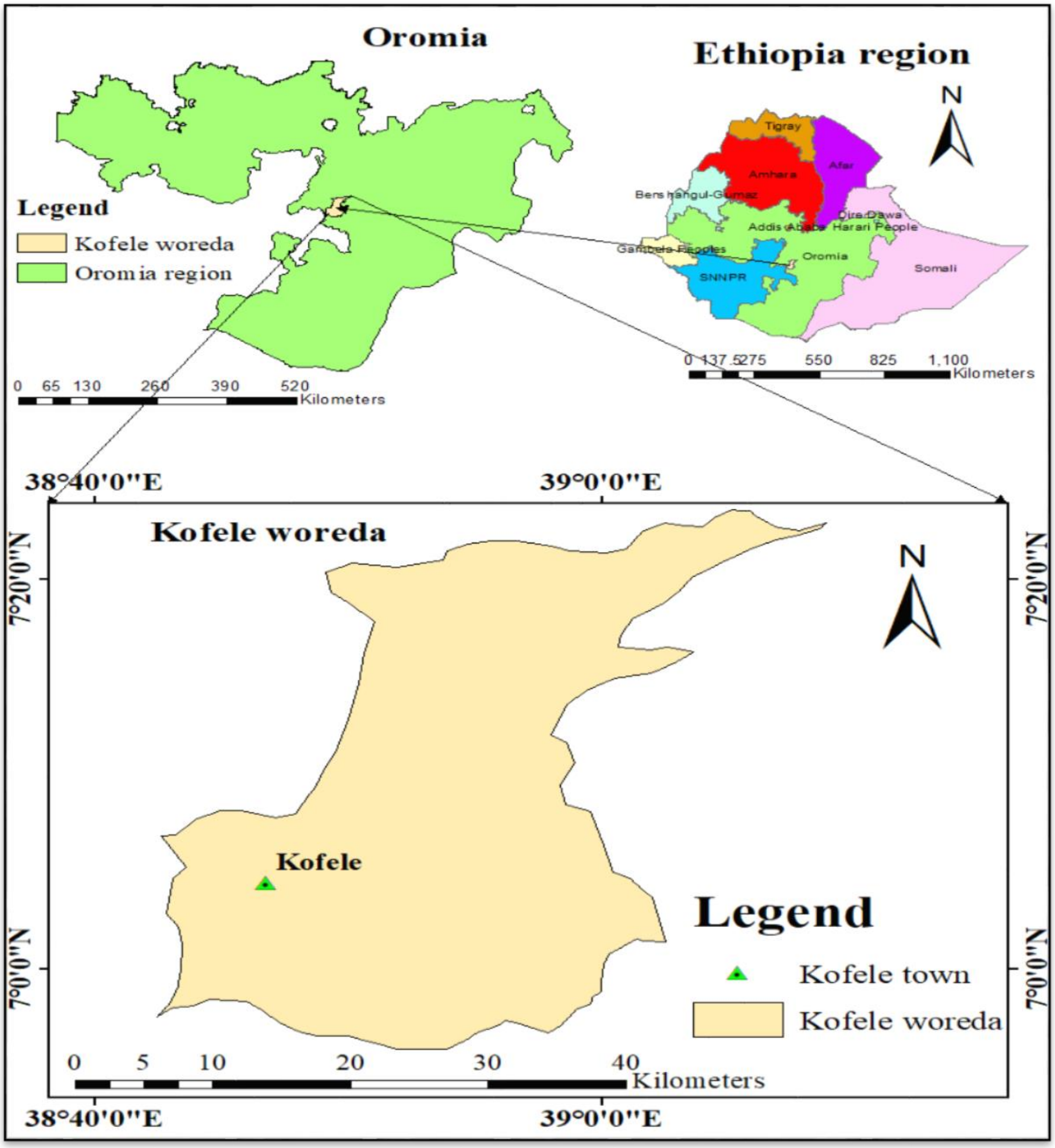


Figure 3.1: Location and Topographic Map of the Study area

3.2. Data Collection and Analyses

Both primary and secondary data were collected, including, population data, water pressure map of the area, the volume of water delivered, reservoir data, pipe size pipe length, pumping hour, elevations, and pipe diameter. The demand will be obtained after considering the population of the study area, also the study area falls under the category of urban settlement. During data collection and field survey, Collect the water loss data from the Kofele Town Water and Sanitation office and different governmental offices. Collect the secondary data by using the checklist and interview the local community. Collection of the survey data for the distribution network, service reservoir, and pump station locations using Hand GPS and from DEM and Google Earth

3.2.1. Identify Problems of Existing Water Supply and Demand

The Town's main source of drinking water is a borehole with a design yield of 10 l/s. This groundwater supplied to the Town is abstracted from the well by the pump. The existing water distribution system of the Town is both a pump and a gravity system. The water from the source is taken to the booster pump and taken from the boaster to the relief tank by the pump and the water from the relief tank is then distributed to the Town by gravity. The water distribution network of the Town consists of about 25 km and 962 m of water pipes ranging in diameter from 80mm to 350mm. The existing distribution system consists of a variety of pipe types: ductile iron, PVC, and galvanized iron. The Town is supplied by water intermittently by water Staff who is managing the system mainly by using control valves.

Data Collection: - The demand will be obtained after considering the population of the study area. The study area falls under the category of urban settlement.

During data collection and field survey, collect the water demand data from the Kofele Town Water Supply and Sewerage Enterprise and different governmental offices.

Water production

The water production has been evaluated as the total annual water supplied to the water distribution system (WDS). The production of water is administered by the Kofele Town Water Utility Office. According to the Water Utility Office of the Town, the design gross water production capacity of the developed borehole is 4320m3 /day but, currently, around 400 m3 /day production is produced from the developed borehole with average working for 8 hours per day.

Water demand

The per capita water demand of urban areas varies depending on population size, economic, social, and climatic factors as well as the mode of service of the town (MoWR, 2006). Three modes of service were identified for domestic water consumers of Kofele Town. These are yard connection (YC), house connection users (HCU), and public tap users (PTU). The rate established for the Oromia region was used to forecast the population of Kofele Town. Population and water demand projection were done making use of the exponential growth method with the base population as recorded by CSA and depending on the existing demand for water. The Exponential increase method is the best method of population forecasting based on past information. This method tends to give a higher estimate than other methods normal since it behaves exponentially. It is more accurately describes the continuous and cumulative nature of the population growth rate(Nuru et al., 2020).

$$pn = poe^{rt} \qquad (3.1)$$

Where, Pn = future population after n decades, Po= present population, t = number of decades, r=growth rate, e= Exponential

Population data

According to CSA (2007), the number of the population of the Kofele Town was collected from the planning commission of the Town. But for the year 2020, the population of the Town was forecasted using an exponential method by using the base year of 2007. The most considered demand events are usually:- average day demand, maximum day demand, peak hour demand, and maximum day of historical recorded (B. Coelho n, 2014).

Average-day demand

The average rate of demand for an average day (past, present, or future)

Maximum-day demand

The average rate of use on the maximum usage day (past, present, or future).

Maximum Daily Consumption = 180% of Average Daily Demand = 1.8q ………… (3.2)

Maximum daily consumption is the design of water consumption for the source of supply and pipe mains.

Peak-hour demand: The average rate of usage during the maximum hour of usage (past, present, or future). Maximum hourly consumption = 150% of avg. hourly demand for max. Day

= 1.5 x (Maximum daily demand/24 ……………………………………….…………………(3.2)

= 1.5 x (1.8q/24) = 2.7 x (q/24 …………………………….. …………………………… (3.3)

Maximum hourly consumption = 2.7 x Annual Average hourly demand ……………… (3.4)

Maximum day of record: The highest average rate of demand. Maximum Hourly Demand of maximum day = 2.7q ……………………………………...………………… ………. (3.5)

Coincident demand or Coincident draft: Maximum daily demand plus fire demand gives the coincident draft. In this design, water consumption is used for the distribution system.

Estimation of domestic water consumption

Average per capita consumption was used to assess the domestic water supply coverage of the town. Data on individual domestic water consumptions, total water consumption (m^3), and total production (m^3) were collected from Kofele Town Water Supply and Sewerage Enterprise bill documents for analyzing average per capita consumption. The water demand at a particular junction was obtained by dividing the total population by the number of junctions and multiplying by Lit/person/day. The following formula was applied for the determination of per capita consumption (liter/person/day) (Desalegn, 2005).

$$\text{Domestic consumption (Lit/person/d)} = \frac{\text{Annual consumption (m3)x1000L/m3}}{\text{Population numberx365}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

During field visits, the utility does not have any recorded data related to average leak flow, the number of repeated bursts and average leak duration due to this, physical loss in the main was assessed based on available data`, and it was adopted by considering the minimum achievable annual physical losses (unavoidable annual real loss) in the system (Farley et al., 2008).

$$\text{UARL (liters/day)} = (18*Lm+0.8*NC+25*LP)*P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

Where, Lm=mains length (km), NC=number of service connections, LP=total length of private pipe, property boundary to customer meter (km), and P=average pressure (m)

Methods:-The water per capita consumption supply of the town will be first evaluated with annual consumption within a specific year. Lastly, estimating the current and future water demand of the town will be conducted by considering per mode of service.

3.2.2. Estmation of water losses of the existing water distribution system

Non-Revenue water includes water losses in the water supply system, illegal connections overflow from reservoirs, improper metering, and losses in the treatment plant. The amount is expressed as a percentage of the total produced water from the water supply system.

The percentage usually varies from 10 to 60 percent depending on the age of the pipes and the complexity of the system. High levels of water losses result from poor management of Water and poor condition of distribution systems. The total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water losses of the town(EPA, 2013).

$$\text{Unaccounted Water\%} = \frac{\text{Water produced by PWS} - \text{Metered water used x 100}}{\text{Water produced by PWS}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

Where; PWS= Public Water Systems

Data Collection: - The water loss data were collected from the Kofele Town Water Supply and Sewerage Enterprise. The data were collected by using the checklist and interview the local community.

Methods:- The total water produced and actual water consumption as aggregated from the individual contracts (customer meters) were used as an input for water loss analysis. After evaluating the total water losses, the possible causes of water losses are tried to be identified.

3.2.3. Performance assessment of the water supply distribution network

Water GEMS is a user-friendly WDS modeling management and analysis software that has a range of functions that helps to improve design productivity. These functions include prefixed model building, data archiving and bespoke graphical data presentation, assessment of water demand, WDS configuration, design, and operational scenarios, and lastly CAD interoperability i.e. ability to model in any familiar platform of choice. Water GEMS was built with certain features and capabilities which differentiate it from other modeling software.

These features include but are not limited to the ability to access fire flow capacity, analyze pipe and valve criticality, build and manage hydraulic models, design WDS, development of maintenance, flushing, and management plans, identify water leakages, and manage energy use. Water GEMS is quite easy to use and is generally considered a flexible and resourceful WDS modeling software (Awe, 2019). Water GEMS V8i (2014) is a hydraulic modeling software package comprised of a wide range of functionality includes graphical and profiling advancements, flexibility in data archiving and representations, advancements in GUI, and its customization, etc. (Sonaje, 2015). Water GEMS V8i is an easy-to-use hydraulic and water quality modeling application for water distribution systems. Utilities, municipalities, and engineering firms trust Water CAD V8i as a reliable, resource-saving, decision-support application for their water infrastructure. From fire flow and constituent concentration analyses to energy cost management and pump modeling, Water GEMS V8i helps engineers and utilities analyze, design, and optimize water distribution systems (Bentley, 2017).

Data Collection:-For hydraulic analysis in the software, all the required input data will be collected. Pipe data such as pipe diameter (mm), C-value, and length (m) are assigned to the network. Input for nodes is the elevation (m), water demand (LPs), and time pattern. Pump head (m) and flow (LPs) are required data for the construction of the pump curve. The layout of the water supply system in the AutoCAD file is also an essential input. Collection of the survey data for the distribution network, service reservoir, and pump station locations using Hand GPS Garmin72 and Google Earth.

3.2.4. Material Type of The Distribution system

In terms of material type, UPVC is the major pipe type in the distribution system. As shown in table 4.7 the UPVC is about 91.28%. The smaller percentage material type used are DCI and GI which are about 4.02% and 4.7% respectively.

Table 3.1: Distribution of pipe material

Pipe type	length	%
GI	1,219	4.7
UPVC	23,698	91.28
DCI	1,045	4.02

Node Elevation

Node elevation is one of the significant requirements to simulate the hydraulic characteristics of water in the distribution system. Node elevation data was collected from the Town Water Service Office, which was prepared as the design report of the Town.

Water Pressure

Higher pressures lead to an increase in leakage in pipes, increased damage of pipes, and consumption increases (P. F. Hopkins, 2015). The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network. The minimum pressure should maintain to ensure that consumers' demand is provided at all times. The maximum pressures also contain a limitation of leakage and lead to water losses in the distribution system.

Table 3.2: The operating pressures in the distribution network

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

(Source: MOWR, 2006)

Methods: - After the entire Town Water Supply network including its attributes like pipe length, diameter, material types, and roughness coefficient of the pipes, Junction point, pumps characteristics, reservoir, and tank section has been collected, then the performance of the water distribution network were evaluated Using the Software Water GEMS V8i.

3.3. Evaluation of Future Water Demand

Water distribution models are created not only to solve the problems of today but also to prevent problems in the future. With almost any endeavor, the future holds a lot of uncertainty, and demand projection is no exception. Long-range planning may include the analysis of a system for 5, 10, and 20-year time frames. When performing long-term planning analyses, estimating future demands is an important factor influencing the quality of the information provided by the model. Scenario management tools in models help make this process easier. Even the most comprehensive scenario management, however, is just another tool that needs to be applied intelligently to obtain reasonable results. The water distribution system is designed to cope mainly with domestic demand. As it is common in Kofele Town, the consumption for industrial, commercial, and institutional demands is included in the domestic consumption figure to form a total water demand per person and day.

4. RESULTS AND DISCUSSION

4.1. Status of the current water supply of Kofele Town

4.1.1. Water deman and Coverage Analysis

To evaluate the potable water supply coverage, the quantity of per capita water consumption was used. The average per-capita water consumption was derived from the yearly consumption of the town that has been aggregated from the individual water meter and public tap. Thus, the annual water consumption data were converted to average daily per capita consumption using the population data of Kofele Town (using equation 3.7). As shown in Table 4.1, the per capita domestic water consumption of Kofele Town was found to be 12.45l/c/d in the year 2020. According to MOWIE, (2015), the quantity of domestic water requirement in urban areas of Ethiopia can be taken as 50 lit/person/day. Accordingly, the domestic water demand of Kofele Town Was below the standard limit. As it is indicated in Table 4.1, the per capita water demand of Town is in decreasing trend as time goes. The main reasons for this are the increase in the population number, pump failure, and seasonal fluctuation of the water source.

Table 4.1: Annual water consumption of Kofele Town

Town Year	Population	Annual domestic Consumption (m3)	Per-capita Consumption (l/c/d)
2019	30,306	155880	14.1
2020	31,579	144,000	12.45

4.1.2. Per Capita Water Demand

The per-capita domestic water demand for various demand categories varies depending on the size of the town and the level of development.

The per capita water demand for adequate supply level has to be determined based on the basic human water requirements for various activities of the demand category. In Kofele Town, because of the growth of the socioeconomic activity in both governmental and private sectors, there was a high water demand in the town. Using the annual water consumption and population figure in (2020), the average per capita consumption of the Town was identified as below.

Per ca pita consumption (L/p⁄ d) = $144000 * 1000 ⁄ 31,579 * 365$ = 12.45 l/p/day. The annual domestic consumption amount in 2020 is 144000m^3 and the current total population of the Town from two Kebeles was estimated as 31,579, therefore by using the above expression the average daily per capita consumption became 12.45 l/p /day.

According to walling ford HR (2003) which is reviewed by Desalegn (2005), a minimum quantity of 25 l/c/day domestic water supply is categorized as a basic level of service which is higher than the average domestic consumption of the town. Besides, according to the standard set by MWIR for a fourth-level town like Kofele, the per capita per day is 50 liters, therefore, the current coverage is only satisfied less than one-fourth of the demand. But, according to the existing town water supply design report; the average per capita water demand of the Town at the end of the design period (2030) was estimated and adopted as 41 l/c/d. The current per capita demand is much lower than the forecasted design demand. This shows that there is a great difference between demand and supply.

With the comparison of this figure, the above-estimated per capita consumption value (12.45 l/c/d) was unrealistic and unacceptable. Hence, it was not adopted for this assessment work. To evaluate the potable water supply coverage, the quantity of per capita water consumption was used.

The average per capita water consumption was derived from the yearly consumption of the town that has been aggregated from the individual water meter and public tap. Thus, the annual water consumption data were converted to average daily per capita consumption using the population data of Kofele Town (using equation 3.1). As shown in Table 4.2, the per capita domestic water consumption of Kofele Town was found to be 12.45 l/c/d in the year 2020. Regarding this value, the domestic water supply of Kofele Town only satisfies 24.9% of the standard value and the quantity of domestic water required in urban areas of Ethiopia is taken as 50 l/c/day for category 4 Towns/cities (towns/cities with a population in the range of 20,000 - 50,000) (MWIE, 2015).

Table 4.2:Projected per capita of Kofele Town water supply

Year (G.C)	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Population growth rate	4.4%	4.4%	4.2%	4%	3.8%	3.6%
Population	25,511	31,579	38,420	46,296	55,251	65799
Per ca pita (l/c/d)	35	12.45	50	60	60	60

4.1.3. Population Growth Rate

The population growth rate is highly dependent on two parameters, namely fertility rate and urbanization. Based on the two parameters and the year 1998 base population CSA has projected the total population in the region from the year 1996 up to the year 2040 for three variants. The urbanization rate or proportion of the urban population in the Oromia region has been considered to follow the same trend (2% increase per year) as suggested in the 1998 CSA Analytical Report until 2040 and presented in Table 4.8 below.

4.1.4. Domestic water supply Coverage

The amount of water used for domestic purposes greatly depends on the lifestyle, living standard, and climate, mode of service, and affordability of the users.

In projecting the domestic water demand of the town the following procedures were followed:

Determining population percentage distribution by mode of service and its future projection establishment of per capita water demand by the purpose for each mode of service; Projected consumption by mode of service. To evaluate the amount of water consumption, the annual water consumption is converted to average daily per capita consumption using the population data of the town and the number of domestic connections per family has been also used to analyze the level of connection.

The average number of persons per housing unit obtained from the last censuses (CSA 2007) shall be applied. For the town, it is 4.20 inhabitants per housing unit. Therefore, concerning the above table 5; the estimated total population figure of Kofele Town was 31,579 during (2020).

4.1.5. Average Water Demand

There are several mathematical methods of estimating the water demands of a given town; including extrapolating historical trends and correlating demand with the socioeconomic Variables of the town. But, the most common means of forecasting future water demand is estimating current per-capital water consumption, and multiply this by the projected population Figure.Therefore, during 2020 the average water demand for Kofele Town was calculated as;

$Q_{avg}.$ =31, 579 $*$ 50 l/c/d = 1578950l/d

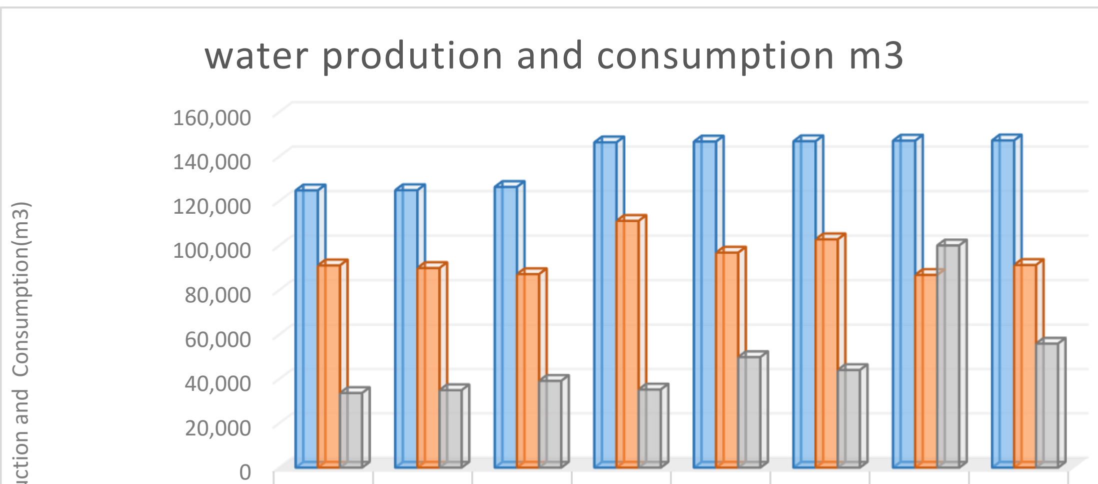
Q_{avg} = 18.27 l/s or 1578.95 $\frac{m^3}{day}$

4.2. Evaluating water losses of the existing water distribution system

The current production of water supply for Kofele Town depends on one borehole out of two boreholes which are administrated by Kofele Town Water Supply and Sewerage Enterprise. The designed water production capacity of this system is 4320 m^3/day or (50 l/s). However, the actual production of water has been much lower than the expected capacity

Production data computed for one borehole shows that the actual average production of water at present from the system is 36m^3/hrs which is 20 % of the total designed capacity.

Based on the analysis, the results of the total water loss from the system were about 31,351 m3/year and approximately 31.125 % of the system input volume. The volume of the water supplied and billed water (consumption) for seven consecutive years was depicted in Figure 4.1



	2011	2012	2013	2014	2015	2016	2017	2018
Production(m3)	124,850	124,940	126,394	146,440	146,800	146,952	147,211	147,312
Consumption(m3)	91140	89,957	87,212	111,152	96,888	102,866	86,855	91,333
loss (m3)	33,710	34,983	39182	35,288	49,912	44,085	100,103	55,979

Figure 4.1: Water production and consumption

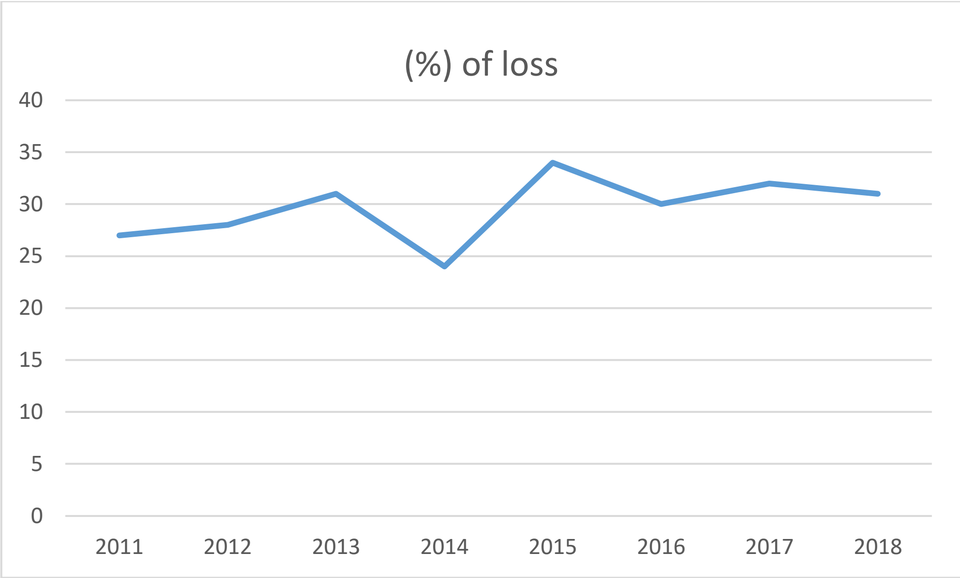


Figure 4.2: Water Lost In Percentage

Water loss from water distribution systems (WDS) has long been a feature of WDS operations management.

An average water loss in Kofele Town was 31.125%, which is greater than 25% that showing a matter of concern, the reduction was needed. The percentage of water loss in the town water distribution system is given in Figure 4.2. The average amount of water, which is reached to the consumers, was only 68.875% of the total production. The water supply system efficiency is acceptable if above 75% of water produced reaches the consumer (Hamilton et al., 2006)., Based on this, the efficiency of the Kofele Town water supply system is not acceptable because only 68.875% of the total production reaches the consumer which is below 75%.

As can be seen from Figure 4.2. Non-revenue water from the system is variable from year to year due to the aging of pipe that leads to leakage, pipe bursting, installation (expansions of the network in a new area), and illegal connection.

4.3. Performance Assessment of the water supply distribution network

Pipe Length of the System

Input parameters for pipes during analysis were obtained from AutoCAD drawing design report which is; diameter, length, roughness coefficient, and material.

As shown in Table 4.6, the major part of the distribution system is covered by a pipe of 80 mm diameter and the lowest is a pipe of 150 mm diameter which is 39.4% and 2.9% respectively

Table 4.3: Pipe size distribution in diameter

Diameter mm	Length m	%
80	10,224	39.4
100	819	3.2
150	7,043	27.1
200	1156	4.5
250	3284	12.6
300	749	2.9
350	3330	12.8
All Diameters	**25,962**	**100**

4.3.1. Pressure Distribution during Steady-State Simulation

During steady-state analysis, 58.4% of the higher pressures in pressure zone two of town (>70 m) were observed at the different junctions due to low elevation and 3.96% of the lowest pressure recorded was junction (KBH02, JC-1, and JC-2). The lowest velocity recorded was

0.5 and the highest 2.3 m/s. Concerning steady-state simulation, the pressure and velocity were summarized in Appendix1 and 2 respectively.

Table 4.4: Distribution of pressure at steady-state analysis

Pressure (m)	Nodes	%
>70	132	58.4
60-70	50	22.1
50-60	34	15
40-50	4	1.9
30-40	3	1.33
20-30	1	0.44
<15	2	0.9
Total	**226**	**100**

4.3.2. Pressure Distribution During Peak Hour Consumption

After hydraulic analysis, 0.9 % of the identified nodes have pressure below 16m. The ranges of lowest pressures recorded were from 2 m to 16 m during peak hour consumption. 58.4% of nodes have pressure above 70m and only 40.77% of the areas have pressure within the recommended limit (15 to70 m) during peak hour consumption. The pressure distribution of nodes pressure at peak hour consumption is given in Figure 4.3

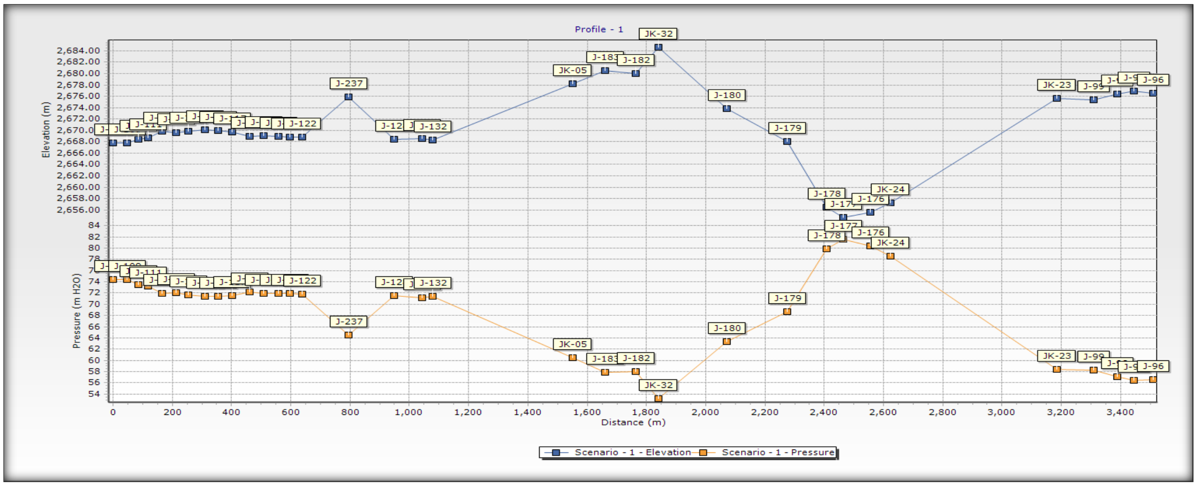


Figure 4.3: Pressure distribution during peak hour consumption for some selected area

4.3.3. Velocity

Velocity in major pipe parts of the distribution system was below 1 m/s at steady-state analysis in all pressure zones.

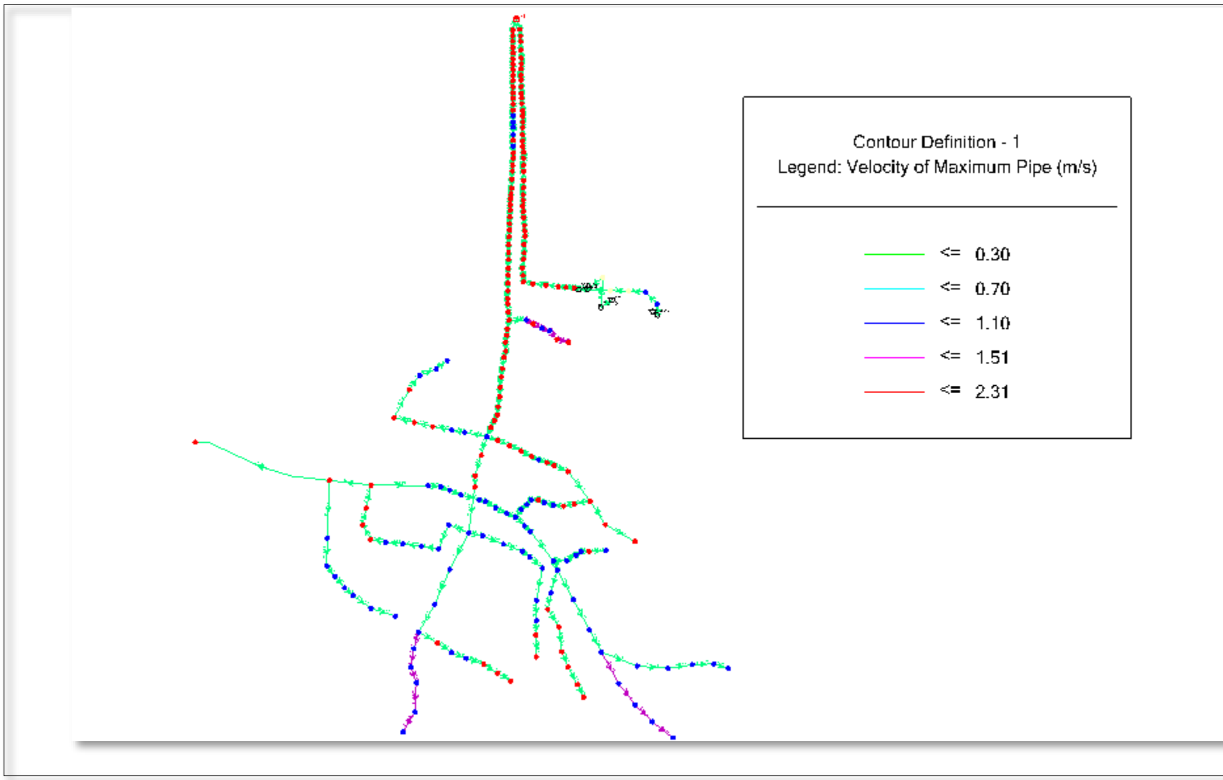


Figure 4.4: Kofele Town water supply Network Layout

Accordingly, Velocity in most parts of the distribution systems was inadequate during steady-state analysis, and figure 4.6 below shows the result of velocity in some selected pipes it is also shown in detail in appendix-2 .

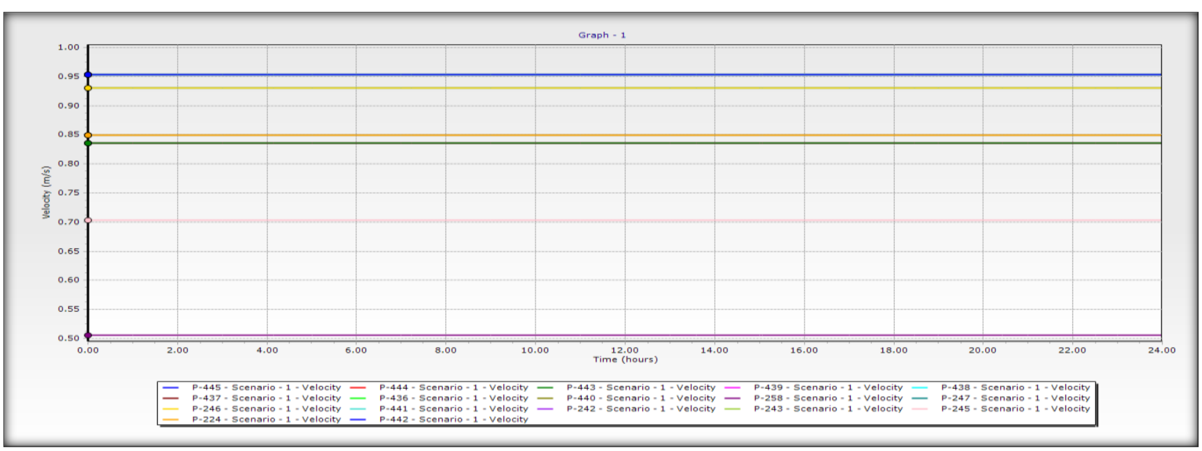


Figure 4.5: Velocity distribution during steady-state vs. time for some selected pipes

4.3.4. Water distribution network simulation

In this study, the distribution network of the town is put in three different pressure zones, namely; Pressure Zone One, Pressure Zone Two, and Pressure Zone Three due to the elevation differences in each Pressure Zones.

From these Pressure zones, pressure Zone Two covers the largest area of the Town's distribution networks where it accounts for about 94.25% of the area. Figure 4.3, shows the distribution network of pressure zones. The pressure Zones are shown in Table in appendix -1.

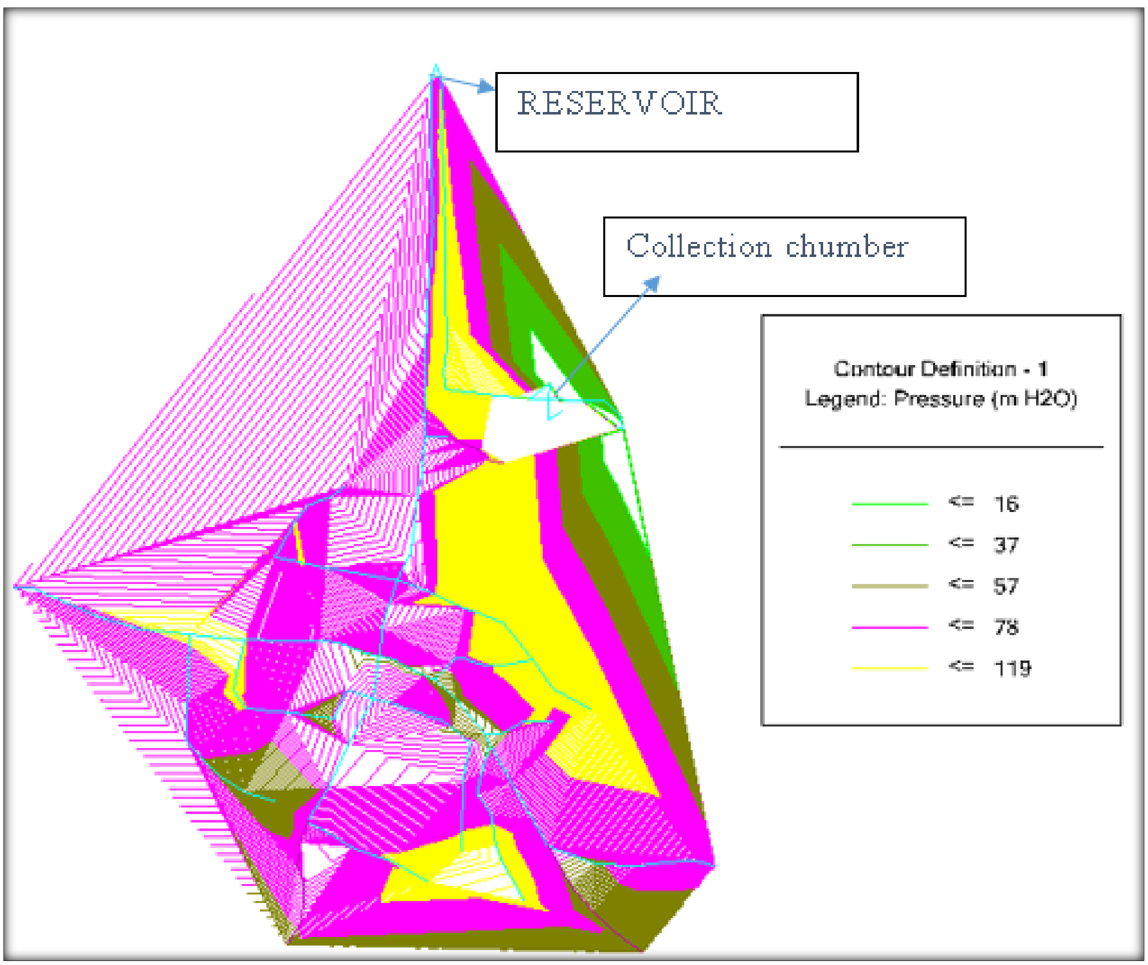


Figure 4.6: Water distribution network map of Kofele Town Pressure zones

4.3.5. Challenges Related to Hydraulic Performance of Town Water Supply

In the modern water supply system, clear water shall be delivered to the service reservoirs directly through the transmission main and which is completely isolated from the distribution system. But, the existing Kofele town water supply distribution system was constructed 44 years ago and as it was the old system; it is not replaced when the new water supply is constructed. So, the impact of this network configuration and the capacity of the distribution system causes the burst of pipes and intermittent of the water supply of the Town.

4.3.6. Existing Reservoirs Capacity

The capacities of reservoirs in the water supply system were determined using different methods. The most appropriate and economical approach to determining the storage volume of the reservoir is the 24 hours of supply-demand simulation mass curves. To develop such types of curves, it requires reliable recorded historical data of hourly water demand figures of the Town. But, in the absence of such type of data, to determine the size of reservoirs, it was adopted the commonly practiced in many water supply systems and based on the urban water supply design criteria of the ministry of water resources; it was used for sizing the reservoir volume as one-third of the maximum daily demand. Therefore, as per the design criteria of the FDRE; MoWRE, the maximum day factor usually varies between 1.0 and 1.3.

Hence, a maximum day factor of 1.25 was adopted for assessing the maximum daily water demand and reservoir capacity for Kofele Town and applied it corresponding to the total average daily demand of a particular year (2020).

Maximum day demand = 1.25 * average day demand.

$= 1.25 * 1578.95 = 1973.625 \frac{m^3}{day}$

Maximum daily consumption=1.8(Average Daily demand)=1.8*1578.95=2842.11$\frac{m^3}{day}$.

Maximum Hourly consumption=2.7(Annulal Average hourly demand)=2.7(1578.95/24)

=177.63$\frac{m^3}{day}$

Accordingly, the current (2020) required reservoirs volume capacity for water demand of Kofele Town was estimated as; Reservoir capacity = maximum day demand *1/3

1973.625*1/3 = 657.875 m^3

Hence, from the above finding to satisfy the current water demands of Kofele Town; the clear water reservoir is accommodated 673.875m^3one-third of the maximum day demand. Hence, from the above finding to satisfy the current water demands of Kofele Town; the clear water reservoir was sized as 1000m^3 volume capacity of the standard reservoir. The existing water supply system of Kofele Town, the service reservoir has a capacity of 1000m^3. This indicates, the capacity of the existing reservoir is enough in size compared with the current water demand of the Town, and it is one of the major factors of the day to day intermittent water distribution in the Town was this reservoir never became full due to the absence of enough water wells.

5. SUMMARY AND CONCLUSION

5.1. Summery

Most problems that occurred in developing countries are intermittent, erratic pressure is not acceptable, inequalities in service provision between the rich and the poor, high rate of water losses from the distribution systems, Population growth, and urbanization, growing urban water demand, infrastructure is aging and deteriorating. Knowledge about actual network performance during different operating situations is a key tool to control and manage the existing water systems or design new networks.

Kofele Town is characterized by having old water distribution networks upon which new extensions are linked to serving new areas, adding complexity to an aging network where full rehabilitation may not be practical due to economic constraints. In the Kofele Town Water Supply Service Office, one of the common problems in the Town Water Supply System is the disconnection of joints in the distribution network during which the Town Water Office does not have an immediate response for maintenance. There was an inadequate amount of water supply and low coverage in the Town because of the low capacity of utilities, weak connection, and damage on valves, uneven distribution, and poor management system. There is no planned and organized system for the maintenance of water supply service. Lack of Manpower, maintenance tools, and facilities are the major problems. Consequently, the distribution system is an old system and susceptible to lots of leakages everywhere in the Town. The leakage was estimated to more than 25% of water production. There is no well-documented data on water production. Therefore, this research work is prepared to assess the Kofele Town water distribution network in terms of hydraulic performance, water loss, and leakage management.

The general objective of this study is to assess the hydraulic performance of the Kofele Town water supply distribution system.

The Town's main source of drinking water is a borehole with a design yield of 10 l/s. This groundwater supplied to the population is abstracted from the well by the pump. The existing water distribution system of the Town is both a pump and a gravity system. The water distribution network of the Town consists of about 25 km and 962 m of water pipes ranging in diameter from 80mm to 350mm. The existing distribution system consists of a variety of pipe types: ductile iron, PVC, and galvanized iron. The Town is supplied by water intermittently by water Staff who is managing the system mainly by using control valves to supply all customers at least twice a week**.** The current population that benefited from the Kofele water Supply system is 31,579. The per capita domestic water consumption of Kofele Town was found to be 12.45 l/c/d in the year 2020. The current production of water supply for Kofele Town depends on one borehole out of two boreholes which are administrated by Kofele Town Water Supply and Sewerage Enterprise. Production data computed for one borehole shows that the actual average production of water at present from the system is $36m^3$/hrs, which is 20% of the designed capacity. Based on the analysis, the results of the total water loss from the system were about 31,351 m3/year and approximately 31.125 % of the system input volume. The average amount of water, which reached the consumers, therefore accounts for only 68.875% of the total water produced and it is less than 75% which is not good. Non-revenue water from the system is variable from year to year due to the aging of pipe that leads to leakage, pipe bursting, installation (expansions of the network in a new area), and illegal connection. The major part of the distribution system is covered by the pipe of 80 mm diameter, and the Pipe of 150 mm diameter is the lowest which are 39.6% and 2.85% respectively.

In terms of material type, UPVC is the major pipe type in the distribution system, which is 91.28% others are DCI and GI. The distribution network of the town is put in three different pressure zones. From these Pressure zones, pressure Zone Two covers the largest area of the Town's distribution networks where it accounts for about 94.25% of the area.

The lowest velocity recorded was 0.34 and the highest 2.31 m/s. concerning steady-state simulation. After hydraulic analysis, 0.9 % of the identified nodes have pressure below 16m. The ranges of lowest pressures recorded were from 2 m to 16 m during peak hour consumption. 58.4% of nodes have pressure above 70m and only 40.77% of the areas have pressure within the recommended limit (15 to70 m) during peak hour consumption. The per capita domestic water consumption of Kofele Town was found to be 12.45 lit/person/d in the year 2020. Regarding this value, the domestic water supply of Kofele Town only satisfies 24.9% of the standard value.

5.2.Conclusions

The findings of this study revealed that the average per capita domestic water consumption of the Town was found to be 12.45l/p/d for the base year which only satisfies 24.9% of the minimum urban water consumption value set by (MWIE, 2015). Non-revenue water is also high (31.125%) in the study area through illegal connection (theft), leakage, during installation, and pipe bursting. In the Town water Supply distribution network 20% of the higher pressures in the town (>85 m) were observed 86.5% of the pressure junction that is the majority of the area has pressure within the optimum range during steady-state analysis. 2.4% of the lowest pressure recorded was junction KBH02 between borehole 02 and boaster station about 2 m and JC-1, JC-2 between borehole one and boaster station at a steady state due to high elevation.

As per this research, the biggest problem observed in the town water supply system is the frequent disconnection of joints in the water distribution network during which the Woreda water office does not have an immediate response for maintenance. Due to the lack of proper maintenance practice, there are also a lot of pipes and valves that are closed and not working at this time. Accordingly, the water distribution network was faced frequent pipe bursts and failures during low demand time and exposed to a large volume of water loss especially in high-pressure zone areas, while during high demand time mostly residences found in the dense population and higher level of the Town were not received and/served continuous water from the system. Thereby, water pressure in the distribution network observed that were not perfectly Performing within the proposed maximum and minimum design criteria set by FDRE, (MWIE, 2015). Due to lack of operation and maintenance practice, the water loss in the Town goes up which makes the water demand and supply unbalance.

Many sectors of water distribution systems in most parts of Kofele Town suffer from the deficiency of water supply quantities and sharp deficiency in the pressure so that to achieve the consumer demand at satisfactory levels, it must be improved and increased the efficiencies of the water distribution operating and management systems. Due to the decrease of water production of the Town the water did not reach the water points. There is no reliable recorded historical data of hourly water demand figures of the Town.

Generally the result of the analysis shows that the overall hydraulic performance of water distribution of the town was poor, which is reflected by low water production rate, low water consumption, and high level of Non-revenue water, low service coverage. Therefore, it is significant to rehabilitate and improve the water distribution system capacities, establishing pressure zone, increase pumping rate and drilling additional borehole. In addition providing more attention to water losses reduction policies and strategies are vital for remedial measures.

5.3.Recommendations0l

The following recommendations concerning water loss, customers' satisfaction, and operation and maintenance have been proposed respectively to improve the performance of the existing Kofele Town water supply system.

There needs to be an increase in the pumping hours of the pump from 8hrs to 18hrs per day by establishing additional standby pumps. To increase the potential water supply of the Town, it is better to drill additional boreholes. There need to be structured operation and maintenance practice to improve the whole pipe water system in the Town and planned and routine inspection for leakage from water supply system components such as transmission and distribution pipes, reservoirs, collection chambers, and pump houses. It is Recommended that Water meters and pressure gauges need to be installed at all sources, reservoirs, and collection chambers and proper water production recording be in place. The water utility should respond immediately to maintenance requests of customers to avoid water loss and complaints from customers and need regular discussions with the customers. The water utility should also conduct a regular survey to know customers' satisfaction levels and the service deficiencies and should make improvements in its service to increase customer satisfaction. There needs to be an updated water supply system map that provides an overall view of the water supply system components like distribution and transmission pipes layout, sizes and length, location of valves, flow meters, reservoirs, pumping stations, and sources should be prepared and be available in the water utility office for proper operation and maintenance of the system. The water production and water consumption recording system need also be updated to have a clear water balance and water loss.

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APPENDICES

Appendix 1: Summary of Minimum Pressure at Each Node during Peak Hour Demand

Label	Elevation (m)	Demand (L/s)	Hydraulic Grade (m)	Pressure (m H2O)	Zone
KBH02	2,613.00	0	2,615.14	2	zone 1
JC-1	2,612.50	0	2,619.05	7	zone 1
JC-2	2,612.00	0	2,627.86	16	zone 1
JC-3	2,612.07	0	2,642.79	31	zone 2
KBH01	2,610.50	0	2,646.44	36	zone 2
JK-21	2,687.87	2	2,727.13	39	zone 2
JK-08	2,679.47	4	2,724.37	45	zone 2
J-275	2,679.92	0	2,725.56	46	zone 2
J-157	2,682.16	0	2,727.96	46	zone 2
J-276	2,678.78	0	2,725.14	46	zone 2
J-274	2,675.00	0	2,726.30	51	zone 2
J-150	2,677.67	0	2,730.92	53	zone 2
JK-32	2,684.63	1	2,737.91	53	zone 2
J-158	2,674.27	0	2,727.59	53	zone 2
JK-29	2,679.87	2	2,733.79	54	zone 2
J-149	2,677.24	0	2,731.71	54	zone 2
J-156	2,673.79	0	2,728.52	55	zone 2
J-309	2,674.66	0	2,729.81	55	zone 2
J-265	2,672.49	0	2,728.09	55	zone 2
JK-12	2,676.24	1	2,732.02	56	zone 2
J-310	2,673.12	0	2,729.31	56	zone 2
JK-20	2,673.30	2	2,729.57	56	zone 2
J-147	2,676.15	0	2,732.62	56	zone 2
J-97	2,676.90	0	2,733.42	56	zone 2
J-96	2,676.52	0	2,733.24	57	zone 2
J-188	2,678.00	0	2,734.80	57	zone 2
J-311	2,672.07	0	2,728.88	57	zone 2
J-148	2,675.18	0	2,732.25	57	zone 2
J-98	2,676.36	0	2,733.57	57	zone 2
J-162	2,674.94	0	2,732.15	57	zone 2
J-183	2,680.47	0	2,738.41	58	zone 2
JK-01	2,675.08	2	2,733.08	58	zone 2
J-296	2,670.81	0	2,728.94	58	zone 2
J-182	2,679.97	0	2,738.12	58	zone 2

J-189	2,676.18	0	2,734.46	58	zone 2
J-99	2,675.41	0	2,733.79	58	zone 2
JK-23	2,675.61	1	2,734.14	58	zone 2
J-258	2,673.80	0	2,732.33	58	zone 2
J-143	2,675.56	0	2,734.55	59	zone 2
J-134	2,679.00	0	2,738.20	59	zone 2
J-273	2,668.59	0	2,728.03	59	zone 2
JK-13	2,672.99	0	2,732.46	59	zone 2
JK-06	2,678.42	2	2,737.92	59	zone 2
JK-19	2,669.35	2	2,728.86	59	zone 2
JK-05	2,678.16	1	2,738.72	60	zone 2
JK-11	2,674.09	1	2,735.48	61	zone 2
J-190	2,671.93	0	2,733.79	62	zone 2
J-185	2,675.31	0	2,737.66	62	zone 2
JK-31	2,668.27	3	2,731.23	63	zone 2
J-167	2,669.96	0	2,732.96	63	zone 2
J-142	2,672.40	0	2,735.47	63	zone 2
J-140	2,673.25	0	2,736.70	63	zone 2
J-180	2,673.87	0	2,737.34	63	zone 2
J-269	2,662.17	0	2,725.72	63	zone 2
J-312	2,664.72	0	2,728.44	64	zone 2
JK-16	2,663.30	3	2,727.21	64	zone 2
J-225	2,670.93	0	2,734.93	64	zone 2
JK-18	2,661.08	5	2,725.23	64	zone 2
J-236	2,674.90	0	2,739.26	64	zone 2
J-267	2,662.56	0	2,727.02	64	zone 2
J-237	2,675.83	0	2,740.45	64	zone 2
J-154	2,664.10	0	2,728.96	65	zone 2
J-191	2,667.81	0	2,732.72	65	zone 2
J-153	2,663.97	0	2,729.30	65	zone 2
J-196	2,665.89	0	2,731.46	65	zone 2
J-241	2,665.72	0	2,731.61	66	zone 2
J-141	2,670.04	0	2,735.99	66	zone 2
J-226	2,667.51	0	2,733.76	66	zone 2
J-257	2,670.98	0	2,737.41	66	zone 2
JK-28	2,662.85	1	2,729.52	67	zone 2
J-186	2,668.62	0	2,736.28	68	zone 2
JK-07	2,669.49	2	2,737.32	68	zone 2
J-235	2,670.22	0	2,738.14	68	zone 2

JK-03	2,673.90	7	2,742.06	68	zone 2
J-240	2,664.34	0	2,732.76	68	zone 2
J-179	2,668.00	0	2,736.83	69	zone 2
J-248	2,672.10	0	2,741.29	69	zone 2
J-168	2,663.73	0	2,733.14	69	zone 2
J-080	2,674.80	0	2,744.46	70	zone 2
J-082	2,674.62	0	2,744.33	70	zone 2
J-081	2,674.64	0	2,744.39	70	zone 2
J-268	2,656.63	0	2,726.49	70	zone 2
J-247	2,671.67	0	2,741.55	70	zone 2
J-079	2,674.62	0	2,744.53	70	zone 1
J-084	2,674.00	0	2,744.12	70	zone 2
J-083	2,674.11	0	2,744.26	70	zone 2
J-297	2,658.39	0	2,728.62	70	zone 2
J-085	2,673.75	0	2,744.03	70	zone 2
JK-30	2,664.11	1	2,734.41	70	zone 2
J-078	2,674.24	0	2,744.60	70	zone 2
J-087	2,673.48	0	2,743.89	70	zone 2
J-077	2,674.21	0	2,744.68	70	zone 2
J-088	2,673.14	0	2,743.75	70	zone 2
J-086	2,673.20	0	2,743.95	71	zone 2
J-076	2,673.74	0	2,744.78	71	zone 2
J-089	2,672.45	0	2,743.68	71	zone 2
J-224	2,664.85	0	2,736.11	71	zone 2
JK-02	2,669.00	6	2,740.28	71	zone 2
J-131	2,668.56	0	2,739.88	71	zone 2
J-234	2,665.53	0	2,736.94	71	zone 2
J-132	2,668.29	0	2,739.80	71	zone 2
J-115	2,670.07	0	2,741.60	71	zone 2
J-099	2,671.41	0	2,742.95	71	zone 2
J-116	2,669.92	0	2,741.50	71	zone 2
J-117	2,669.70	0	2,741.39	72	zone 2
J-128	2,668.40	0	2,740.10	72	zone 2
J-090	2,671.87	0	2,743.61	72	zone 2
J-098	2,671.29	0	2,743.06	72	zone 2
J-114	2,669.89	0	2,741.74	72	zone 2
J-100	2,670.94	0	2,742.89	72	zone 2
J-097	2,671.15	0	2,743.11	72	zone 2
J-122	2,668.86	0	2,740.82	72	zone 2

J-112	2,669.88	0	2,741.95	72	zone 2
J-120	2,668.93	0	2,741.02	72	zone 2
J-119	2,669.04	0	2,741.13	72	zone 2
J-121	2,668.79	0	2,740.92	72	zone 2
J-113	2,669.59	0	2,741.83	72	zone 2
J-091	2,671.22	0	2,743.56	72	zone 2
J-118	2,668.88	0	2,741.25	72	zone 1
J-096	2,670.66	0	2,743.17	72	zone 2
J-101	2,669.96	0	2,742.81	73	zone 2
J-092	2,670.55	0	2,743.48	73	zone 2
J-095	2,670.19	0	2,743.25	73	zone 2
J-075	2,671.74	0	2,745.02	73	zone 2
J-111	2,668.69	0	2,742.06	73	zone 2
J-298	2,654.77	0	2,728.14	73	zone 2
J-093	2,670.01	0	2,743.41	73	zone 2
J-073	2,671.63	0	2,745.16	73	zone 2
J-074	2,671.53	0	2,745.09	73	zone 2
J-094	2,669.67	0	2,743.33	74	zone 2
J-110	2,668.45	0	2,742.14	74	zone 2
J-072	2,671.48	0	2,745.24	74	zone 2
J-253	2,666.00	0	2,739.82	74	zone 2
J-071	2,671.47	0	2,745.30	74	zone 2
J-102	2,668.66	0	2,742.75	74	zone 2
J-070	2,671.27	0	2,745.37	74	zone 2
J-069	2,671.10	0	2,745.44	74	zone 2
J-109	2,667.73	0	2,742.23	74	zone 2
J-108	2,667.76	0	2,742.30	74	zone 2
J-068	2,670.96	0	2,745.50	74	zone 2
J-067	2,670.77	0	2,745.56	75	zone 2
J-103	2,667.70	0	2,742.67	75	zone 2
J-066	2,670.62	0	2,745.64	75	zone 2
J-192	2,657.11	0	2,732.18	75	zone 2
J-165	2,657.53	0	2,732.72	75	zone 2
J-064	2,670.53	0	2,745.78	75	zone 2
J-065	2,670.39	0	2,745.71	75	zone 2
J-107	2,666.84	0	2,742.38	75	zone 2
J-104	2,666.99	0	2,742.60	75	zone 2
J-105	2,666.60	0	2,742.52	76	zone 2
J-106	2,666.49	0	2,742.46	76	zone 2

JK-26+JK-27	2,654.04	4	2,730.24	76	zone 2
J-246	2,664.88	0	2,741.91	77	zone 2
J-258	2,658.79	0	2,736.18	77	zone 2
J-063	2,670.53	0	2,748.06	77	zone 2
J-062	2,670.39	0	2,748.71	78	zone 2
J-249	2,662.23	0	2,740.66	78	zone 2
J-208	2,654.75	0	2,733.37	78	zone 2
JK-24	2,657.28	0	2,735.96	79	zone 2
J-061	2,670.62	0	2,749.41	79	zone 2
J-233	2,656.27	0	2,735.27	79	zone 2
J-060	2,670.77	0	2,749.98	79	zone 2
J-059	2,670.96	0	2,750.60	79	zone 2
J-227	2,652.63	0	2,732.59	80	zone 2
J-178	2,656.46	0	2,736.50	80	zone 2
JK-25	2,655.40	2	2,735.47	80	zone 2
J-058	2,671.10	0	2,751.24	80	zone 2
J-176	2,655.53	0	2,736.13	80	zone 2
J-057	2,671.27	0	2,751.92	80	zone 2
J-056	2,671.47	0	2,752.50	81	zone 2
J-177	2,654.67	0	2,736.36	82	zone 2
J-055	2,671.48	0	2,753.24	82	zone 2
J-169	2,651.36	0	2,733.31	82	zone 2
J-054	2,671.53	0	2,753.89	82	zone 2
J-053	2,671.74	0	2,754.62	83	zone 2
J-052	2,673.74	0	2,756.89	83	zone 2
J-051	2,674.21	0	2,757.82	83	zone 2
J-050	2,674.24	0	2,758.59	84	zone 2
J-049	2,674.62	0	2,759.19	84	zone 2
J-048	2,674.80	0	2,759.89	85	zone 2
J-170	2,647.89	0	2,733.47	85	zone 2
J-047	2,674.64	0	2,760.56	86	zone 2
J-046	2,674.62	0	2,761.16	86	zone 2
J-045	2,674.11	0	2,761.83	88	zone 2
JK-22	2,636.77	3	2,724.77	88	zone 2
J-503	2,674.00	0	2,763.13	89	zone 2
J-300	2,637.05	0	2,726.54	89	zone 2
JK-09	2,640.25	5	2,729.89	89	zone 2
J-299	2,637.37	0	2,727.12	90	zone 2
J-504	2,673.75	0	2,763.95	90	zone 2

J-301	2,634.26	0	2,725.74	91	zone 2
J-505	2,673.20	0	2,764.74	91	zone 2
JK-10	2,640.00	3	2,731.56	91	zone 2
J-506	2,673.48	0	2,765.34	92	zone 2
J-228	2,638.10	0	2,731.40	93	zone 2
J-507	2,673.14	0	2,766.66	93	zone 2
J-508	2,672.45	0	2,767.31	95	zone 2
J-256	2,643.16	0	2,738.44	95	zone 2
J-255	2,643.67	0	2,739.19	95	zone 2
JK-17	2,634.40	3	2,730.42	96	zone 2
J-509	2,671.87	0	2,767.92	96	zone 2
J-510	2,671.22	0	2,768.15	97	zone 2
J-511	2,670.55	0	2,768.90	98	zone 2
J-512	2,670.01	0	2,769.69	99	zone 2
J-172	2,631.93	0	2,732.00	100	zone 2
J-0018	2,669.67	0	2,770.49	101	zone 2
J-313	2,626.79	0	2,727.75	101	zone 3
J-0017	2,670.19	0	2,771.29	101	zone 2
J-0016	2,670.66	0	2,771.97	101	zone 2
J-0015	2,671.15	0	2,772.94	102	zone 2
J-0014	2,671.29	0	2,773.43	102	zone 2
J-0013	2,671.41	0	2,774.41	103	zone 2
J-0012	2,670.94	0	2,775.03	104	zone 2
JK-14+JK-04	2,634.98	2	2,740.35	105	zone 3
J-0011	2,669.96	0	2,775.75	106	zone 2
J-0010	2,668.66	0	2,776.37	107	zone 3
J-0009	2,667.70	0	2,777.10	109	zone 3
J-0008	2,666.00	0	2,778.14	112	zone 3
J-0007	2,665.00	0	2,778.58	113	zone 3
J-0006	2,664.00	0	2,779.01	115	zone 3
JK-15	2,617.87	4	2,733.53	115	zone 3
J-0005	2,663.00	0	2,779.54	116	zone 3
J-259	2,617.21	0	2,734.96	118	zone 3
J-0004	2,662.00	0	2,780.01	118	zone 3
J-260	2,616.00	0	2,734.24	118	zone 3
J-0003	2,661.00	0	2,780.42	119	zone 3

Appendix 2: Summary of Velocity range in each Pipe during Peak Hour Demand

Label	Start Node	Stop Node	Diameter (mm)	Material	Velocity (m/s)	Length (User Defined) (m)
P-112	JK-19	J-156	80	PVC	0.34	208
P-113	J-156	J-157	80	Ductile Iron	0.34	265
P-114	J-157	J-158	80	Ductile Iron	0.34	175
P-115	J-158	JK-21	80	Ductile Iron	0.34	215
P-235	JK-03	J-246	80	PVC	0.4	70
P-236	J-246	J-247	80	PVC	0.4	158
P-237	J-247	J-248	80	PVC	0.4	115
P-238	J-248	J-249	80	PVC	0.4	284
P-239	J-249	JK-14+JK-04	80	PVC	0.4	136
P-154	JK-07	J-140	80	PVC	0.5	186
P-155	J-140	J-141	80	PVC	0.5	217
P-156	J-141	J-142	80	PVC	0.5	156
P-157	J-142	J-143	80	DCI	0.5	215
P-158	J-143	JK-29	80	DCI	0.5	175
P-256	JK-12	J-162	150	PVC	0.51	79
P-257	J-162	J-258	150	PVC	0.51	108
P-260	J-165	J-167	150	PVC	0.51	142
P-261	J-167	J-168	150	PVC	0.51	112
P-262	J-168	J-169	150	PVC	0.51	104
P-263	J-169	J-170	150	PVC	0.51	95
P-264	J-170	JK-15	150	PVC	0.51	38
P-258	J-258	JK-13	150	PVC	0.51	79
P-259	JK-13	J-165	150	PVC	0.51	159
P-282	JK-06	JK-07	150	PVC	0.51	356
P-109	JK-20	J-153	150	PVC	0.53	152
P-110	J-153	J-154	150	PVC	0.53	191
P-369	J-154	JK-19	150	PVC	0.53	58
P-446	J-109	JK-03	150	PVC	0.53	93
P-104	J-148	JK-12	150	PVC	0.55	115
P-102	JK-01	J-147	150	PVC	0.55	237
P-103	J-147	J-148	150	PVC	0.55	195
P-178	JK-11	J-188	80	PVC	0.57	162
P-179	J-188	J-189	80	PVC	0.57	79

P-180	J-189	J-190	80	PVC	0.57	158
P-181	J-190	J-191	80	PVC	0.57	253
P-182	J-191	J-192	80	PVC	0.57	128
P-183	J-192	JK-10	80	PVC	0.57	146
P-228	JK-30	J-208	80	PVC	0.59	231
P-229	J-208	J-240	80	PVC	0.59	134
P-230	J-240	J-241	80	PVC	0.59	254
P-231	J-241	JK-31	80	PVC	0.59	84
P-265	J-309	J-310	80	PVC	0.59	110
P-266	J-310	J-311	80	PVC	0.59	95
P-267	J-311	J-312	80	PVC	0.59	97
P-268	J-312	J-313	80	PVC	0.59	152
P-269	J-313	JK-16	80	PVC	0.59	121
P-448	JK-24	JK-25	150	PVC	0.59	223
P-192	JK-20	J-296	80	PVC	0.59	138
P-193	J-296	J-297	80	PVC	0.59	69
P-194	J-297	J-298	80	PVC	0.59	103
P-195	J-298	J-299	80	PVC	0.59	222
P-196	J-299	J-300	80	PVC	0.59	126
P-197	J-300	J-301	80	PVC	0.59	174
P-198	J-301	JK-22	80	PVC	0.59	211
P-150	JK-05	J-134	150	PVC	0.62	214
P-151	J-134	JK-06	150	PVC	0.62	116
P-270	JK-19	J-265	100	PVC	0.67	175
P-271	J-265	J-267	100	PVC	0.67	240
P-272	J-267	J-268	100	PVC	0.67	120
P-273	J-268	J-269	100	PVC	0.67	175
P-274	J-269	JK-18	100	PVC	0.67	109
P-130	J-96	J-97	150	PVC	0.67	65
P-131	J-97	J-98	150	PVC	0.67	55
P-132	J-98	J-99	150	PVC	0.67	80
P-133	J-99	JK-23	150	PVC	0.67	124
P-129	J-96	JK-01	150	PVC	0.67	55
P-280	JK-05	J-185	80	PVC	0.68	178
P-176	J-185	J-186	80	PVC	0.68	232
P-177	J-186	JK-11	80	PVC	0.68	134
P-254	JK-15	J-172	80	PVC	0.69	249
P-255	J-172	JK-17	80	PVC	0.69	256

P-449	JK-25	JK-26+JK-27	80	PVC	0.7	830
P-245	J-237	JK-02	200	PVC	0.7	81
P-447	JK-23	JK-24	150	PVC	0.73	561
P-172	JK-32	J-180	200	PVC	0.76	230
P-171	J-180	J-179	200	PVC	0.76	205
P-170	J-179	J-178	200	PVC	0.76	132
P-169	J-178	J-177	200	PVC	0.76	57
P-168	J-177	J-176	200	PVC	0.76	91
P-167	J-176	JK-24	200	PVC	0.76	69
P-390	T-1	J-064	350	PVC	0.8	152
P-391	J-064	J-065	350	PVC	0.8	48
P-392	J-065	J-066	350	PVC	0.8	52
P-393	J-066	J-067	350	PVC	0.8	53
P-394	J-067	J-068	350	PVC	0.8	42
P-395	J-068	J-069	350	PVC	0.8	46
P-396	J-069	J-070	350	PVC	0.8	47
P-398	J-071	J-072	350	PVC	0.8	43
P-399	J-072	J-073	350	PVC	0.8	55
P-400	J-073	J-074	350	PVC	0.8	48
P-401	J-074	J-075	350	PVC	0.8	54
P-402	J-075	J-076	350	PVC	0.8	167
P-403	J-076	J-077	350	PVC	0.8	69
P-404	J-077	J-078	350	PVC	0.8	57
P-405	J-078	J-079	350	PVC	0.8	44
P-406	J-079	J-080	350	PVC	0.8	52
P-407	J-080	J-081	350	PVC	0.8	49
P-408	J-081	J-082	350	PVC	0.8	45
P-409	J-082	J-083	350	PVC	0.8	49
P-410	J-083	J-084	350	PVC	0.8	96
P-411	J-084	J-085	350	PVC	0.8	61
P-412	J-085	J-086	350	PVC	0.8	58
P-413	J-086	J-087	350	PVC	0.8	44
P-414	J-087	J-088	350	PVC	0.8	98
P-415	J-088	J-089	350	PVC	0.8	48
P-416	J-089	J-090	350	PVC	0.8	45
P-417	J-090	J-091	350	PVC	0.8	41
P-418	J-091	J-092	350	PVC	0.8	55
P-419	J-092	J-093	350	PVC	0.8	46

P-420	J-093	J-094	350	PVC	0.8	57
P-421	J-094	J-095	350	PVC	0.8	59
P-422	J-095	J-096	350	PVC	0.8	50
P-423	J-096	J-097	350	PVC	0.8	46
P-424	J-097	J-098	350	PVC	0.8	36
P-425	J-098	J-099	350	PVC	0.8	72
P-426	J-099	J-100	350	PVC	0.8	46
P-427	J-100	J-101	350	PVC	0.8	53
P-135	J-101	J-102	350	PVC	0.8	46
P-136	J-102	J-103	350	PVC	0.8	54
P-428	J-103	J-104	350	PVC	0.8	47
P-429	J-104	J-105	350	PVC	0.8	57
P-430	J-105	J-106	350	PVC	0.8	47
P-431	J-106	J-107	350	PVC	0.8	52
P-141	J-107	J-108	350	PVC	0.8	59
P-141	J-108	J-109	350	PVC	0.8	46
P-397	J-070	J-071	350	PVC	0.8	50
P-279	JK-05	J-183	200	PVC	0.8	109
P-173	JK-32	J-182	200	PVC	0.8	77
P-174	J-182	J-183	200	PVC	0.8	105
P-207	JK-28	J-273	80	PVC	0.81	183
P-208	J-273	J-274	80	PVC	0.81	212
P-209	J-274	J-275	80	PVC	0.81	90
P-210	J-275	J-276	80	PVC	0.81	51
P-211	J-276	JK-08	80	PVC	0.81	95
P-108	J-309	JK-20	150	PVC	0.82	58
P-443	J-237	J-128	250	PVC	0.84	154
P-444	J-128	J-131	250	PVC	0.84	94
P-445	J-131	J-132	250	PVC	0.84	35
P-452	J-132	JK-05	250	PVC	0.84	472
P-224	J-237	J-236	80	PVC	0.85	133
P-243	J-236	J-235	80	PVC	0.85	125
P-242	J-235	J-234	80	PVC	0.85	134
P-241	J-234	J-233	80	PVC	0.85	186
P-240	J-233	JK-30	80	PVC	0.85	96
P-246	JK-02	J-253	150	PVC	0.93	89
P-247	J-253	J-255	150	PVC	0.93	124
P-248	J-255	J-256	150	PVC	0.93	147
P-249	J-256	J-257	150	PVC	0.93	202

P-250	J-257	J-258	150	PVC	0.93	243
P-251	J-258	J-259	150	PVC	0.93	238
P-252	J-259	J-260	150	PVC	0.93	142
P-253	J-260	JK-15	150	PVC	0.93	139
P-201	JK-07	J-224	80	PVC	0.94	113
P-202	J-224	J-225	80	PVC	0.94	110
P-203	J-225	J-226	80	PVC	0.94	109
P-204	J-226	J-227	80	PVC	0.94	110
P-205	J-227	J-228	80	PVC	0.94	111
P-206	J-228	JK-09	80	PVC	0.94	141
P-143	J-109	J-110	300	PVC	0.95	40
P-144	J-110	J-111	300	PVC	0.95	32
P-145	J-111	J-112	300	PVC	0.95	46
P-432	J-112	J-113	300	PVC	0.95	49
P-433	J-113	J-114	300	PVC	0.95	42
P-434	J-114	J-115	300	PVC	0.95	56
P-435	J-115	J-116	300	PVC	0.95	45
P-436	J-116	J-117	300	PVC	0.95	46
P-437	J-117	J-118	300	PVC	0.95	58
P-438	J-118	J-119	300	PVC	0.95	48
P-439	J-119	J-120	300	PVC	0.95	50
P-440	J-120	J-121	300	PVC	0.95	40
P-441	J-121	J-122	300	PVC	0.95	41
P-442	J-122	J-237	300	PVC	0.95	156
P-166	JK-25	J-196	80	PVC	0.96	353
P-165	J-196	JK-28	80	PVC	0.96	171
P-105	JK-12	J-149	150	PVC	0.99	55
P-106	J-149	J-150	150	PVC	0.99	139
P-107	J-150	J-309	150	PVC	0.99	196
P-592	T-1	J-063	250	PVC	2.18	152
P-593	J-063	J-062	250	PVC	2.18	48
P-594	J-062	J-061	250	PVC	2.18	52
P-595	J-061	J-060	250	PVC	2.18	42
P-596	J-060	J-059	250	PVC	2.18	46
P-597	J-059	J-058	250	PVC	2.18	47
P-598	J-058	J-057	250	PVC	2.18	50
P-599	J-057	J-056	250	PVC	2.18	43
P-600	J-056	J-055	250	PVC	2.18	55
P-601	J-055	J-054	250	PVC	2.18	48

P-602	J-054	J-053	250	PVC	2.18	54
P-603	J-053	J-052	250	PVC	2.18	167
P-604	J-052	J-051	250	PVC	2.18	69
P-605	J-051	J-050	250	PVC	2.18	57
P-606	J-050	J-049	250	PVC	2.18	44
P-607	J-049	J-048	250	PVC	2.18	52
P-608	J-048	J-047	250	PVC	2.18	49
P-609	J-047	J-046	250	PVC	2.18	45
P-610	J-046	J-045	250	PVC	2.18	49
P-611	J-045	J-503	250	PVC	2.18	96
P-612	J-503	J-504	250	PVC	2.18	61
P-613	J-504	J-505	250	PVC	2.18	58
P-614	J-505	J-506	250	PVC	2.18	44
P-615	J-506	J-507	250	PVC	2.18	98
P-616	J-507	J-508	250	PVC	2.18	48
P-617	J-508	J-509	250	PVC	2.18	45
P-618	J-509	J-510	250	PVC	2.18	17
P-619	J-510	J-511	250	PVC	2.18	55
P-221	J-511	J-512	250	PVC	2.18	59
P-219	J-512	J-0018	250	PVC	2.18	59
P-218	J-0018	J-0017	250	PVC	2.18	59
P-217	J-0017	J-0016	250	PVC	2.18	50
P-216	J-0016	J-0015	250	PVC	2.18	72
P-215	J-0015	J-0014	250	PVC	2.18	36
P-214	J-0014	J-0013	250	PVC	2.18	72
P-213	J-0013	J-0012	250	PVC	2.18	46
P-212	J-0012	J-0011	250	PVC	2.18	53
P-199	J-0011	J-0010	250	PVC	2.18	46
P-191	J-0010	J-0009	250	PVC	2.18	54
P-190	J-0009	J-0008	250	PVC	2.18	77
P-189	J-0008	J-0007	250	PVC	2.18	32
P-188	J-0007	J-0006	250	PVC	2.18	32
P-187	J-0006	J-0005	250	PVC	2.18	39
P-186	J-0005	J-0004	250	PVC	2.18	35
P-185	J-0004	J-0003	250	PVC	2.18	30
P-184(2)	J-0003	PMP-3	250	PVC	2.18	11
P-184(1)	PMP-3	R-3	250	PVC	2.18	22

P-450	R-3	JC-1	150	PVC	2.18	246
P-05	JC-1	JC-2	150	Cast iron	2.18	275
P-04	JC-2	JC-3	150	Cast iron	2.18	466
P-03	JC-3	KBH01	150	Cast iron	2.18	114
P-02	KBH01	PMP-1	150	Cast iron	2.18	114
P-01	PMP-1	R-1	150	Cast iron	2.18	20
P-175	R-3	KBH02	150	Cast iron	2.31	60
P-331	KBH02	PMP-2	150	Cast iron	2.31	150
P-92	PMP-2	R-2	150	Cast iron	2.31	20

Appendix 3**:** Demand pattern Report

Label	Demand (Base) (L/s)	Pattern (Demand)	Zone
JK-21	1.70	Fixed	zone 2
JK-08	4.06	Fixed	zone 2
JK-32	1.42	Fixed	zone 2
JK-29	2.49	Fixed	zone 2
JK-12	1.23	Fixed	zone 2
JK-20	2.23	Fixed	zone 2
JK-01	2.13	Fixed	zone 2
JK-23	1.00	Fixed	zone 2
JK-19	2.34	Fixed	zone 2
JK-06	1.89	Fixed	zone 2
JK-05	1.40	Fixed	zone 2
JK-11	0.57	Fixed	zone 2
JK-31	2.95	Fixed	zone 2
JK-16	2.95	Fixed	zone 2
JK-18	5.25	Fixed	zone 2
JK-28	0.79	Fixed	zone 2
JK-07	1.89	Fixed	zone 2
JK-03	7.40	Fixed	zone 2
JK-30	1.32	Fixed	zone 2
JK-02	5.65	Fixed	zone 2
JK-26+JK-27	3.53	Fixed	zone 2
JK-24	0.49	Fixed	zone 2
JK-25	2.06	Fixed	zone 2
JK-22	2.98	Fixed	zone 2
JK-09	4.70	Fixed	zone 2
JK-10	2.85	Fixed	zone 2

JK-17	3.49	Fixed	zone 2
JK-14+JK-04	2.02	Fixed	zone 3
JK-15	4.02	Fixed	zone 3