Hydraulic Performance Analysis of Water Supply Distribution Networks Using WaterGEMS in the Case of Dukem Town, Ethiopia

Boki Tesfaye Geleta

A Thesis Submitted to

The Department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement of the Degree of Master's in Water Resources Engineering (Specialization in Water Supply and Environmental Engineering)

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

Hydraulic Performance Analysis of Water Supply Distribution Networks Using WaterGEMS in the case of Dukem Town, Ethiopia

Boki Tesfaye Geleta

Advisor: Andinet Kebede (PhD)

A Thesis Submitted to

The Department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement of the Degree of Master's in Water Resources Engineering (Specialization in Water Supply and Environmental Engineering)

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis entitled "*Hydraulic Performance Analysis of Water Supply Distribution Networks Using WaterGEMS in the case of Dukem Town, Ethiopia*" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

____________________	____________________	____________________
Name of the student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "*Hydraulic Performance Analysis of Water Supply Distribution Networks Using WaterGEMS in the case of Dukem Town, Ethiopia*" prepared under my guidance by Boki Tesfaye Geleta submitted in partial fulfilment of the requirements for the degree of Mater's of Science in Water Supply and Environmental Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

__________________________ _______________________ ________________

Major Advisor Signature Date

APPROVAL PAGE

I, the advisor of the thesis entitled "*Hydraulic Performance Analysis of Water Supply Distribution Networks of Dukem Town Using WaterGEMS*" and developed by Boki Tesfaye Geleta, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Andinet Kebede (PhD)	________________	______________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Boki Tesfaye Geleta have read and evaluated the thesis entitled "*Hydraulic Performance Analysis of Water Supply Distribution Networks of Dukem Town Using WaterGEMS*" and examined the candidate during open defence. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Water Supply and Environmental Engineering

Keneni Alemu (PhD)	________________	______________
Chairperson	Signature	Date
Dereje Birhanu (PhD)	________________	______________
Internal Examiner	Signature	Date
Tamiru Tesseme (PhD)	________________	______________
External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

______________________	________________	______________
Department Head	Signature	Date
______________________	________________	______________
School Dean	Signature	Date
______________________	________________	______________
Office of Postgraduate Studies,	Dean Signature	Date

ACKNOWLEGMENT

First of all, thank you to God, who gave me peace and helped me reach this time and complete this work. Secondly, I would like to express my sincere gratitude to my Advisor, Dr. Andinet Kebede, for his close consultation, guidance, determination and unreserved assistance from the start to the end of my paper work.

Next, I would like to thank the Dukam Town Water Supply and Sewerage Enterprises Office for providing me with the necessary data requested to accomplish this work and especially I like to convey my special thanks to Mr. Surana Ayana (Technician in the office) for his continuous assistance in the field.

At last but not least, I would like to thank my family and friends who have encouraged and stood by me through my work.

TABLE OF CONTENTS

LISTS OF TABLES

LISTS OF FIGURES

LISTS OF ACRONYMS AND ABBRIVATONS

CSA	Central Statistical Agency
EPS	Extended Period Simulation
WaterGEMS	Water *Geospatial Engineering Modelling Software*
GI	Galvanized Iron
GIS	Geographic Information System
GTP-II	Growth and Transformation plan -II
HC	House Connection
HDPE	High Density Polyethylene
L/c/d	Liters per capita per day
mH_20	Meter of water
NRW	Non-revenue Water
PF	Public Fountain
PHD	Peak Hour Demand
PRV	Pressure Reducing Valve
PVC	Polyvinyl Chloride
MOWIE	Ministry of Water, Irrigation and Electricity
MOWR	Ministry of Water Resources
USEPA	United States Environmental Protection Agency
WDNs	Water Distribution Networks
WDSs	Water Distribution Systems
YC	Yard Connection

ABSTRACT

Analysing the status of a town's water distribution network is necessary to monitor its current and future management patterns. Generally, the hydraulic performance of the water distribution systems in developing countries is inadequate to transport available water to consumption points. Specifically, Dukem Town's existing water distribution system is not properly functioning, and the utility does not deliver the required demand to customers due to fluctuations in pressure and demand in large parts of the town. Thus, this study's main goal was to analyse the town's water distribution system's hydraulic performance efficiency and users' perception. To achieve the objective, the hydraulic performance of the distribution network and the level of customer satisfaction were evaluated. Both primary and secondary data were gathered for this investigation, and tools like WaterGEMS, ArcGIS 10.7.1, GPS, Google Mapper v18, and SPPS v27 were employed. GIS and WaterGEMS were used to provide a graphical display of results obtained from both hydraulic simulation and a modified water distribution network. 376 households were selected from a total of 21,595 to investigate the level of customer satisfaction with the town's water supply services. The results showed that the average water consumption of the town is 49.8 l/c/d in 2023, which is less than the national standard of 100 l/c/d for category one towns. The current water production is 5338 m3/d, and to satisfy the projected demand of 7997.74 m^3/d by 2030, new sources should be provided. The WaterGEMS model was calibrated using eight node data points at minimum and peak hour consumption, with corresponding R^2 of 0.97 and 0.99, respectively. The result of the analysis at steady state simulation indicated that only 50.38% of nodes have pressure within the desired limit of 10–70 m of water; the remaining 45.11 and 4.51% of the nodes have pressure above and below the desired limit of pressure, respectively, at average daily demand. At peak hour demand, only 34.3% of the nodes have pressure within the desired limit, and 20.81 and 44.89% of the nodes have pressure above and below the desired limit, respectively. The analysis of pipe velocity showed that only 45.71 and 48.57% of pipes have a desired limit of velocity (0.5-2 m/s) at average daily demand and peak hour demand, respectively. The extended-period simulation showed 45.36% of the nodes to have pressure within the desired limit, whereas 51.88 and 3.76% of nodes had pressure above and below the desired limit, respectively. Correspondingly, 62.86% of pipes had less than the allowable velocity limit, and 37.14% of them were within the desired limit. Even though there are water interruptions, the customers' satisfaction with the existing water supply service is 55.4%. Finally, by applying pressure-reduced valves, it was possible to make 99% of the nodes' pressures within the desired range, and the map of the modified network was prepared.

Key Words: Customers Perceptions, Dukem Town, Hydraulic performance, *WaterGEMS* Water Distribution Networks.

1. INTRODUCTION

1.1 Background

The most critical factor in ensuring public safety and the on-going execution of urban activities is the efficiency of water distribution systems (WDSs), which are components that are made to deliver large amounts of water to customers with sufficient pressure and acceptable quality (Ataoui & Ermini, 2015)**.** It is important to evaluate the WDN's performance by identifying the problematic areas and components in the network and minimising the operational as well as maintenance costs.

The water distribution network (WDN) is one of the essential parts of the water supply system created to meet the water demand for homes, business centres, institutions, and industries with sufficient pressure (Adesogan et al., 2019). For better living conditions and economic growth, particularly in metropolitan areas, there should be a well-designed and constructed WDN,but in developing countries like Ethiopia, most WDNs cannot fulfil their aim of providing sufficient water due to the frequent failure of their elements associated with poor design, construction, operation, and maintenance(Terlumun et al., 2019). Generally, the focus of urban water management is on building infrastructure, whose prime attention is for augmentation, but the distribution network hydraulics are usually ignored, and this mismanagement does not lead to sustainable services (Jaiswal et al., 2021).

The most recent software created by Bentley, WaterGEMS, is one of the hydraulic modelling programmes used for the analysis and design of water distribution networks (Shinde et al., 2018). Its robust design method enables it to meet the standards for accuracy in the design of water distribution networks, control of distribution network variables including flow, pressure, and velocity, as well as their optimisation (Ostfeld et al., 2013).

By using GIS, the network will be spatially analysed for long-term and sustainable system maintenance information about a physical object that may be expressed as numerical values in a geographic coordinate system is referred to as spatial data and offers a consistent environment that is particularly helpful while making decisions (Abdelbaki et al., 2017).

Customer satisfaction level is also strongly linked to the four fundamental components of water service: quality, quantity, continuity, and price. The quantity and accessibility of water, the supply system, the continuity of the water supply, the consistency of the time of delivery, and the affordability of the water, which is the cost of the water in relation to the ability of the consumers (Budiyono et al., 2020). It is essential to maintain the customer's confidence in the drinking water quality and the services provided by a utility so that satisfied customers will pay their bills properly and will provide support for necessary rate increases. Therefore, to ensure that water is delivered at a safely managed service level, rigorous assessments of piped water service providers should be conducted (Ajeng et al., 2018).

Due to growing living standards brought on by economic development, population growth brought on by nature, rural-urban migration, and rising per capita income, there has been an increase in demand for water in urban areas over time. Thus, in terms of coverage, amount, dependability, and acceptable quality, a well-functioning urban water supply network should provide water supply for domestic as well as industrial and other applications by taking into account the present and future realities of the city (Kefyalew, 2019).

Dukem Town's water distribution system is not properly functioning and could not reach the required demand to customers due to fluctuations in pressure and demand in large parts of the town. The water distribution network of the town sometimes fails, which can be due to poor hydraulic performance of the distribution elements. Since recently, there has been a frequent interruption of water supply in some parts of the town, and efficient demand could not reach customers for unknown reasons. Tambde et al. (2022) stated that it is very difficult to identify the location of valves and junctions as the underground asset if it is not GIS-based. The town also does not have appropriate wastewater disposal systems, and if the leaking pipes are not promptly maintained, pollution may make its way into the network system (Mohammed et al., 2013).

So that, this research was focused on hydraulic performance analysis and upgrading of water distribution network of the town's by using WaterGEMS software to analyse the hydraulic parameters and optimise pressures and velocity of the system by considering correspondingly appropriate solutions as well as assessing of costumer's satisfaction to existing water supply service.

1.2 Statement of the Problem

Dukem Town has faced an unbalance of supply and demand, which increases from time to time as the population grows rapidly in the town. Behind this, the existing water distribution system is not properly functioning and could not reach the required demand to customers due to fluctuations in pressure and demand in large parts of the town. The water distribution network of the town frequently fails, which can be due to poor hydraulic performance of the distribution elements. Especially since recently, in some parts of the town, the pipeline that used to distribute water is no longer doing so for unknown reasons, and it is very difficult to identify the location of valves and junctions as the underground asset is not GIS-based (Tambde et al., 2022).

Besides, Mohammed et al. (2013) reported that a high proportion of households used unsafe wastewater disposal methods and did not have appropriate wastewater disposal systems. Thus, if the leaking pipes are not promptly maintained, pollution may make its way into the network system. Consequently, it is important to use hydraulic computational tools, which are effectively combined with GIS tools, to assess and then improve the efficiency of the water distribution system (Tabesh et al., 2010).

Thus, the objective of the current study was to use GIS and WaterGEMS to ensure that drinking water reaches consumers and to solve the problems limiting the sustainability of the system. Finally, the customer’s perception of the existing water supply system was assessed, and a mapping of the distribution network was performed to easily detect problem areas and gradually replace old pipes in the future.

1.3 Objective of the Study

1.3.1 General objective

The general objective of this study is to analyse the hydraulic performance of water supply distribution networks of Dukem Town using WaterGEMS.

1.3.2 Specific objectives

To realise the general objective, the following specific objectives are used as operational steps.

- To assess the existing water supply coverage and the water demand
- To analyse the hydraulic performance of the existing water distribution networks
- To modify the distribution networks by considering critical hydraulic parameter values.
- To analyse the customer's perception to existing water supply service

1.4 Research Questions

In line with the specific objectives listed above, the study tries to get answers to the following research questions.

1. What is the current water supply coverage and water demand of the town?
2. What is the overall hydraulic performance of the existing distribution network?
3. Which hydraulic parameters should be optimised to improve the efficiency of the town's water distribution network?
4. What is the consumer's response and satisfaction level to the current water distribution system?

1.5 Significance of the Study

Hydraulic analysis which assesses the pressure and velocity of water in water distribution networks is an important tool for determining the efficiency of water distribution systems(Adesogan et al., 2019). The significance of this study is to analyse the hydraulic performance of town water distribution network as well as assess customers' satisfaction with the existing water supply distribution system in Dukem town. The results of this research will be used by municipal officials to better understand and manage the network and delivery systems in the future. The assessed, analysed, and improved results and estimates will in turn contribute to knowing the overall performance level of the system to help decision-makers and especially the town water utility (water supply service office) in planning future expansions. It may serve as baseline data for any further investigation, town water supply and sewerage offices, government organisations, NGO's, and academic purposes.

1.6 Scope and Limitation of the Study

This study is limited to hydraulic performance assessment and upgrade water distribution network in terms of pressure, flow, or velocity, domestic demand and customer satisfaction within existing water supply system. Therefore, the research does not include tariff, billing system, management and financial aspect and analysing overall water loss of the water utility. Besides, due to insufficient funding, and limited access to laboratories, this study does not include water quality analysis. Although there were many questions to determine the overall level of customer satisfaction with the existing water supply, only those that were relevant to the topic and could be meaningful for good decision making were addressed.

1.7 Thesis Organization

The thesis was typically grouped into five chapters, a reference section, and appendices. The study's purpose, problem statement, significance, and scope are all presented in the first chapter, including introduction parts of study. The literature review related to the study is discussed in Chapter 2. The third chapter discusses the study's materials and methods as well as identified the study area, collected and analysed the data that was available, and clearly stated the steps to take in order to address objectives the study. The study's findings and feedbacks are covered in chapters four and five, which also explore the study's recommendations and conclusion.

2. LITERATURE REVIEW

2.1 Status of Water Supply Coverage

In developing countries like Ethiopia, the number of populations who have access to potable water has increased between 1990-2020. However, many people still do not have access to clean water in their homes and only 17% of Ethiopia's citizens had access to clean water in 1990(MOWIE, 2022). More than 55% of urban Ethiopians have no access to water from safely managed water services, which is lower than the average for Sub Sahara African countries and the world by 9% and 41%, respectively(Beker & Kansal, 2023). Safely managed water services are the improved source accessible from the premises or the point of collection within the dwelling area, compound, yard, estate or safe, clean water is delivered to the household. According to WHO (2021) Ethiopia is categorized under countries with a high scarcity of drinking water among SSA countries, especially at the rural and national levels and only 45% of the urban Ethiopian population has been using water from safely managed water services in 2020 and according to MOWIE (2022) Provide urban water supply access with GTP-2 minimum service level of 100 l/c/day for category-1 towns/cities, 80 l/c/day for category-2 towns/cities, 60 l/c/day for category-3 towns/cities, 50 l/c/day for category-4 towns/cities, up to the premises and 40 l/c/day for category-5 towns/cities within a distance of 250m with piped system for 75% of the urban population

2.2 Water Demand Management

Urban water demand is escalating as the world population is increasing and more and more urbanisation is taking place worldwide. On the other hand, there are limited water resources available, increasing competition over different water uses and interests (urban, agricultural and environmental) and decreasing access to good-quality water as most of the nearby and good-quality sources have already been overexploited or exhausted. As the traditional supply-driven urban water management is not sustainable, water utilities should embrace water demand management (WDM) measures to meet increasing water demand. Developed countries are using different technological and management measures to reduce urban water demand as a part of their integrated urban water management strategy. However, all these measures might not be directly applicable for the developing countries(Sharma & Vairavamoorthy, 2009)

2.3 Water Supply System Components

A water supply system's general components include raw water extraction, transportation, treatment, and storage, as well as elements for distributing clean water (Lejano, 2006**)**. Water distribution systems (WDSs) entail a network or interconnection of pipes that deliver water for end-use. Components, including reservoirs, pumping stations, water towers, and other elements like hydrants, valves, monitoring equipment, etc., are typically connected in the system to achieve optimal performance. By maintaining a constant pressure and flow, one can obtain sufficient quantities and qualities of water. The risk of external pollutants is minimised by making sure that pipes are consistently under pressure (Vicente et al., 2016). Additionally, water that is moving at a regular pressurised flow reduces retention durations, prevents a decline in water quality due to the development of sediments, suppresses the growth of microbes, and has a low chlorine residual.

2.4 Water Distribution System and Its Performance

A water distribution system (WDS) is created and maintained in order to deliver a dependable water supply, that is, to adequately meet water user demand, especially under crucial operational conditions such as periods of peak demand. Consequently, an essential requirement in the framework of WDS reliability is the study of the influence of water demand parameters (Zhan *et al*., 2020).

The water distribution networks play a crucial role in infrastructure systems that are prone to failure. The components of a typical WDN include a network of pipes, nodes connecting the pipes, storage tanks, reservoirs, pumps, and optional extras like valves. Water distribution systems are an essential part of public works and account for a sizable amount of the investment in urban infrastructure. The major objective is to create water distribution systems that can provide potable water over vast areas at the necessary pressures and amounts. (Vicente et al., 2016).

Therefore, hydraulic models for water distribution networks have become indispensable tools for understanding system behaviour by simulating pressures and flows at different locations and times in the networks

The assessment of the hydraulic performance of a water distribution network (WDN) could show if the system can provide consumers with the necessary amount of water at all times and locations **(**Shah, 2021**).** System serviceability and water supply reliability can be used to gauge how well water distribution networks are working. As a result, gauging the performance of water distribution networks is done by assessing their reliability.

On the other hand, to improve the performance of utilities that provide critical services, like water delivery, the assessment of customer satisfaction is of utmost importance. Understanding levels customer satisfaction to water supply can help to improve the level of water services and water management. This is to understand for certainty of water supply whether or not it reaches the target communities and used for improvement action on the areas

2.5 Impact of Hydraulic Parameters on Water Distribution Network

2.5.1 Water loss due to high pressure

In many towns and cities around the world, water distribution system losses are at alarmingly high levels. Physical losses (leaks), illegal use, unmetered use, and under-registration of water meters are some of the different components that make up water losses. Leakage contributes significantly to overall water losses, sometimes accounting for more than 70%. Pressure in the distribution system is one of the key elements affecting leakage (Van Zyl & Clayton, 2013)

When there is little demand, high pressure can bust pipes, produce leaks, and result in significant water loss across distribution networks. Therefore, PRVs should be employed to lower and control system pressure while dealing with high pressures. (Walski. et al., 2013). In order to solve these issues and maintain a suitable pressure in the system, pipes and pumps must be sized to overcome these problem

2.5.2 Low pressure in water distribution network

However, pressure loss occurs due to friction at the pipe wall, and the amount lost depends on a number of factors, including the amount of water required, the characteristics of the fluid being transported through the pipe, the speed at which it is moving, the degree of internal pipe roughness, the length, gradient, and pipe diameter. Such circumstances may arise when there are properties on high ground, remote properties at the ends of long lengths of pipe, demands that are higher than the design demand, pipes with inadequate capacity (too small a diameter), unreliable equipment, such as pumps and valves, and rough pipes (such as corroding iron pipes or pipes with a build-up of silt). In general, poor pressures tend to be caused by inadequate capacity in a pipe or pump, high elevations, or some combination of the two (Adhikary et al., 2013).

Therefore, maintaining sufficient water pressure inside the pipe is one of the most important aspects of hydraulic integrity. In order to attain a high level of hydraulic integrity, the water utilities should combine effective system design, operation, and maintenance with good monitoring.

2.5.3 Pipe velocity in water supply network

Reducing retention durations helps to minimize quality degradation brought on by low chlorine residuals, the emergence of sediments, the growth of microorganisms, etc. by moving the water at an optimum velocity. Hence, potable water in transport and distribution systems must always be kept under a certain minimum velocity and for hygienic reasons should not be left stagnant in pipes **(**Shamsaei *et al*., 2013).

2.6 Theoretical Background of Hydraulic Performance Analysis

The flow through a WDN should conform to three fundamental laws or equations when the demand is known. These are the energy principle (conservation of energy), loop equation, and the law of conservation of mass, sometimes known as the continuity equation. The continuity of substance serves as the fundamental guiding concept when working with pipe flows. It says that the algebraic total of the discharge in all of the pipe joining data nodes, along with any external flows, is zero for incompressible fluids(Shah, 2021).

Equations for each link (between nodes *i* and *j*) and each node k written as;

$$\sum_i Qik - \sum_i Qkj \pm Qk = 0 \tag{2.1}$$

where *Qik* is flow into the node *k*, *Qkj* is the flow out from the node *k*, and *QK* is the flow consumed (-) or supplied (+) at node *k*.

Further, the principle of conservation of energy is also satisfied and stated as the total energy of flow at two cross-sections of pipes will be the same if there is no energy loss. The total energy in terms of the head of water is expressed by the Bernoulli Eq. (2.2).

$$Z1 + \frac{P1}{\gamma} + \frac{v_1^2}{2g} = Z2 + \frac{P2}{\gamma} + \frac{v_2^2}{2g} + hl_{,1\text{-}2} \quad (2.2)$$

where $Z1$ is the elevation head at cross-section 1, $P1$ pressure head, γ is the unit weight of water $V1$ the velocity of flow; subscripts 1 and 2 denote that the variable refers to cross-section 1 and 2; and $hl.1-2$ refers head loss between two cross-sections.

Finally, the hydraulic flow through WDN also satisfies the loop equation that states as the algebraic sum of pressure drops around a loop must equal zero. Mathematically written as:

$$\sum \pm \Delta hi = 0 \quad (2.3)$$

where *hi* is head loss/gain the *i*th element of the loop.

The hydraulic equation in WDN can be calculated either in terms of unknown flow rate or in terms of the unknown head at the demand node explicitly (Shah, 2021).

2.7 Approaches for WDN Performance Assessment

The aim of performance analysis is to evaluate if, and how much, the performance requirement is achieved. Since aspects related to water quality are generally treated separately from the others, reference will be made to the analysis of hydraulic aspects only, the likes of which can be carried out using two different approaches (Coelho & Alegre, 1998).

2.7.1 Deterministic approach

This approach serves to check if the desired performance is reached by referring to a limited number of operative working conditions (project conditions). If the system performs as desired for all the pre-determined project conditions, analysis results give an adequacy response; in the case of inadequacy, the analysis provides the diagnostic elements to indicate corrective actions to be taken.

2.7.2 Probabilistic approach

This approach evaluates the functioning of a system with reference to many different working conditions which are not usually taken into consideration on a design level, but they do however have a certain probability of occurring. Statistical elaboration of results enables an evaluation of the extent to which performance requirements are met in probabilistic terms; the probability value/s obtained provide us with a measure of the system performance efficacy.

In particular, the performance of WDS is defined and can be measured using the following three concepts:

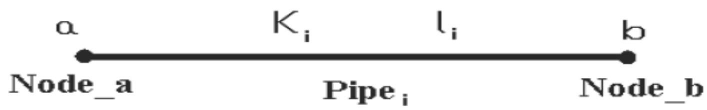
- Reliability: the probability that the system does not fail. i.e. total failure times divided by total operating times
- Resilience: the swiftness at which the system begins full operation after a failure.
- Vulnerability: the probable harm after a failure.

The performance of the system has been evaluated by extensive literature research on the WDN performance metrics. Despite the fact that the meaning of each indicator has undergone numerous iterations over the years, they all provide helpful indicators of system performance (Gunawan et al., 2017). Water distribution systems (WDSs) are crucial infrastructures that must be resilient to withstand extreme conditions and recover immediately after them in a hard and uncertain future. Investigating indicators that may accurately measure the extent of system resilience is crucial to include resilience into the design of WDSs. (Zhan et al., 2020).

2.8 Base Demand Allocation for Water Distribution Network

According to WaterGEMS Manual (2014), to assign existing demand data to the network, there are three method of total demand assigning to nodes in Water GEMS software's by Load builder tool bars. Those are Point load data, Area load data and Population or land use data. Under point data load there are options of loading which are billing meter aggregation, nearest node and nearest pipe. Under area load data there are four options such as equal flow distribution, proportional distribution by area, proportional distribution by population and Unit Line Method. And also population or land use data method has two options which are population by land use and load estimation by population

From the above method of assigning existing demand to distribution network, point data method which is unit Line option is the best to assign demand data to model, since inaccuracy data especially in developing country. The Unit Line Flow Method divides the total demand in the system (or in a section of the system) into 2 parts: known demand (metered) and unknown demand (leakage and unmeasured user demand (Momenzadeh et al., 2018) . The following diagram shows a sample pipe. The known (metered) demands at *nodes a and b* are *qa* and *qb* respectively. The unknown demand is computed by considering if there are users on none, one, or both sides of the pipe. This is accounted for using the coefficient.



Where

li = length of *Pipei*

Ki = coefficient indicating the capability of Pipei to consume water

If there are no users on either side of the pipe (the pipe is only used to transfer water to another part of the system), then K is 0. If there are users along only one side of the pipe (for example, pipes along a river), K is 0.5. If both sides of the pipe supply water to users, K is 1.

The equations below are used to determine the total demands at nodes a and b manually

$$Qa = qa + \frac{1}{2}\frac{Qtotal\ unknown}{(\sum_{j=1}^{n} Kj*lj)}*\sum_{i=1}^{m} Ki * li \tag{2.4}$$

$$Qb = qb + \frac{1}{2}\frac{Qtotal\ unknown}{(\sum_{j=1}^{n} Kj*lj)}*\sum_{i=1}^{m} Ki * li \tag{2.5}$$

Where *Qa* = the total demand at node *a*

Qb = the total demand at node *b*

qa = The known demand at node *a*

qb = The known demand at node *b*

Total unknown = Total real demand minus total known demand (for the network or selection set)

n = number of pipes in network (or selection set)

m = the number of pipes connected to node *a* or *b*

2.9 Scenario management and alternatives

A crucial component of the decision assistance and optimization tool are scenarios. They significantly affect the planned transformation strategy. The scenario management approach combines the evolution of the various drivers and ensures realistic modelling. Different scenarios covering a large range of factors can be created because the approach uses a wide variety of drivers. The advantage of user-specified situations is that the user's knowledge is taken into account. The number of potential adaption measures can be lowered by specifying situations. The robustness of predicted transformation strategies can subsequently be examined by sensitivity analysis for various scenarios. As a result, the modelling process' uncertainties can be decreased (Momenzadeh et al., 2018).

2.10 Model Calibration and Validation

Model calibration is the process of comparing the model findings to actual field observations and, if necessary, modifying the data in the model that defines the system until the model's anticipated performance and the measured performance of the system reasonably agree under a variety of operating conditions. The model pressures are compared to recorded pressures using measured flows in order to calibrate the model under steady state conditions. Prior to calibration, the model must be given the system operating parameters at the time the recorded pressures were obtained. (Alves et al., 2014).

WDS calibration is required to forecast the behaviour of water distribution network models under various conditions and to prepare for their extension in growth studies. A network model must demonstrate that it can forecast with a reasonable degree of accuracy from field data before being used for future research. The network's conduct ought to correspond to the actual situation. A process like this is known as "calibration" of the model. (Zimoch & Bartkiewicz, 2018).

A hydraulic model's accuracy is influenced by the calibration process and how thoroughly it has been calibrated. Calibration is the process which compares the model results against field observations and focuses on the adjusting the model hydraulic conditions until model-predicted performance reasonably matches with measured system performance over a wide range of operating conditions (Kadgaonkar et al., 2015). Therefore, model will not be hundred percent correct and to be calibrating it must be accurately simulating the observed data.

In order to achieve agreement between observed and computed pressures and flows, calibration can be carried out by changing simply internal pipe roughness values or nodal demand estimates. This assertion is supported by the fact that, in contrast to pipe lengths, diameters, and tank levels, which can be measured precisely, pipe roughness values and nodal demands are often estimated, leaving space for correction (Kadgaonkar et al., 2015).

2.11 Water Distribution System Simulation

There are two most basic types of simulations that a model may perform, depending on what the modeller is trying to observe or predict.

2.11.1 Steady State Simulation

It makes the premise that hydraulic demands and boundary conditions do not change over time while it estimates the system's state (flows, pressures, pump operating characteristics, valve position, etc.). A steady-state simulation provides information on the equilibrium flows, pressures, and other variables describing the state of the network for a particular set of hydraulic demands and boundary conditions. (Beckwith, 2004).

In general, steady-state models are used to analyse specific worst-case scenarios where the effects of time are not particularly significant, such as peak demand periods, fire protection usage, and system component breakdowns.

2.11.2 Extended period simulation

Extended period simulation is a type of linked steady state run that monitors a system over time. Because system activities evolve over time, extended period simulations are required to demands change throughout the day, pumps and wells go on and off, Valves open and close and tanks fill and draw (Beckwith, 2004).

2.12 Customers satisfaction level to water supply system

It's crucial to preserve a customer's faith in a utility's services and the purity of its drinking water. Customers who are happy with the service will pay their bills on time and support political initiatives such as rate rises or bond issues. It is not feasible to identify all significant customers, their preferences, expectations, needs, and requirements, and then to investigate means of achieving those expectations while taking into account any resulting implications in order to evaluate a water distribution network. Major users, such as residential, industrial, and firefighting users, as well as public health officials, may require those facilities that account for a sizeable amount of supply demand in a region. An ideal strategy may be to determine the amount of water required for each individual customer, the duration of their water need, and the optimum water quality level to meet their requirements. The quantity of water should be estimated in a way that accurately reflects client preferences and expectations. Customer satisfaction is higher and the water utility is handled better when requirements of customers are more closely satisfied (Budiyono et al., 2020).

2.13 Upgrading the Performance of Water Distribution Networks

According to Hajibabaei et al. (2019), performance of water distribution network can be improving by considering scenarios that have been taken into consideration are as follows: (1) lowering the average pressure in the WDN; (2) lowering the per capita water demand of the WDN; (3) lowering the mean age of the system by renewing it; and (4) lowering both the average pressure and per capita water demand in the WDN.The first and most obvious step is to enhance a water distribution system's hydraulic performance because it's essential to supply a specific set of demand areas with the appropriate flow and pressure while avoiding significant variations in the parameters.

2.13.1 Pressure Management

In recent years, it has become clear that effective leakage management depends on pressure management in the water distribution network (WDN). The advantages of controlling pressures include lowering water loss, limiting the wear and tear on network parts (joints, valves, pipes, etc.), and decreasing the frequency of new leaks in the system (Laucelli & Meniconi, 2015)**.** Pressure management, which involves lowering system pressures to effectively lower the amount of water being driven out via the leak holes, is one simple method of minimising leakage volumes. Although this technique does not locate and fix leaks, it does have the effect of lessening the frequency of new leaks and bursts. Although there are other ways to control system pressures, basic water utilities most frequently employ their existing gate/isolation valves to reduce pressures in specific locations. (Gupta et al., 2014).

Pressure Reducing Valves (PRVs) and variable speed control pump systems are more efficient ways to lower pressure in pumping systems. A straightforward PRV can lower upstream pressure to a defined downstream setting, the magnitude of which must be chosen by the water company. This is frequently accomplished by assessing the pressure in the zone being fed at the minimum pressure point and figuring out what pressure set at the PRV provides enough pressure at the minimum pressure point during peak demand.

According to the national standard, the operating pressure in the distribution network should be (15–60 m) under normal conditions and (10–70 m) under exceptional conditions, and water velocity should be between 0.6 and 2 m/s, although one can find pipelines with zero velocity in the looped system (MoWR, 2006) . Installing pumps equipped with variable frequency drives

(VFDs) or variable speed drives (VSDs) is another frequently used technique for managing system pressures. These pumps are turned by motors, the frequency or speed of which can be changed to alter the pump's outlet pressure.

2.13.2 Creating a Zoned Network

The goal of the network upgrade was to increase network performance and reduce losses for utility practitioners by advancing infrastructure management. Zoning was one of the basic network management techniques. In order for utility personnel to understand the network and more easily analyse pressure and flow profiles and issue locations, the zoning idea has been widely established (Sela Perelman et al., 2015). A zone that cannot be supplied by gravity can be isolated by boundary valves and supplied by a booster pump, for example, to generate zones as discrete pressure areas. To minimise quality issues, zones can be formed to divide water supplied from various sources. Any network's capacity is reduced when too many valves are closed, which could result in operational or water quality issues(Darvini et al., 2020)

In order to reduce the number of mains crossing a zone, it is ideal for zone boundaries to be natural geographic and hydraulic boundaries. Rail lines, rivers, canals, and major highways are a few examples of these boundaries. The mains network often has some level of redundancy to permit zoning without creating supply issues. (Darvini et al., 2020)**.**

2.13.3 Optimization of water Distribution system

Operators must take a number of steps to maintain water distribution systems (WDSs) properly in order to ensure optimal performance. Normally, all needs ought to be changed at once. As a result, multi-criteria optimisation techniques are frequently used to support the decision-making process. Connecting minor water supply networks into group systems will significantly improve the conditions under which WDSs operate (Świtnicka et al., 2017).

2.14 Bentley Water GEMS

A comprehensive yet user-friendly decision-support tool for water distribution networks is offered by Open Flows Water GEMS. The most recent software created by Bentley, WaterGEMS, is one of the hydraulic modelling programmes used for the analysis and design of water distribution networks (Shinde et al., 2018). Its robust design method enables it to meet the standards for accuracy in the design of water distribution networks, control of distribution network variables including flow, pressure, and velocity, as well as their optimisation (Ostfeld et al., 2013) .The software develops knowledge of how infrastructure behaves as a system, reacts to operational strategies, and should change as population and demand increase. Open Flows Water GEMS, a superset of Open Flows Water CAD and attractive with numerous graphical tools, contains all you need in a flexible multiplatform environment, from fire flow and water quality simulations to criticality and energy cost analysis.

WaterGEMS is far superior to other WDN model software, especially EPANET, because to its integration with several platforms graphic applications (GIS tools, AutoCAD, and Micro Station tools). As a result, any data submitted in any form will be analysed by this programme and sent to the network for further processing (Bentley, 2014)

2.15 Application of GIS in water distribution system

According to (Shamsi, 2005), there are three methods to model a WDN based on GIS. They defined as the interchange method, interface method, and integration method. GIS integration, is the merging of a model with a GIS so that the merged application provides both GIS and modelling capabilities. This strategy offers the most direct link between a GIS tool and a hydraulic modelling tool. Using GIS has made it possible to take immediate action to identify issues in the system and quickly find solutions to maximise network maintenance effort and create a foundation for continual improvement.

2.15.1 System mapping of distribution network

Population growth and the demand for portable pipes, the activities of people and borne water in the majority of developing country cities have a significant impact on the underground pipe networks. It has been a challenge to find such pipes and the components put in them. Therefore, current technologies like the usage of geographic information technology must be effectively led in order to ensure proper surveillance and monitoring of laid down pipe across the metropolis (Pindiga & Sani, 2015). System maps frequently serve as the most helpful materials for understanding a water distribution system in its entirety because they provide examples of a wide range of important system characteristics (Gilbert, 2012).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

Dukem town is located 37 km south-east of Addis Ababa along the Adama-Dire Dawa-Djibouti transport axis. Geographically, the study area is located at latitudes 8° 45' 25" N and 8^0 50' 30" N and longitudes 38° 51' 55" E and 38° 56' 5" E, covering a total area of 35.96 km^2 (Figure 3.1). It is located at an average altitude of 2100 m above sea level. The town has four Kebeles and shares boundaries with Bishoftu in the east, Ada'a Woreda in the north, and Akaki Woreda in the south and west directions. According to the office data the total population estimation is about **141,622** and coverage of the clean drinking water reaches **65.7%**by the year 2020. Total number of people supplied with potable water reaches **121,160**. The town average annual temperature and precipitation is 15.6 °C and about 1500 mm respectively.

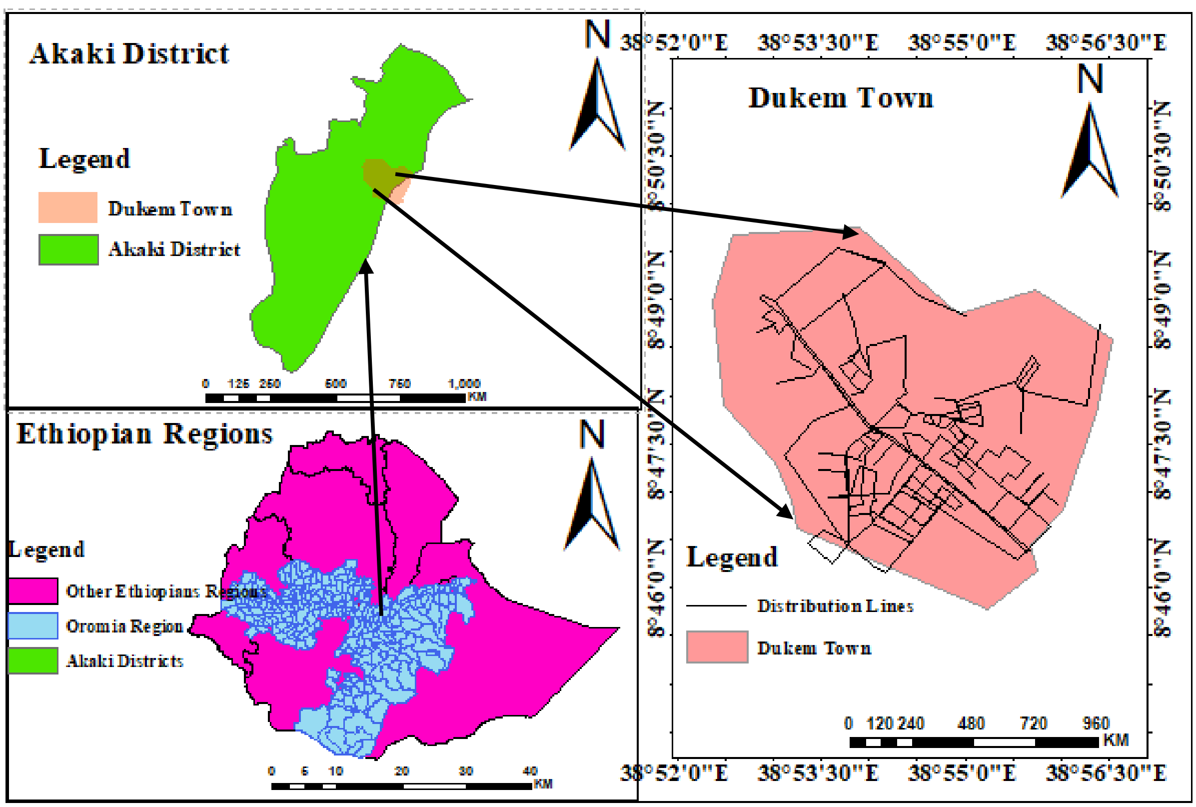


Figure 3-1: Description of the study area

The 2007 Ethiopian national census reported that the total population of the town was 25,071 (51% females and 49% males), excluding the population of rural kebeles that merged with the town administration. The population of the city is rapidly mounting from year to year at an average growth rate of more than 6.93% per annum. Population dynamics in a given settlement area are the result of fertility, mortality, and migration. Those demographic processes are complex phenomena involving social, cultural, economic, political, and psychological factors. In urban environments, migration (from rural to urban) has a predominant role in changing population characteristics and reflects the urbanisation rate. The data obtained from the population projection made by the Dukem Finance and Economic Cooperation Office and the council of the city approved has a total population of 121,240 and households of 21,595 by the year 2020. From the total population, 67,655 (49.12%) are males and 70,079 (50.88%) are females, including the rural kebeles currently incorporated under the administration of the city.

The city is a good place to live due to its conducive environment and its accessibility to Addis Ababa and the surrounding towns; many government and non-government employees who are working in the nearby cities and towns are living in the town. Hence, the population of the town is estimated to be higher than the stated figure because of investment expansion and the inflow of job seekers and employees at different factories

As population growth increases, the amount of solid waste generated from households, street sweeping, garages, big-installed institutions, cattle fattening enclosures, and other commercial establishments can degrade the image of the town and pose serious threats to human health. Solid waste management is one of the priorities of the town administration and the public to protect the environment.

3.2 Existing Water Supply System Components of the Town

3.2.1 Boreholes

The water supply system of Dukem Town is fed by groundwater. The groundwater has source from nine well field areas of deep boreholes as shown in Table 3-1. However, there are newly constructed wells that have not yet started operations. The town's wells are located in various directions, including the centre, behind, and outskirts of the town. Currently, the total production of clean water in the town is 61.8 l/s or 5,339.5 m^3/d.

Table 3-1: Existing Boreholes of the town with corresponding yield

S.no	Borehole Name	Depth (m)	Average yield (l/s)	Year constructed	X (m)	Y (m)	Elevation (m)
1	Michael	180	5	1994	488908	972402	1954
2	Condominium*	280	4	1998	490437	970993	1929
3	Melka dukem*	300	7.8	2000	489096	971374	1939
4	Qona magala 1	200	3	2004	489080	971387	1927
5	Qona magala 2	180	4	2006	489092	971342	1930
6	Big yatu	500	14	2005	491775	972100	1939
7	Mandalloo	260	10	2005	487197	973846	2033
8	Gogecha	200	8	2005	487733	972424	1938
9	Tadecha	200	7	2005	491138	972085	1934
Total			**61.8**				

*Directly connected to households

(Source: Dukem Water Supply and Sewerage Enterprise, 2023)

3.2.2 Reservoirs

The utility has five storage tanks, which function by storing water and equalising flow to each service area. The municipality uses these storage tanks as a pressure zone boundary based on the topography to manage the distribution network (Table 3-2).

Table 3-2: Existing Reservoirs of the town

Storage tanks	**X(m)**	**Y(m)**	**Elevation (m)**	**Volume (m^3)**	**Diameter (m)**
Tadecha Storage(R-1)	490280	972700	2026	1500	15
Mandalo storage(R-2)	487201	974153	2052	300	3
Gimashe storage (R-3)	490879	974263	2110	250	10
Bakacho storage (R-4)	488932	973708	1982	100	2
Gogecha storage(R-5)	490576	973568	2040	100	3

(Source: Dukem Water Supply and Sewerage Enterprise, 2023)

3.2.3 Distribution Pipes

Pipes are essential elements of distribution systems which link pumps, reservoirs, junctions (nodes), tanks and valves. The materials, types and dimensions of pipes of the town are given in Table 3-3 and the corresponding roughness coefficient of the pipe materials is given in Table3-4.

Table 3-3: Pipe Materials, Length and Diameters used for analyses

Material	Internal diameter (mm)	Length (km)	Remarks
HDPE Pipe	100	4	-
	90	14.5	New
	63	43.33	
	40,65	9,1.5	New
DCI Pipe	200	9.5	
	150	3	
	150 Steel pipe	0.4	New
	100	0.300	
UPVC	200	4	
	150	5	
GS pipe	GS PIPE 100	2	
	GS PIPE 76	6	
	GS PIPE 65	3	New
	GS PIPE 50	12	
	GS PIPE 40	4	

(Source: Dukem Water Supply and Sewerage Enterprise, 2023)

Table 3-4: Roughness coefficient (C) for different pipe materials

Types of pipes	C	
	Old pipes	New pipes
UPVC	100-120	150
GI	90-110	110
DCI	100-110	120
HDPE		150

Source (WaterGEMS, 2018)

3.3 Data Sources

Primary data was collected through first-hand observations and measuring nodal junction pressure for the calibration process from March and April 2023. From the field survey, missed x and y coordinates of nodes, tanks, and boreholes were collected. The data collected was transferred to WaterGEMS and simulated at Extended Period simulation to compare simulated result with observed data. Interviews were also carried out by using a calculated sample to answer the questions about per capita consumption of water, frequency of water supply, accessibility to water sources, and overall satisfaction with the existing water supply system. The overall customer’s response was analysed by using SPPS v29 and Ms. Excel 2013.

On the other hand, secondary data were collected from Dukem town's water supply and sewerage service. The data, such as population data, water demand, water consumption, water production, water loss, and borehole history data like depth, static water level, dynamic water level, discharge, pump head, and pumping hours, were obtained in the above office. Newly connected and existing pipe materials, junction, pump, and tank data were also collected from this office's annual reports and from censuses, information collected by government departments, organisational records, published journals, articles, and research papers.

3.4 Materials Used

The equipment and materials used for this study include a pressure gauge to measure pressure at a selected node, a GPS instrument to collect the required elevation data during the pressure reading to identify the exact location of the sample points conducted in the March 2023. To collect additional relevant data for calibration purposes, WaterGEMSv10.2.3, ArcMap v10.7.1, MS Excel 2013, and Global Mapper v20. Google Earth for pre- and post-processing was used to collect, organise and analyse the data. ArcMap v10.7.1 were used to display the overlapped shape file of the distribution network on the topographic map of the town and also for delineation of the study area. Global Mapper v20 was used to check the elevation of the junction, storage tank, water source, and coordinates of each node. Finally, IBM SPPS v21 and MS Excel were used to analyse the customer’s response to the existing water supply service.

In this research, the data generated was analysed through the above software, and descriptive statistical methods like percentages, graphs, and cross-tabulation were used in order to come up with the appropriate result.

3.5 Data Collection and Analyses Methods

3.5.1 Population forecasting

Considering the factors influencing the distribution, size, and growth rate of the population is necessary to forecast the population of a given area. Births, deaths, and migration are the primary determinants of population change in Ethiopia. The geometric increase and CSA were compared with percentage of error to project the future population due to both methods used for towns having vast scopes of expansion in population.

Table 3-5: Population Data from town Mayor Office

Year	Population number
2007	25,215
2015	71,160
2020	121,240

The selected methods were geometric increase and CSA methods since both are used to project populations with a vast scope of expansion. So that population projections for the current town were done by using two methods in order to identify which method has the lowest percentage of errors and be used for future estimation of the town's population. As a result, the appropriate method for forecasting Dukem Town's population was the geometric increase method described in Table 3-6.

Table 3-6:Comparison of Percentage Error Between Geometric and CSA Methods

Methods	Population Number at 2015	Actual population at 2020	Estimated population at 2020	Percentage of Error
Geometric increase method	51,160	121,240	75883	26.90
CSA Method	51,160	121,240	63431	27.95

The formula for geometric increase method is as follows

$$P_n=P_o(1+r)^n \quad \text{……………………………………………………..3.1}$$

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

Table 3-7: Population growth rate of Oromia Regional State

No of year	2020	2023	2025	2030	2035	2040	2045
Growth rate (%)	4.15	3.93	3.93	3.68	3.68	3.27	3.15

(Source: (OWWDSE, 2008)

The formula for Central Statistical Authority method is as follows

$$Pn=Poe^{rn} \quad \text{……………………………………………………..3.2}$$

Where; Pn=population of n decade or year, n =number of years r=growth rate

Table 3-8: Annual Growth Rate by CSA, Ethiopia

Year	1994	2008	2010	2015	2020	2025	2030	2035
Annual growth Rate (%)	-	4.4	4.5	4.3	4.1	3.9	3.8	3.6

Source (CSA, 2007)

3.5.2 Demand projection

The projection of water demand will depend on the estimated population for a defined year. According to the town water service office reports, there are three major modes of service for domestic water consumers: house connections (HC), yard connections (YC) shared, and public fountains (PF) or communal taps.

Table 3-9: Base per Capita Water Demand by Mode of Service

Mode of services	Per capital demand (l/d)
House connection (HC)	70
Yard connection (YC)	30
Public fountain users (PFU)	25

(Source: MoWR, 2014)

3.5.3 Importing Existing Data

The data for the existing water distribution network in Dukem town was generated in QGIS and Excel. Since the data from QGIS was lacking in visuals, Google Earth Pro was used to relocate the distribution network, and all data relocated was saved by kml and added to Global Mapper v2022 to generate X and Y coordinates of junctions and reservoirs. The coordinates for each point were generated in Global Mapper v20 and then exported to Microsoft Excel 2013. Then data exported to Excel was transferred to WaterGEMS 10.2.3 Software through the model builder toolbar to prepare setup for the network. The processed data in Water GEMS was assessed and upgraded, then transferred to integrated Water GEMS for ArcGIS for further mapping of the network.

The hydraulic model components imported were used to directly manage entities through their associated GIS geometry by searching and accessing their attributes and simulation results. The length of the pipe and elevations of junctions were automatically generated in the ArcGIS environment. The elevation of the junction is critical input data that is assigned to each node.

3.5.4 Assigning Base Demand

Base water demand was brought into the model by using WaterGEMS to load the building bar by the point data method with the option of unite line demand allocation. This method is used when the actual demand of each junction is unknown and the known total water demand of the town is recorded (WaterGEMS Manual, 2014). In the same case, Dukem Town Water Supply Service has recorded total water demand and not the demand of each junction rather than locating the position of junctions using QGIS software.

The demand scenario for peak hours was used for modelling. Demand was calculated for each supply node using the demand multiplier factors for a 24-hour flow period and the estimated base demand. As a result, the analysis took into account the peak flow period, the minimum flow condition, and the actual population supplied by the system

Table 3-10: Proposed Maximum Day Factor and Peak Hour Factor

Population size	Maximum day factor	Peak hour factor
<2000	1.3-1.5	2.6
2000-10,000		2.4-2.2
10,000-50,000		2.2-1.8
50,000-80,000	1.2	1.8-1.7
>80,000		>1.7

(Source: (OWWDSE, 2008)

3.5.5 Model calibration and Validation

By using a portable pressure gauge to take readings at 2-10% of all nodes, from low pressures to high pressures, calibration was carried out in accordance with USEPA water distribution system calibration guidelines. Pressure from eight sample nodes (J-7, J14, J-30, J-44, J-61, J-71, J-109, and J-113) was measured near the corresponding location using a pressure gauge to calibrate and validate the model. The sensitive parameters (pipe roughness and nodal demand) were then mildly adjusted until the simulated results resembled actual or field results.

Following the initial run, the model was calibrated using the Darwin calibrator by modifying delicate flow-related parameters such the pipe roughness coefficient and water demand until they were within the allowed range. In order to compare and calibrate the computed pressure data with the actual measured pressure data, the model data was finally evaluated.

The validation was done manually using the correlation coefficient equation (R^2) method using micro soft Excel sheet and scatter plot. The following formula was used

$$R^2 = \frac{\sum(X-X^{-})(Y-Y^{-})}{\sqrt{\sum(X-X^{-})^2} * \sqrt{\sum(Y-Y^{-})^2}} \quad \ldots\ldots 3.6$$

Where: R^2 = coefficient of determination, X and Y are the computed and observed pressure values, and X^{-} and $\bar{Y}$ are mean value of computed and observed pressure, respectively. According to Tomas et al. (2003), the calibration process was performed by adjusting sensitive parameters related to flow, like pipe roughness coefficient and water demand, until they were within the acceptable limit of 85% of field test measurements.

3.5.6 Hydraulic Performance Analysis of Distribution Network

Pressure and velocity were performed at steady state and extended period simulations. The values of maximum and minimum adopted pressure and velocity are taken from local design guidelines. The Ministry of Water Resources water supply design criteria (2006 E.C.) recommended the pressure range in the distribution system to be 10–70 m water head and a minimum velocity of 0.5 m/s and a maximum velocity of 2 m/s.

3.5.6.1 Steady State Simulation analysis

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

3.5.6.2 Extended period simulation (EPS) analysis

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

3.5.7 Modification of the distribution network

After hydraulic model analysis, water network modification work was done. Accordingly, pressure- reducing elements were applied to the junctions identified as having high pressure

3.5.8 Mapping of distribution network

Because they display a wide range of important system characteristics, system maps are often the most helpful materials for comprehending a water distribution system in its whole (Gilbert, 2012). obviously it is possible to estimate elevations with more accuracy the narrower the contour interval. A topographic map shows the heights of the ground surface using collections of lines known as contours. Finally, mapping of the network was done to visualise the actual location of each topology for future decisions about the town's water distribution system and all throughout the distribution network, the solution to the problem presented will be indicated by overlaying a topographic map on a map of the network model.

3.5.9 Creating Model in GIS and Water GEMS

In general, ArcGIS has been utilised in this research to build an integrated model for water distribution networks that allows for future quick intervention and the detection of future problems. Here, an integrated model for water distribution networks is created using ArcGIS, and the system has six basic steps. (Awad et al., 2017). The establishment of geodatabases to store network data, then the creation of digital vector maps. To ensure accurate network drawing, geometric network construction is then required, followed by the development of topology rules to assure precise spatial links. Relationship classes are then used to connect the data from external models to the GIS database. Last but not least, relationship classes were used to connect data from external models with the GIS database

3.5.10 Assessment of customer satisfaction for current water supply service

The goal of customers' perception to water supply service is to check overall efficiency of evaluated hydraulic performance of the town. The sample size was established based on sample size determination that was developed by Kothari (1990):

$$n=\frac{Z^2*p*q*N}{(N-1)*e^2+Z^2*p*q} \quad \ldots\ldots 3.7$$

Where n is the sample size, Z is the standard variant at a given confidence level of 1.96, p is the sample proportion if there is no previous study on the key parameters (P is taken as 50%), N is the number of households, q = 1–p, and e is the precision (significance level 5%).

3.6 Conceptual Framework of the Study

Following is a description of the methods used for each system component to run the model.

- All the existing water distribution systems and other related available data were collected.
- Missed data from the system was generated.
- All the existing and generated data was imported into the hydraulic model.
- The model was simulated for a single period and an extended period.
- The model has been examined using various situations, and after that, the water distribution system has been upgraded or improved.

Therefore, the overall process to achieve this research was described in Figure 3-3, which represents the beginning-to-end procedure of this study.

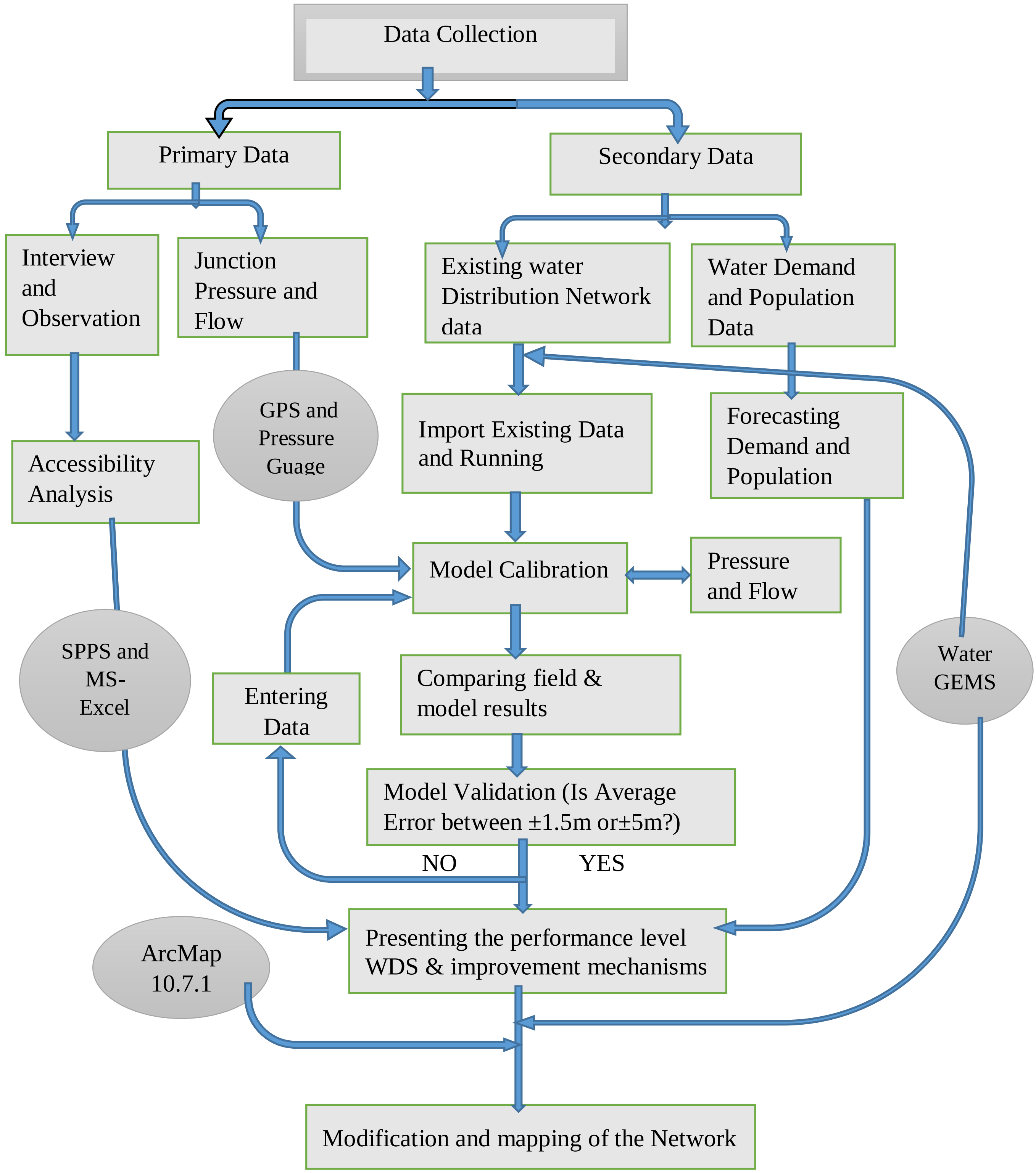


Figure 3-2:Conseptual Framework of the Study

4. RESULTS AND DISCUSSION

4.1 Analyses of Existing Water Supply Coverage and Water Demand

4.1.1 Population Projection for the Town

The population to be served has a significant impact on a town's water consumption. According to the municipal finance and economic development office, the last three years (2020) population of Dukem Town was 121,240, which was used as the base population for current and future estimation.

So that, the population was estimated by geometric method from 2023-2030 as summarized in table 4-1.

Table 4-1: Projected Population of the town (2020-2030)

No of year	2020	2023	2025	2030
Growth rate (%)	4.15	3.93	3.93	3.68
Projected Population	121240	136103	147011	176127

4.1.2 Projection of Present and Future Water Demand

The aim of water demand projection is to check whether the existing sources satisfy current and future demand or not. Therefore, this is an important point of the research and should be used as a baseline for the overall performance of the water supply system in the town.

a) Analyses of Existing Per capita Demand in the Town

The average daily demand for water in any town or city is the most important indicator of the accessibility and efficiency of the water supply system. So, the average water consumption given by the town utility for the 2020 year was 5330 m^3/d (1,948,370 m3/yr). Based on this data, the average water consumption required was projected at 7458.83 m3/d (2,722,473.95 m^3/yr) in 2023, and the population number was 136,103.

Average per capita Consumption = $\frac{2{,}722{,}473.95\frac{m3}{yr}*1000 l/m3}{136103*365}$ = 49.8 l/c/d

According to Ministry of Water Resource and Irrigation to GTP-II (2022) ; the per capita consumption standard set for category-one town like Dukem Town is 100 l/d. But the current water supply coverage is satisfying about 65% of the demand.

b) Population Percentage (%) Distributions by Mode of Service

There are three main service options for domestic water users, according to reports from the town water service office: private home connections (HC), shared garden connections (YC) and public fountains (PF) or communal taps. Different percentages of the population will benefit from each sort of service, and these percentages will change over time. Improvements in living standards, service levels, building standards, and the water supply service's ability for development are responsible for the difference. The prediction in Table 4-2 was based on the demand category (MoWR, 2006).

Table 4-2: Projected Population of % Distributions by Mode of Service

Connection type	**Year**			
	2020	2023	2025	2030
HC (%)	33.00	33.14	34.20	34.50
YC (%)	45.60	48.20	50.10	51.00
PF (%)	21.40	19.66	15.70	14.50

c) Per-Capital Domestic Demand by Mode of Service

Depending on the size and level of development of the town, the type of water delivery system used, and the socioeconomic circumstances of the town, different demand groups have different per-capita household water demands. Based on the fundamental human water needs for various activities in the demand category, the per capita water demand for an adequate supply level must be calculated. (MoWR, 2006). Therefore, the projected per capita demand by mode of service in the town was estimated as described in Table 4-3.

Table 4-3: Projected Per capita Demand by Mode of service (2020-2030)

Connection type	Year			
	2020	2023	2025	2030
HC(l/d)	70	71	75	80
YU(l/d)	30	31	35	40
PT (l/d)	25	26	30	3

d) Analysing for Water Demand Projection and Coverage

As described in Appendix B, the current total average water demand projected is 5953.37 m^3/d. But, according to the town water service office, the utility has nine boreholes with a total average daily production of 5338 m^3/d, which cannot meet the water demand after 2023. The result showed that the average water production of 2020 can cover demand by 89% of 2023.

Therefore, utilities should provide additional sources which produce 2044.37 m^3/d to satisfy demand by 2030 which projected to 7997.74 m^3/d.

4.1.3 Analysis of Yearly Water Production, Water Consumption and Water Loss

Water loss analyses is also the important factor which determined from difference of water production and water consumption. General data were analysed by using data that is recorded by Dukem water supply and sewerage service. Although the water utility office gave the data of water production, water consumption and water loss for the last ten years, they could not identify the main causes of water loss. However, the geographical conditions and reservoirs location as well as the performance of water distribution network show that the main reason for water loss in this town is most probably, due to the high pressure and velocity of water in some areas.

Non-revenue water is generally defined as the amount of water that is added to a water distribution system minus the amount that customers are charged. Physical (actual) losses, commercial (apparent) losses, and unbilled authorised usage make up Non-Revenue Water

Table 4-4:Water Production, Consumption and Loss(2014-2021)

Year	Water Produced	Water Consumed	Water loss	Water loss %
2014	362175	231792	130383	36.0
2015	450851	351664	99187	22.0
2016	579998	468580	111418	19.2
2017	560344	459089.8	101254.17	18.1
2018	631708	588337.3	43370.71	17.0
2019	727586	527354.3	200231.66	27.5
2020	1515676	1060973	454703	30.0
2021	1063868	700829	363039	30.0

Based on above Table 4-4, both water production and consumption increased from 2014 to 2020 but decreased in 2021. The annual water loss of the town decreased somewhat from 2014–2018 (36%–17%) and unexpectedly rose to 2021 (30%). So this shows that, as water production increases and consumption increases, water loss increases altogether. But the amount of water produced by 2021 will be much lower than in 2020, and this implies that there is a serious problem with the town's water supply system.

Therefore, the concerned authorities should thoroughly investigate the types of causes of water loss and why this loss is directly proportional to water production and consumption. The yearly water loss recorded by the utility office from 2014 to 2021 is described in Figure 4-1.

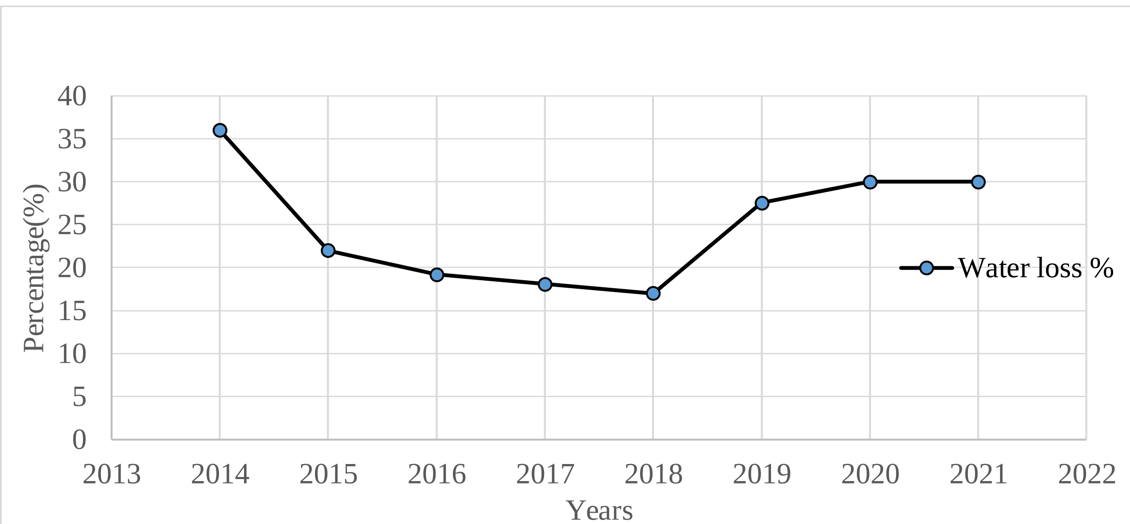


Figure 4-1:Yearly Water Loss Percentage (2014-2021)

$$\text{Average Water loss(\%)} = \frac{(\text{Total Water produced} - \text{Total Water billed}) * 100\%}{\text{Total water produced}}$$

$$= \left(\frac{5892206 - 4588619.4}{5892206}\right) * 100\%$$

$$= 39.5\%$$

The World Bank's permitted maximum of 25% is greatly exceeded by the water loss in Ethiopian cities. (Beker & Kansal, 2023). Therefore, the average water loss for Dukem's water supply system was above the allowable limit recommended which is 39.5%.

4.2 Hydraulic Performance Analysis of the Existing Water Distribution Network

Running the model under scenarios of peak hour demand and average daily demand for the current year has allowed for an investigation of the present system's hydraulic performance. As indicated in the Figure 4-3, the network has 133 junctions, 176 pipes, 7 reservoirs, and 3 pumps, which were used in the analysis of the town water distribution network. Currently, the average water production of the town is 5338 m3/d, or 61.78 l/s, as presented in Section 4.2.2. This water production is used to evaluate the performance of the existing distribution system based on the estimated water demand within the required water patterns

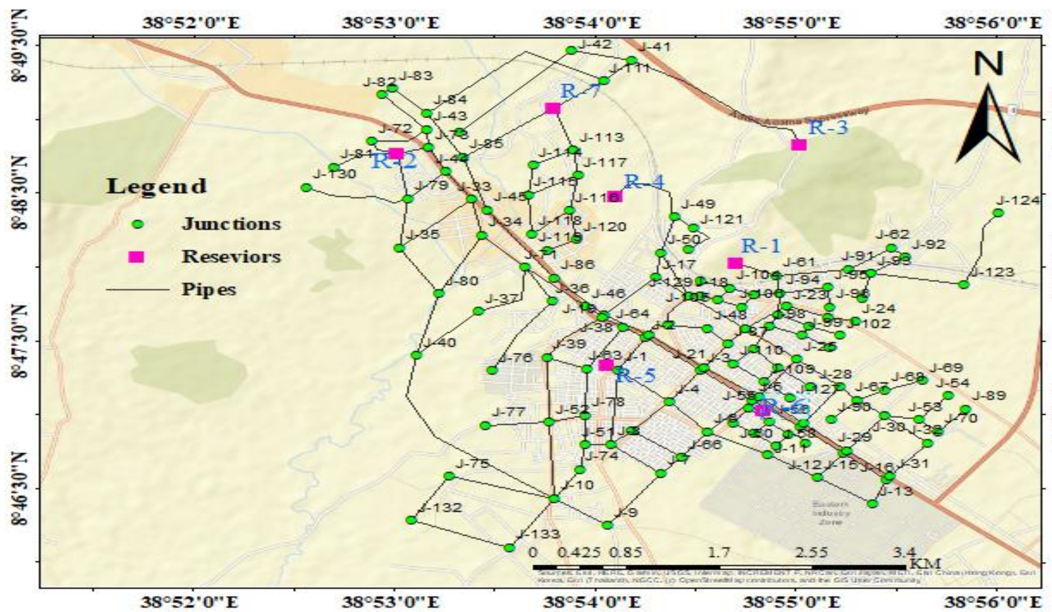


Figure 4-2:Water Distribution Network of the Town

4.2.1 Demand pattern of the town

The Water demand in a distribution system fluctuates over time. This variation in demand over time can be modelled using demand pattern.

Figure 4.4 illustrates a typical diurnal curve for a residential area. Consumption is generally low at night when most people are asleep, increases early in the morning as people get ready for the day, decreases in the middle of the day, and then increases once again in the early evening as people head back to their homes.

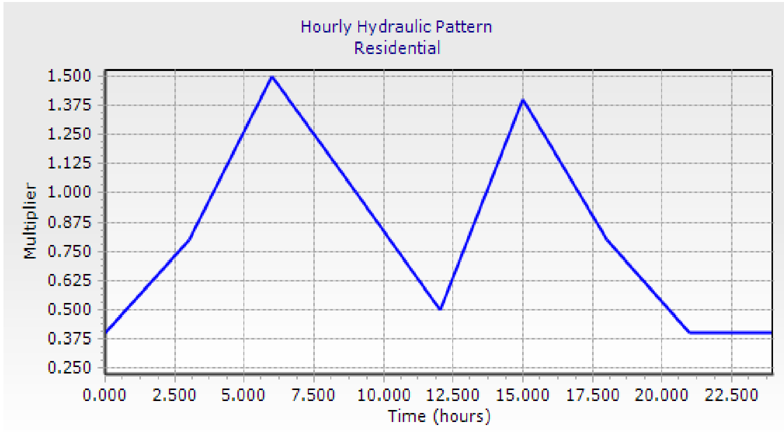


Figure 4-3:Variation of Water Demand During 24-Hours

(Source; Dukem Town Water Supply and Sewerage Service)

4.2.2 Model Calibration and Validation

In this research, the 8 numbers of nodes were selected based on the standards of USEPA water distribution system calibration guidelines (Los, 2005), which recommend that 2–10% of total nodes be calibrated from low pressures to high pressures by the use of a portable pressure gauge. Therefore, the selected junctions for calibrations are indicated in Figure 4.4.

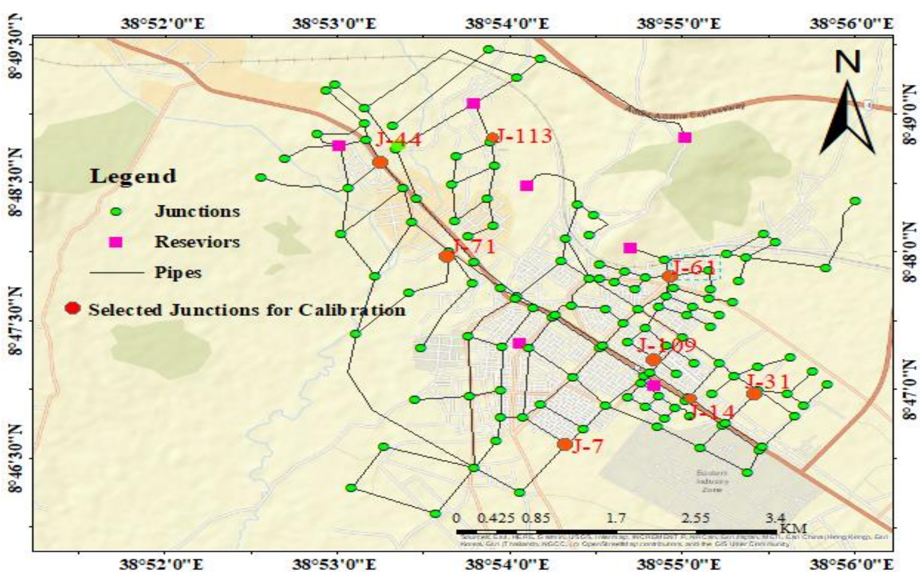


Figure 4-4:Junctions Selected For Calibrations

Field measurements of pressures at each junction for calibration were performed on home faucets near the junctions. The calibration of the model was performed at peak hour consumption in the morning (6.30–8.00 AM) and minimum hour consumption in the afternoon (2.30–4.00 PM).

The calculated values described under APPENDIX C are within an average error at peak demand of 2.36 m and minimum demand of 1.06 m of pressure simulated and observed values. As a result, the model's calibration is acceptable since it meets the calibration and validation standards for establishing pressure calibration and validation (average error 1.5 m to maximum 5m). According to AWWA (2012) the liner regression relationship of pressure, which showed a typical difference error of between ±1.5m or ±5m is considered an acceptable level of model performance. The observed values at minimum hour demand and peak hour demand were described in Figures 4-5 and 4–6, respectively.

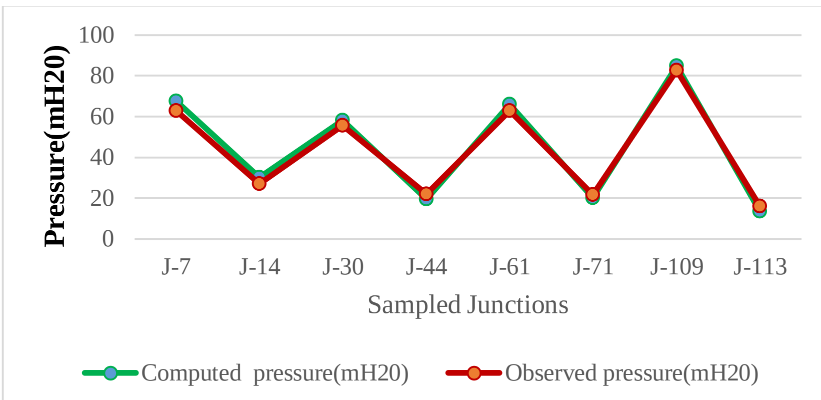


Figure 4-5:Computed and Observed Pressures at Peak Hour Consumptions

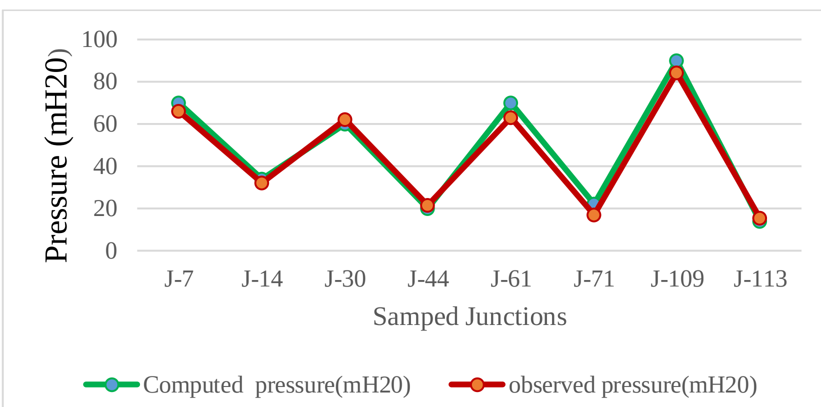


Figure 4-6:Computed and Observed Pressures at Minimum Consumptions Hour

The validation was done by the mentioned formula, and the statistical correlation between the measured and simulated pressure during calibration for peak hour demand and minimum demand recorded a R^2 of 0.98 and 0.97, respectively. According to AWWA (2012), typically, $R^2 > 50\%$ is considered acceptable for model performance, and the result indicated that there is a strong relationship between computed and observed values. Even though the detailed calculation of the regression coefficient appeared under APPENDIX-D, the summarised validations at minimum and peak hour consumptions are described in Figures 4-7 and 4-8, respectively.

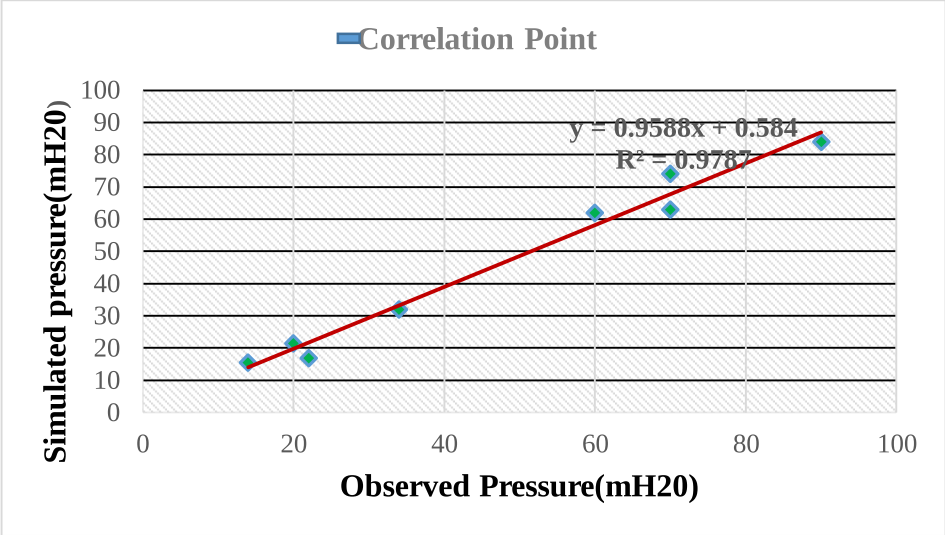


Figure 4-7:Validation at Minimum Hour Consumption

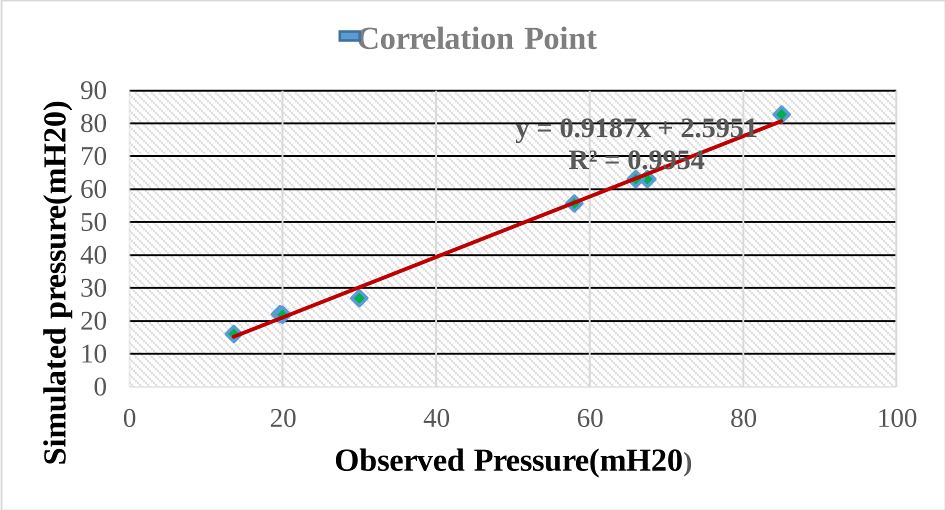


Figure 4-8:Validation at Peak Hour Consumptions

4.2.3 Pressure and Velocity Analysis at Steady State Simulation

4.2.3.1 Pressure Analysis at Peak and Average Water Demand

The distribution network model has been investigated in steady state for average daily demand and peak hour demand, which is the demand at each node that remains constant during a 24-hour period. Typically, main pressures should not be less than 10 mH20 in order to maintain the maximum supply idea in the system during peak use. In order to prevent leaks and pipe stress during low consumption hours, the maximum pressure in the mains is anticipated to not be more than 70 m. (MoWR, 2006). With regard to the current simulation, the result of pressure at peak and average consumption in Dukem Town is summarised in Table 4.5.

Table 4-5: Analysed Pressure Junctions in Average and Peak Hour Demand

Pressure(mH20)	No of Nodes at Average daily Demand	Percentage (%)	No of Nodes at Peak Hour Demand	Percentage
>71	60	45.11	33	20.81
61-70	8	6.02	2	1.50
15-60	43	32.33	8	20.02
10-15	16	12.03	17	12.78
<10	6	4.51	73	44.89
Total	133	100.00	133	100.00

As summarised in Table 4.5, the pressures at average daily demand show that 45.11% of the junctions have excessive pressure (>71 mH20), especially around J61, J85, and J94-J111, which have very high pressure due to reservoirs located at high elevations to the distribution area, as well as J125, J126, J217, J128, and A129, which have excess pressure due to lower elevations to the distribution line. In total, 50.38% of the junctions have pressure within the recommended limit, including acceptable in special conditions (10m to 70m), and 4.51% have undesirable pressure (<15 mH20). The analysed values of pressure junctions at average daily demand are described in Figures 4–9.

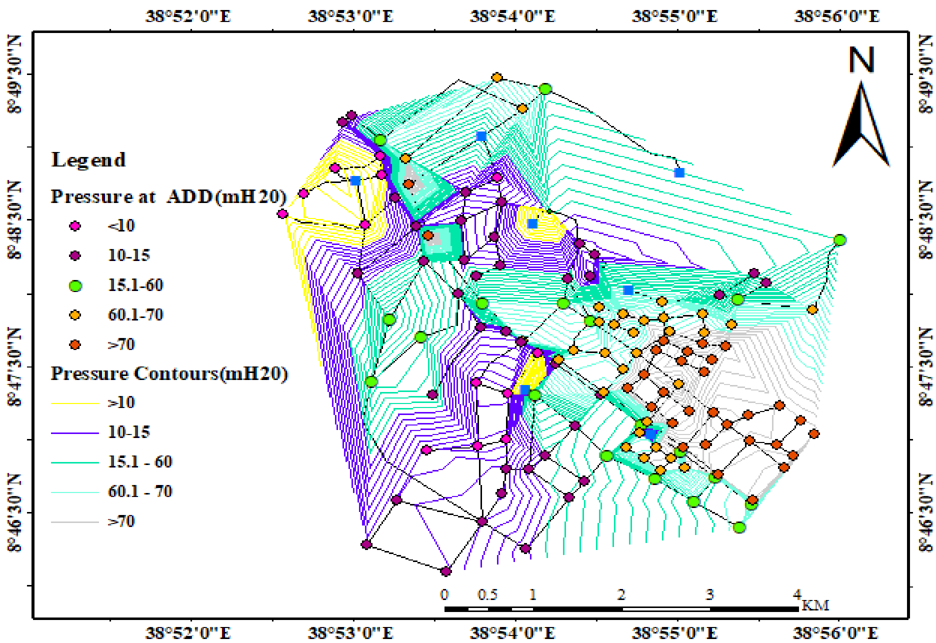


Figure 4-9:Map of Junctions Pressure Analysed at Average Daily Demand

The scenario of pressures at peak hour demand indicated as in Table 4.4, only 20.81% of the junctions have pressure (>71m H20), and 34.3% of junctions have pressure within the recommended limit (10m to 70m). But, most of the junctions in this scenario (44.89%) have less than the allowable limit (15 mH20). The detail map of pressure at peak hour demand is indicated on figure 4-10

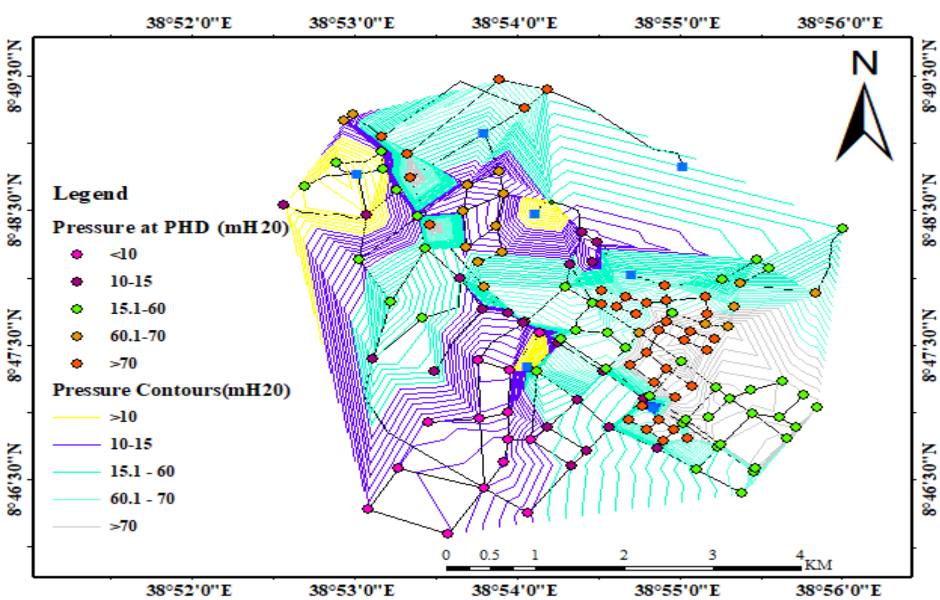


Figure 4-10:Map of Junctions Pressure at Peak Hour Demand

4.2.3.2 Velocity Analysis of Average and Peak Hour Demand

One of the key criteria in a hydraulic model to assess the performance of water supply, distribution, and transmission lines is the velocity of water flow in a pipe. According to MoWR (2006), the maximum and minimum velocity in the water distribution system were allowed as 0.6 m/s and 2 m/s, respectively. However, if the water flow rate in the pipe is too slow (less than 0.6 m/s), it will stagnate, causing silt to build up and bacterial development. And also, if velocity is too high (>2 m/s), it can damage the piping surface and, ultimately, lead to piping failure, which usually results from some combination of erosion and corrosion (Zabnieska-Góra & Dudkiewicz, 2018). Therefore, the analysed velocity for the water distribution system for Dukem Town was summarised in Table 4.6.

Table 4-6: Pipe Velocity Analysed in Average and Peak Hour Demand

Velocity (m/s)	No of Pipes at Average Daily Demand	Percentage	No of Pipes at Peak Hour Demand	Percentage
>2	0	0.00	15	8.57
0.5 -2	80	45.72	85	48.57
<0.5	95	54.29	75	42.86
Total	175	100.00	175	100.00

As summarized in Table 4.6 at Average Daily Demand, no pipes have above allowable limit of velocity, 45.71% acceptable limit of velocity(0.5-2.00m/s) and 54.29% pipes have under acceptable limit (<0.50 m/s) of velocity. This indicates that pipe velocity was very low at minimum hour consumption since there is high pressure in the system as indicated in Figure 4-11.

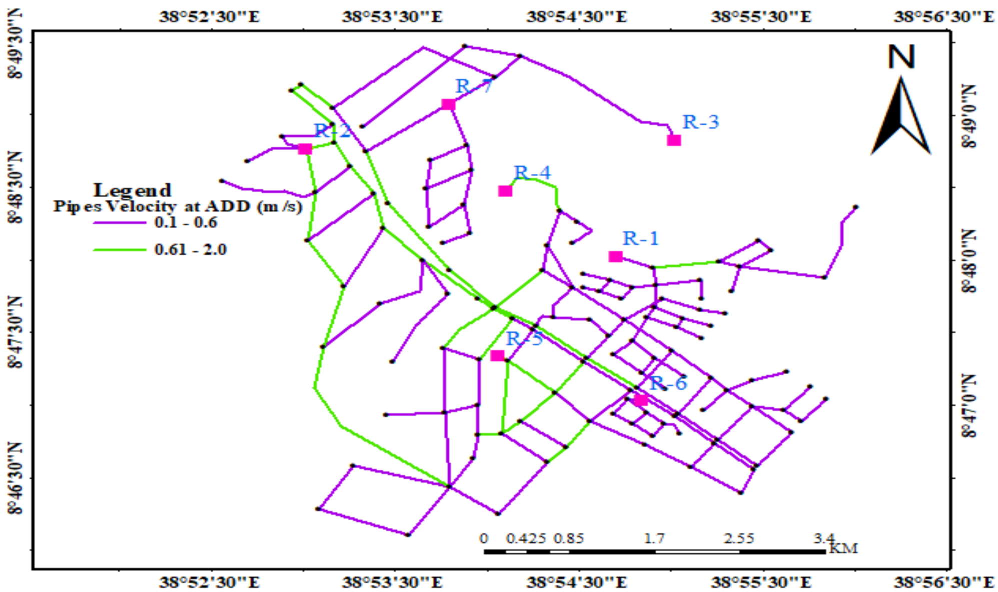


Figure 4-11:Map of Pipes Velocity Analysed at Average Daily Demand

But at Peak Hour Demand as described in Figure 4-12, 8.57 % of pipes have above allowable limit (>2m/s), most pipes of 48.57% have acceptable limit of velocity(0.5-2.00m/s) and 42.86 % pipes have under acceptable limit of velocity (<0.5 m/s). According to the continuity equation, decreasing the diameter of the pipe will increase the volume flow rate or velocity of the fluid that passes through it, and increasing the size of the water pipe will decrease the upper limit of velocity (a bigger pipe can carry the same flow at a slower rate).

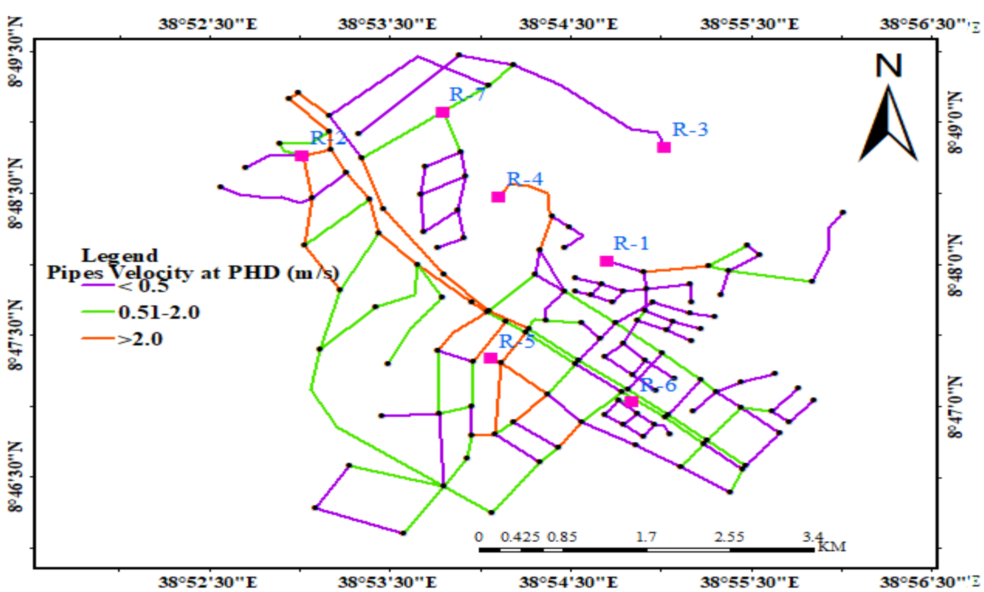


Figure 4-12:Map Of Pipes Velocity at Peak Hour Demand

4.2.4 Pressure and Velocity Analysis in Extended period simulation

4.2.4.1 Pressure Analysis

For every hour over a twenty-four-hour period, the model was simulated, as were pressure and flow velocity changes in the system in response to variable demand. Demand patterns can be used to simulate this fluctuation in demand over time.

Demand patterns are temporally variable multipliers added to a base demand, most typically the average daily demand (Bentley Systems Inc., 2011). Therefore, average daily demand was used for pressure and velocity analyses at the extended-period simulation of this research work.

The junctions' pressures are performed at an extended period simulation at average daily demand by considering times of highest and lowest water consumption in the town based on the demand pattern given by the utility office. As a result, the summarised pressures of junctions at extended-period simulations of average daily demand are explained in Table 4.7.

Table 4-7: Junctions Pressure Analysed at Extended Period Simulation

Pressure (mH20)	**No of Nodes**	**Percent**
>71	69	51.88
61-70	12	9.02
15-60	43	32.33
10-15	4	3.01
<10	5	3.76
Total	133	100.00

As summarized in Table 4-7, most of junctions have high pressures as demand fluctuates over 24-hours. The result indicated that 51.88% of junctions have above allowable limit of pressures, 45.36 junction have allowable limit of pressure and 3.76% of junction have below allowable limit of pressures at average daily demand. This suggests that the town's water distribution system had unusually high water pressure. Therefore, it is believed that the significant pressure in the town's distribution system is caused by the substantial water loss in the system each year.

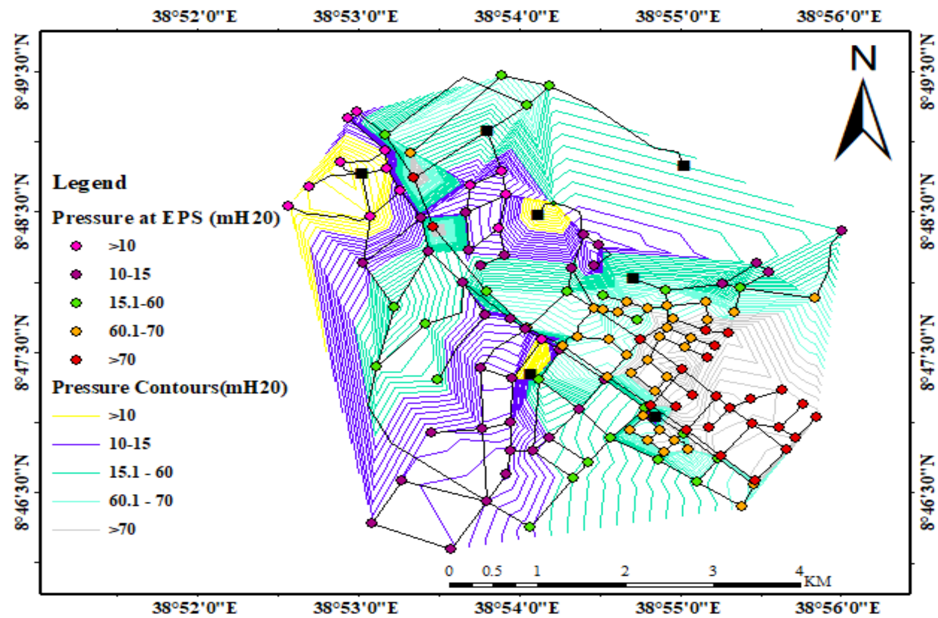


Figure 4-13: Map of Junctions Pressure at EPS

4.2.4.2 Velocity Analysis

The pipes velocity also analysed at extended period simulation through 24-hours with respect to average daily demand. As the result the summarized pipes velocity at this simulation was summarised in Table 4-8.

Table 4-8: Pipes Velocity Analysed at Extended Period Simulation

Velocity (m/s)	Number of Pipes	Percent
0.61-2	20	11.43
0.5-0.6	45	25.71
<0.5	110	62.85
Total	175	100.00

As indicated Table 4-8, 62.86 % of the distribution system has pipe flow velocity less than 0.5m/s, 37.14 pipes have velocity 0.6m/s to 2m/s which is optimum adopted velocity and there is no pipe with velocity greater than 2m/s in the distribution system. The values of each pipe velocity was indicated on Figure 4-14.

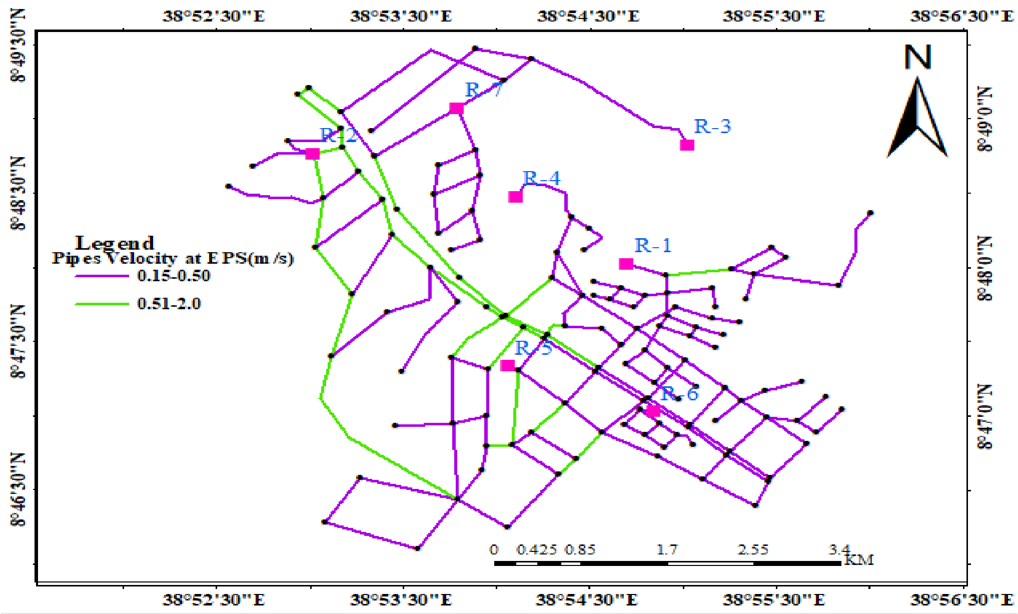


Figure 4-14:Map of Pipes Velocity at EPS

4.2.5 Main Problems Observed in the Existing Water Supply System

The overall water supply system of Dukem Town was analysed with the help of Bentley WaterGEMS by considering all hydraulic parameters of the network. Based on analysis performed in both steady-state and extended-period simulations, the following major problems were identified:

- As a whole, the main problem in the water distribution system of this town is that there is more than the permissible pressure in the system due to the reservoirs being located at an elevation. Especially during low consumption hours, the pressure level is very high and becomes far away from the maximum allowable limit (>70 mH20). So the high water loss in the system every year is understood to be the cause of this huge pressure in the town's distribution system due to the reservoirs being located at an elevation. Especially during low consumption hours, the pressure level is very high and becomes far away from the maximum allowable limit (>70 mH20). So the high water loss in the system every year is understood to be the cause of this huge pressure in the town's distribution system. However, during high consumption hours, the water pressure was occasionally below the required level.

- Another problem observed in the existing water supply system was that pipe velocity fluctuated with pressure. This means that when the pressure increases significantly, the pipe velocity is much below the minimum requirement of less than 0.5 m/s, to the extent of causing zero (no) flow conditions in some of the pipes. Therefore, to improve the observed problem, it should be worked on to adjust the pressure to the allowable limit of pressure in the water distribution network by applying additional elements to the system.

4.3 Modification of the Existing Water Distribution Network

The distribution system can be adjusted to minimise the observed high pressure and boost low pressure and velocity based on the results of the model simulation. As a result, a new pressure zone was created by applying pressure reducing valves (PRV) to decrease the high pressure observed in the system, and a pipe size arrangement was proposed to increase pipe velocities and pressure to overcome the overall problem observed in the system.

4.3.1 Reducing high pressure to an allowable limit

Pressures reducing valves are assigned to the system by considering high pressure observed as described in the Table 4-9.

Table 4-9: Pressure Reduced Valves Proposed for Improvement of Network

Label	Elevation (m)	Y (m)	X (m)	Valve Dia. (mm)	Pressure (mH_2O)	
					From	To
PRV-1	1,952.33	972,553.01	490,668.05	100.0	73	28
PRV-2	1,977.68	972,497.65	488,739.75	100.0	131	22
PRV-3	1,957.56	973,006.09	488,109.79	100.0	91	26
PRV-4	1,949.88	972,260.54	490,027.25	100.0	60	44
PRV-5	1,934.00	971,262.84	490,309.42	80.0	62	33

As the result, 5 PRV applied to representative pipes such as, P-119, P-127 P-88(2), P-102(2), P-85(2), P-5 (2) and P-79 for decrease high pressure observed in these areas.

As pressure of junctions has been adjusted, velocity of pipes also improved and lower pressure junctions become interval of minimum allowable limit pressure in water distribution networks. The arranged junctions pressure and velocity of pipe was indicated detail on Figure 4-15

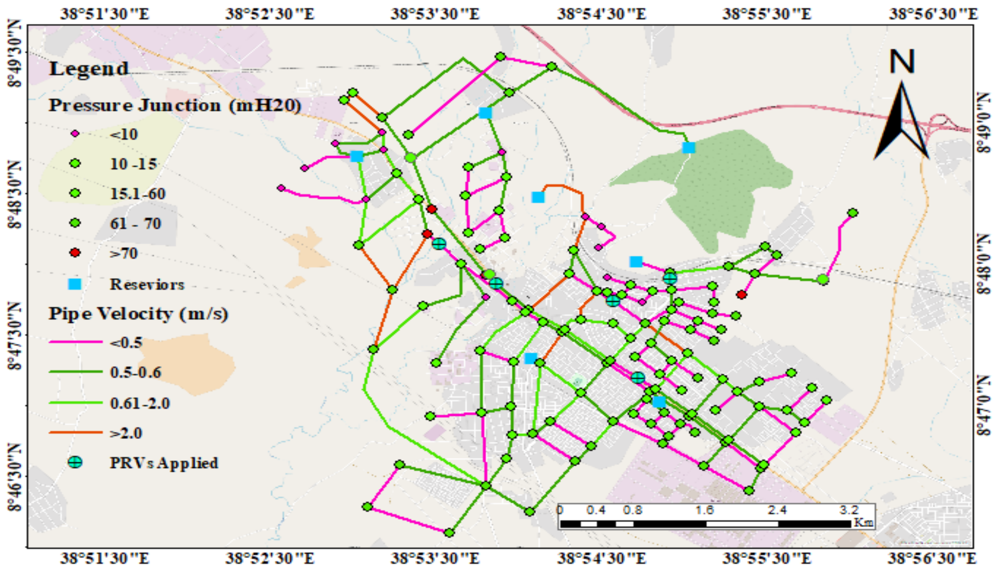


Figure 4-15:Map of Modified Pressure Junctions and Pipes Velocity of the System

4.3.2 Zoning of water supply system

Allocating nodes to their proper pressure zoning would give the chance for the nodes to receive better flow and pressure head. Pressure zones are set up to regulate pressure in locations where large grade changes will create too much pressure at the lower end of the system and not enough pressure in the higher ends. The boundaries of the six pressure zones were suggested for Dukem Town's water supply system based on PRV placement and consideration of dispersed water sources in the town, as illustrated in figure 4-16..

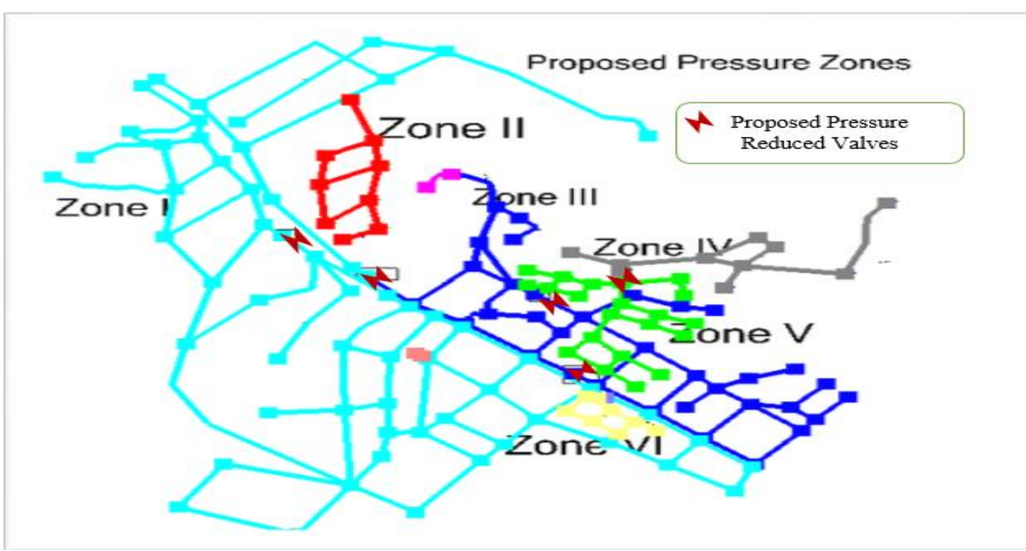


Figure 4-16:Map of Pressure Zones for the System

4.4 Customer Satisfaction to Existing Water Supply System

From 21,595 total households, 376 were randomly selected to investigate the level of customer satisfaction with the town's water supply services.

4.4.1 Sample Size Taken from Each Kebeles

According to the Dukem town mayor's administrative office, the highest density of population numbers is recorded in Melka Dukam Kebele, which is 29.79% because of its early establishment. Koticha Kebele has the lowest population numbers, which are 17.88%. As a result, the town is expanding through this area, and a large population is settling in this area.

4.4.2 Demographic Characteristics.

Table 4-10: Demographic Characteristics of the Town

Demographic Characteristics	Valid	Frequency	Percent(%)
1. Sex of Respondent	Male	137	36.1
	Female	239	63.9
2. Age of Respondent(Years)	21-30	90	23.7
	31-40	148	39.1
	41-50	98	25.9
	above 51	25	6.6
3. Educational Level	Illiterate	14	3.7
	Primary school	67	17.7
	Secondary school	105	27.7
	Diploma	101	26.6
	Degree and above	88	23.2
4. Income source	Business/peaty trade	93	24.70
	Farming	91	24.20
	Daily labour	100	26.66
	Government employee	90	23.94
	Others	2	.5
5. Family members of each households	2	25	6.6
	3	105	27.7
	4	167	44.1
	Above 5	77	20.3

As summarised on Table 4-10, the majority of respondents for existing water service were females, which is 63.9%, and 36.1% were males from the total household of 376. The majority age of respondents for this service was 31–40 years, which is 39.1%, and the next age group of respondents was 41–50 years, which is 25.9%. The majority of consumers at the consumer education level are finished secondary school and diploma graduates, which are 27.7% and 26.6%, respectively. The income sources of the respondents were mostly daily labour, business/trade, and farming, which are 26.6%, 24.73%, and 24.23%, respectively. The majority of family members, which is 44.1% and 27.7% of the respondents, are living with 4 and 3 people per household, respectively. Based on the total household response, the average family size is 3 people per household

4.4.3 Customer response on adequacy, pressure status and affordability

As can be seen from Figure 4-17, the number of households with access to adequate water is 59.50%, and the number of households without access to adequate water is 40.50%. Most of the respondents who said no were from Melka Dukem Kebele, and the main reason they gave was that the installed water pipes had no water and there was unavailability of water from the sources.

With regard to pressure in water, most respondents are satisfied with pressure in the pipe (66.00%), and 34.00% of the respondents are not satisfied with pressure because of the lower area with respect to reservoir location. Concerned with the affordability of drinking water, 63.60% of respondents are less satisfied, and 36.40% are satisfied with their economic status.

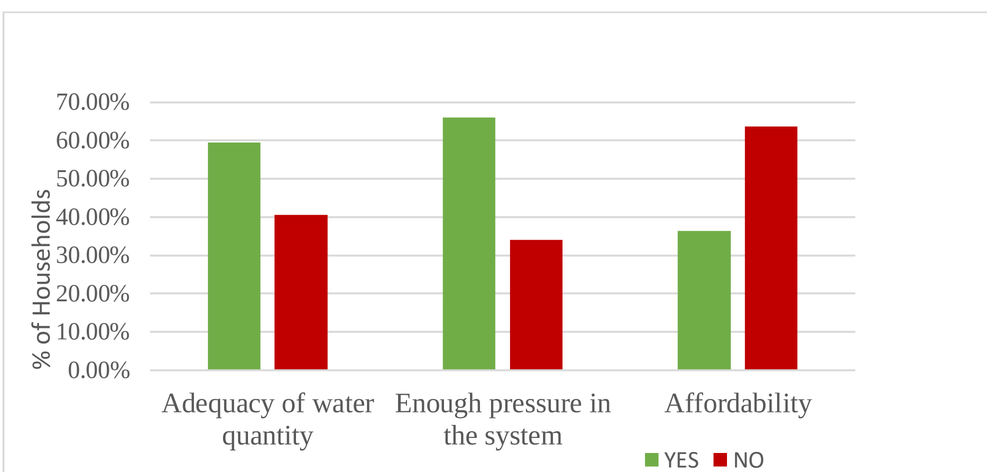


Figure 4-17:Customers Response to Adequacy, Pressure Status and Affordability to Water

4.4.4 Customer Satisfaction Along with General Water Supply Service

As summarised in Figure 4-18, most households use Yard Connection(YC) (35.6%), and 34.1% of households use Public Fountain(PF) next to Yard Connection. But the number of households that use House Connection (HC) is small, at 24.1%. This shows that most households are currently using communal pipes and need additional water supply to upgrade the system of piping inside their house.

With respect to the quantity of water collected from the source as indicated in Figure 4-19, the respondents replied that 34.6% of total households use 10–25 l/d, 32.8% of households get 26–35 l/d, 27.7% of households get 36–45 l/d, and 5% of households get above 46 l/d. This study shows that on average, most households (34.5%) get 22.5 l/d, 32.8% of households get 32 l/d, 27.7% get 42.5 l/d, and 5% of households get 54 l/d, respectively.

The average water consumption of each household will be 37.75 l/d. But, since the average family size is 3 people per household, the average per capita demand of the town is 12.58 l/c/d. This means that most households do not have access to an improved water supply while it is below the World Health Organization criteria of at least 20 l/p/d for a basic assessment of per capita demand (Kennedy, 2006).

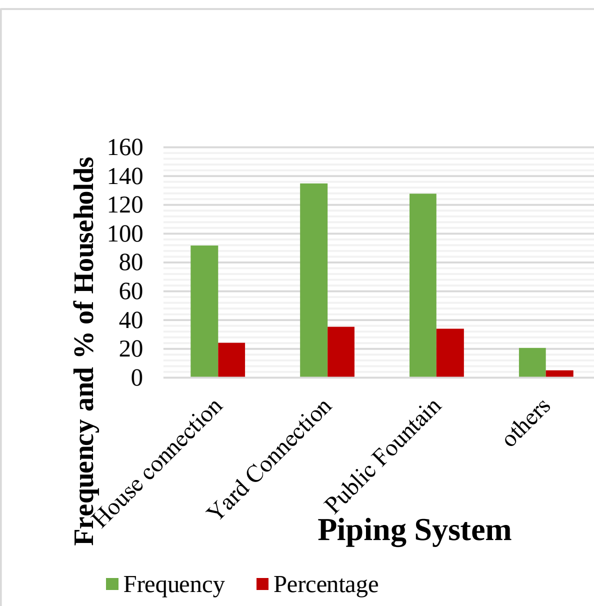


Figure 4-18 :Customers Response to Piping System

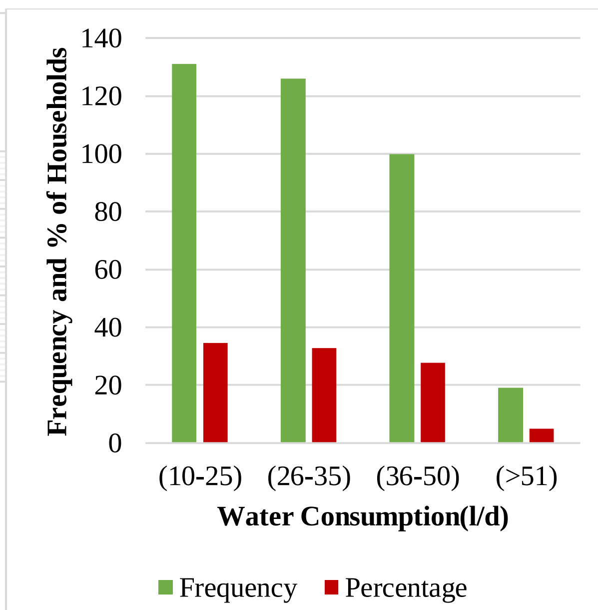
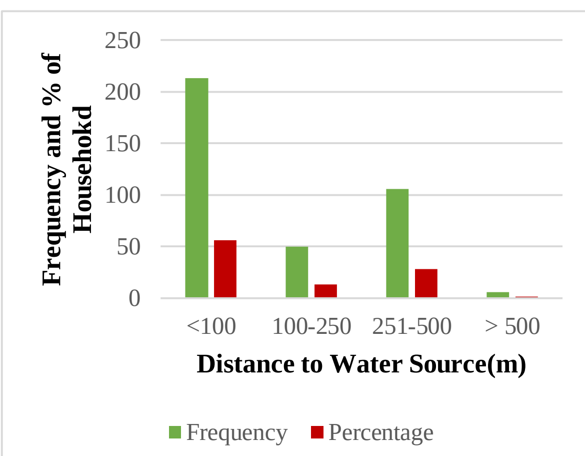


Figure 4-19:Customers Response to Daily Consumptions

Regarding the accessibility of customers to water sources shown in Figure 4-20, 56.2% of households, or half of the total households, have access to water at a distance of less than 100 m, and 13.2% of households have access to water sources at a distance of 100–250 m. But, 28% of household's access water 251-500m and 1.6% of households have access water >500m. For customer satisfaction within distance (distance travelled to water sources), 29.6% of customers were not satisfied when compared with the standards (maximum distance) set by Growth and Transformation Plan-II (Ministry of Water, 2022). According to the standard, urban population must have access to urban water supply with a GTP-II minimum service level of 100 l/c/day for category-1 towns and cities at a distance of 250 m.

According to 39.21% of the households, they have to walk more than 500m to get water due to drought (winter), water scarcity, and nearby community pipes that are sometimes closed. Regarding the duration of supply, 43.5% of households get water once a day, which stays for 1-3 hours, 41.7% get water once in two days, which stays for 3-5 hours, and the others get it twice a week, which stays for more than 5 hours.

Concerned with the water quality status as indicated in Figure 4-21, most respondents replied that they get very clean water from the sources. But some respondents replied that they get somewhat clean, especially in the winter seasons



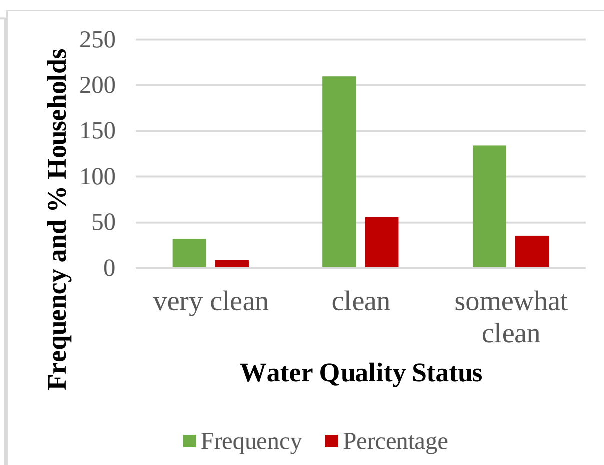


Figure 4-20:Customers Response to Accessibility Figure 4-21: Response to Water Quality

4.4.5 Overall Customers Satisfaction with the Existing Water Supply

Overall, 5.5% of respondents were very satisfied, 49.9% of the respondents were satisfied, and 33.2% of respondents were intermediate, while the smallest proportion of respondents, 11.4%

of the respondents, were dissatisfied. According to Practice et al. (2017) the overall satisfaction of the town with the existing water supply service should be at an average of 50% and above. As well as According to Mohammed et al. (2013), a majority of Dukem Town's households had access to improved sources of drinking water, and most of them had such access within 200 metres Therefore, this study shows that there is a level of satisfaction with the existing water supply service in Dukem Town that is greater than 50% as shown in figure 4-22.

Figure 4-22:Overall Customers Satisfaction to Existing System

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The hydraulic performance of the town's water distribution system and the degree of customer satisfaction were also evaluated. In the case of projected demand, the current total average water demand projected is 5953.37 m3/d, and the result showed that the average water production of 2020 can cover demand by 89% in 2023. Therefore, utilities should provide additional sources that produce 2044.37 m^3/d to satisfy demand by 2030, which is projected to be 7997.74 m^3/d.

The result of the analysis at steady state simulation at average daily demand and peak hour demand was analysed. As a result, 50.38% of nodes have pressure within the desired limit; the remaining 45.11 and 4.51% of the nodes have pressure above and below the desired limit of pressure, respectively, at average daily demand. At peak hour demand, only 34.3% of the nodes have pressure within the desired limit, but 20.81 and 44.89% of the nodes have pressure above and below the desired limit, respectively. The analysis of pipe velocity showed that only 45.71 and 48.57% of pipes have a desired limit of velocity (0.5-2 m/s) at average daily demand and peak hour demand, respectively. The extended-period simulation showed 45.36% of the nodes to have pressure within the desired limit, whereas 51.88 and 3.76% of nodes had pressure above and below the desired limit, respectively. Correspondingly, 62.86% of pipes had less than the allowable velocity limit, and 37.14% of them were within the desired limit. Finally, modifications for the existing water distribution system were proposed by creating pressure zones and providing pressure-reduced valves to reduce very high pressures.

Customers satisfaction levels with respect to water supply services such as connection level (piping system), per capita demand of water, accessibility of customers to water sources, affordability, and overall satisfaction with the system were analysed. Concerning piping systems, most households use private pipe inside the compound (35.6%), and 34.1% of households use communal pipe systems next to private pipe inside the compounds. With respect to the quantity of water collected from the source, the average water collection per household was 37.5 l/d. Concerned with the accessibility of customers to water sources, most households have access to water at a distance of less than 250 m, and only 28% and 1.6% of household’s access water at 251–500 m and >500 m, respectively. Concerned with the affordability of drinking water, most respondents are less satisfied with their economic status.

Generally, even though the interruption water supply town due to low hydraulic performance of water distribution network, the majority of the customers responded that they were satisfied with the existing water supply service by 55.4%.

5.2 Recommendation

Based on the analysed results, the following recommendations were made for Dukem Town's existing water supply system:

- Since the existing water production of the town is 5338 m^3/d and the average daily demand projected for 2023 is 5737.57 m^3/d, the existing water production will not meet the required demand after 2023, and the development of new sources should be provided to meet increasing water demand in the future.
- In order to minimise the high pressures and reduce leakage or water loss in the system, the proposed improvement methods need to be implemented
- In the future, it recommends that researchers conduct in-depth research on the types of water loss (Non-Revenue water and leakage).
- It is recommended that the water supply office need to gather customer’s perceptions on water distribution system from time to time to know their attitude and take necessary decisions.
- To improve customers’ overall satisfaction, the water utility office need to be focus on continuous water supply, water pressure, and scheduling of water service, and consideration need to be given to those who cannot afford it according to their economy.
- As a final recommendation, it is strongly advised that all relevant documentation, feasibility studies, borehole histories, and detailed design as built drawings of all current water supply system components for the source and reservoirs be well organised and made available in the water utility office for future reference.

REFERENCES

Abdelbaki, C., Benchaib, M. M., Benziada, S., Mahmoudi, H., & Goosen, M. (2017). Management of a water distribution network by coupling GIS and hydraulic modeling: a case study of Chetouane in Algeria. *Applied Water Science*, *7*(3), 1561–1567.

Adesogan, S. O., Sasanya, B. F., Ajagbe, W. O., Akinmuyiwa, A. T., & Ganiyu, A. A. (2019). Towards a Sustainable Water Future: Proceedings of OICWE2020 HYDRAULIC ANALYSIS OF WATER DISTRIBUTION NETWORKS AT THE UNIVERSITY OF IBADAN. *Ice Publishing*,

Adhikary, S. K., Chaki, T., & Rahman, M. (2013). Scenario-Based Simulation and Design of Proposed Water Supply Network in Lohagara Municipality, Narail, Bangladesh. *Journal of Engineering Science*, *04*(1), 35–46.

Ajeng, R., Roekmi, K., Chua, L. H. C., & Baskaran, K. (2018). Analysing piped water service provider performance based on consumer perceptions. *Utilities Policy*, *55*(May), 79–89.

Alves, Z., Muranho, J., Albuquerque, T., & Ferreira, A. (2014). Water distribution network's modeling and calibration. A case study based on scarce inventory data. *Procedia Engineering*, *70*, 31–40.

Ataoui, R., & Ermini, R. (2015). Overall performance of water distribution system: a methodology. *Journal of Applied Water Engineering and Research*, *3*(1), 19–28.

Awad, H., Yassin, A., & Ayad, A. (2017). Geographic Information Systems in Water Distribution Networks. *Conference Paper*, *June*, 14.

Beckwith, S. (2004). Advanced Water Engineering. *Bentley Institute Press*, *June 2014*, 2016–2020.

Beker, B. A., & Kansal, M. L. (2023). Complexities of the urban drinking water systems in Ethiopia and possible interventions for sustainability. In *Environment, Development and Sustainability* (Issue 0123456789). Springer Netherlands.

Bentley. (2014). WaterGEMS V8. *Bentley WaterGEMS V8i User's Guide*, *02*, 591–600.

Budiyono, B., Pamungkas, C., & Darundiati, Y. H. (2020). The Customer Satisfaction of the Drinking Water in the Coastal of Semarang and the Risk Management. *EDP Sciences.*, *05015*.

Coelho, S. T., & Alegre, H. (1998). Performance analysis in water distribution. In *Water Supply* (Vol. 16, Issues 1–2).

Darvini, G., Ruzza, V., & Salandin, P. (2020). Performance Assessment of Water Distribution Systems Subject to Leakage and Temporal Variability of Water Demand. *Journal of Water Resources Planning and Management*, *146*(1), 1–10.

Dukem Water Supply and Sanitation Service Enterprise(2022).Annual report 50-72

Gilbert, I. J. A. (2012). Practical Design of Water Distribution Systems. *PDHonline Course*, *182*.

Gunawan, I., Schultmann, F., & Zarghami, S. A. (2017). The four Rs performance indicators of water distribution networks: A review of research literature. *International Journal of Quality and Reliability Management*, *34*(5), 720–732.

Gupta, R., Baby, A., Arya, P. V., & Ormsbee, L. (2014). Upgrading reliability of water distribution networks recognizing valve locations. *Procedia Engineering*, *89*, 370–377.

Hajibabaei, M., Nazif, S., & Sitzenfrei, R. (2019). Improving the performance of water distribution networks based on the value index in the system dynamics framework. *Water (Switzerland)*, *11*(12).

Jaiswal, A. K., Thakur, P. K., & Kannaujiya, S. (2021). Geospatial modeling of water supply distribution system : A case study of Dehradun city , India. *H20pen Journal*, *4*(1), 393–412.

Kadgaonkar, S., Nimbalkar, P. T., & Kulkarni, D. R. (2015). Water Distribution Calibration Network ' s Modelling and. *International Journal of Science Engieneering and Technology*, *3*(6), 145–151.

Kefyalew, L. (2019). *Urban Water Supply System Performance Assessment: The cause of Alem gena town, Ethiopia*. *MSc Thesis*, 41–67.

Kuma, T., & Abate, B. (2021). Evaluation of Hydraulic Performance of Water Distribution System for Sustainable Management. *Water Resources Management*, *35*(15), 5259–5273.

Laucelli, D., & Meniconi, S. (2015). Water distribution network analysis accounting for different background leakage models. *Procedia Engineering*, *119*(1), 680–689. https://doi.org/10.1016/j.proeng.2015.08.921

Lejano, R. P. (2006). Optimizing the layout and design of branched pipeline water distribution systems. *Irrigation and Drainage Systems*, *20*(1), 125–137.

Mohammed, A., Zungu, L., & Hoque, M. (2013). Access to Safe Drinking Water and Availability of Environmental Sanitation Facilities among Dukem Town Households in Ethiopia

Momenzadeh, R., Azarm, R., & Aghamajidi, R. (2018). Demand Allocation Pattern for Consumption Points in Domestic Water Distribution Networks A Case Study of Ilam Campus. *Journal Of Biochemical Technology*, *2*, 67–72.

MOWIE. (2022). Second Growth and Transformation National Plan for the Water Supply and Sanitation Sub-Sector (2015/16 - 2019/20). *Report*, *June 2022*, 1–44.

MoWR. (2006). Urban water supply design criteria. *Water Resources Administration Urban Water Supply and Sanitation Department*, 1–60.

Ostfeld, A., Salomons, E. I., Alle, A. G., & F, M. H. H. (2013). Building Water Distribution Network Hydraulic Model by Using WaterGEMS. *Journal of Water Resources Planning and Management*, *136*(5), 1–10.

OWWDSE. (2008). Oromia Water Works Design and Supervision Enterprise. *Design Guideline For Water Supply Projects*.

Pindiga, A. M., & Sani, M. J. (2015). Mapping of Water Distribution Network using GIS Technology in Bauchi Metropolis , Nigeria. *Journal of Environment and Earth Science*, *5*(13), 88–95.

Sela Perelman, L., Allen, M., Preis, A., Iqbal, M., & Whittle, A. J. (2015). Automated sub-zoning of water distribution systems. *Environmental Modelling and Software*, *65*, 1–14.

Shah, B. (2021). Sustainable Landfill Site Selection for Construction and Demolition Waste Management Using GIS and AHP. In *Lecture Notes in Civil Engineering: Vol. 142 LNCE*.

Shamsaei, H., Othman Jaafar, I., & Basri, N. E. A. (2013). Effects velocity changes on the water quality in water distribution systems. *Research Journal of Applied Sciences, Engineering and Technology*, *5*(14), 3783–3790.

Shamsi, U. M. (2005). GIS Applications for Water, Wastewater, and Stormwater Systems. In *GIS Applications for Water, Wastewater, and Stormwater Systems*. https://doi.org/10.1201/9781420039252

Sharma, S. K., & Vairavamoorthy, K. (2009). Urban water demand management: Prospects and challenges for the developing countries. *Water and Environment Journal*, *23*(3), 210–218.

Shinde, P., Patil, P., & Hodage, R. (2018). Design and Analysis of Water Distribution Network Using Water GEMS. *International Research Journal of Engineering and Technology (IRJET)*, *07*(03), 545–552.

Świtnicka, K., Suchorab, P., & Kowalska, B. (2017). The optimisation of a water distribution system using Bentley WaterGEMS software. *ITM Web of Conferences*, *15*, 03009.

Tabesh, M., Delavar, M. R., & Delkhah, A. (2010). Use of geospatial information system based tool for renovation and rehabilitation of water distribution systems. *International Journal of Environmental Science and Technology*, *7*(1), 47–58.

Tambde, A., Chikane, S., & Dhage, S. (2022). GIS-Based Asset Mapping , Utilities Infrastructure Mapping , Consumer Mapping & Studying Feasibility Parameters for Water Supply System. *Research Square*.

Terlumun, U., Oloche Robert, E., Kelimeler, A., Analiz, K., & Parametreler, H. (2019). Evaluation of Municipal Water Distribution Network Using Watercard and Watergems. In *KUJES* (Vol. 5, Issue 2).

Van Zyl, J. E., & Clayton, C. R. I. (2007). The effect of pressure on leakage in water distribution systems. *Proceedings of the Institution of Civil Engineers: Water Management*, *160*(2), 109–114.

Vicente, D. J., Garrote, L., Sánchez, R., & Santillán, D. (2016). Pressure Management in Water Distribution Systems: Current Status, Proposals, and Future Trends. *Journal of Water Resources Planning and Management*, *142*(2), 1–13.

Walski M., T., V. Chase, D., A. Savic, D., Grayman, W., Beckwith, S., & Koelle, E. (2013). Advanced Water Distribution Modeling and Management. *Bentley Institute Press*, *January*, 750–800.

Watergems, B. (2014). *WATER REUSE AND ENVIRONMENTAL CONSERVATION PROJECT WaterGEMS Training Manual*. *04*.

WHO. (2021). Progress on household drinking water, sanitation, and hygiene 2000–2020: five years into the SDGs

Zhan, X., Meng, F., Liu, S., & Fu, G. (2020). Comparing Performance Indicators for Assessing and Building Resilient Water Distribution Systems. *Journal of Water Resources Planning and Management*, *146*(12), 1–8.

Zimoch, I., & Bartkiewicz, E. (2018). Process of hydraulic models calibration. *E3S Web of Conferences*, *59*, 1–5.

APPENDICES

APPENDIX A: General data for Dukem water supply assets

No	Description	Unit	Quantity (size) with unit and items	
1	Boreholes	No	Total=13	9 on functional 4 not functional
2	Valves	No	112-from50mm to 200mm in size	
3	Transmission net work	km	8.5	
4	Distribution line	km	91.89	
5	Metered connections	No	13855	
6	Pump sub type	No	Submersible pump	
7	Generator	No	02	
8	Public water point	No	Total =11	9 on functional 2 not functional
10	Reservoirs: Capacity	m3	1500,300,250,150	
11	Supply pipe	km	100.39	
13	Total production of clean water	m3/d	5338	
14	Coverage of water	%	70.7	

(Source: Dukem Water Supply and Sewerage Enterprise ,2023)

APPENDIX B: Overall summary of Water Demand Analyses (2020-2030)

Summary of Water Demand Analysis

Population Percentage (%) Distributions by Mode of Service				
Connection type	Year			
	2020	2023	2025	2030
HC(%)	33.00	33.14	34.20	34.50
YC(%)	45.60	48.20	50.10	51.00
PF(%)	21.40	19.66	15.70	14.50
Distribution of population by service mode				
Year	2020	2023	2025	2030
Population projected	121240	136103	147011	176127
HC	40009	45105	50278	60764
YC	25945	26758	23081	25538
PF	55285	65602	73653	89825
Percapita Demand by mode of service				
Year	2020	2023	2025	2030
HC(l/d)	70	71	75	80
YU(l/d)	30	31	35	40
PT (l/d)	25	26	30	3
Demand Service By Standard				
Year	2020	2023	2025	2030
HC(m3/day)	2800.64	3202.43	3770.84	4861.10
YU(m3/day)	778.36	829.50	807.83	1021.54
PT (m3/day)	1382.14	1705.65	2209.58	269.47
Average domestic water demand(m3/d)	**4961.14**	**5737.57**	**6788.24**	**6152.11**
Commercial & institutional demand (m3/d)(10%)		573.75	678.82	615.21
Unaccounted water demand(m3/d)(20%)	992.23	1147.51	1357.65	1230.42
Total average water demand Projected(m3/d)	**5953.37**	**7458.83**	**7824.71**	**7997.74**
Maximum hour factor	1.2	1.2	1.2	1.2
Maximum daily Demand(m3/d)	**7144.04**	**8950.60**	**10589.65**	**9597.29**
Peak hour factor	1.6	1.6	1.6	1.6
Peak hour Demand(m3/d)	**9525.39**	**11934.13**	**14119.53**	**12796.39**

APPENDIX C: Sample Nodes Selected for Calibration and Validation

a) Sample nodes and corresponding field test site location

Software simulation				**Field Measurement**			Head loss Between points(m)
Junction ID	X(m)	Y(m)	Elevation (m)	X(m)	Y(m)	Elevation (m)	
J-7	489612	970172	1919	489610	970170	1919.8	0.8
J-14	490879.4	970753	1923	490881	970755	1922.2	0.8
J-30	491648	970882	1916	491651	970880	1917.5	-1.5
J-44	487646	973937	2007	487644	973939	2007.9	-0.9
J-61	490663	972640	1956	490662	972645	1957.4	-1.4
J-71	488355.78	972741	1953	488353	972742	1952.6	1.6
J-109	490554.41	971311	1931	490556	971315	1930.8	0.8
J-113	488802.2	974203	1985	488804	974208	1986.8	-1.8

b) Simulated and Observed pressure run at first time

No of sample	Junction ID	Measurement Time	Computed Pressure (mH20)	Measured Pressure (mH20)	Error (m)
1	J-7	At minimum consumption hour (2.30 -4.00 PM)	70	66	4
2	J-14		34	32	2
3	J-30		60	62	-2
4	J-44		20	21.5	-1.6
5	J-61		70	63	7
6	J-71		22	17	5
7	J-109		90	84	6
8	J-113		14	15.5	-1.5
Average Error					**2.36**
1	J-7	At Peak Hour Consumption (6.00 -8.30 AM)	63	59	4.5
2	J-14		27	24	3
3	J-30		58	55.7	2.3
4	J-44		19.6	22	-2.4
5	J-61		66	63	3
6	J-71		17	18.8	-1.8
7	J-109		80	77.7	2.3
8	J-113		12.6	14	-2.4
				Average Error	**1.06**

APPENDIX D: Model Validation Using Regression Method

A) Model Validation using Regression During Minimum Hour Consumption

$$R^2 = \frac{\sum(X-X^-)(Y-Y^-)}{\sqrt{\sum(X-X^-)^2} * \sqrt{\sum(Y-Y^-)^2}} = 0.98$$

Junctions	Computed Pressure	Observed Pressure	Y-X	Y-Y¯	X-X¯	, (Y-Y¯)^2	(X-X¯)^2	(X-X¯) * (Y-Y¯)	(X-X¯)^2 * (Y-Y¯)^2
J-7	70	74	4	27.875	22.5	777.016	506.25	627.1875	393364.1602
J-14	34	32	-2	-14.125	-13.5	199.516	182.25	190.6875	36361.72266
J-30	60	62	2	15.875	12.5	252.016	156.25	198.4375	39377.44141
J-44	20	21.5	1.5	-24.625	-27.5	606.391	756.25	677.1875	458582.9102
J-61	70	63	-7	16.875	22.5	284.766	506.25	379.6875	144162.5977
J-71	22	17	-5	-29.125	-25.5	848.266	650.25	742.6875	551584.7227
J-109	90	84	-6	37.875	42.5	1434.52	1806.25	1609.6875	2591093.848
J-113	14	15.5	1.5	-30.625	-33.5	937.891	1122.25	1025.9375	1052547.754
Total	**380**	**369**	**-11**	**-12**	**-17**	**5340.38**	**5686**	**5451.5**	**5267075.156**
Mean	47.5	46.125							
					R^2= 0.98				

B) Model Validation using Regression During Peak Hour Consumption

$$R^2 = \frac{\sum(X-X^-)(Y-Y^-)}{\sqrt{\sum(X-X^-)^2} * \sqrt{\sum(Y-Y^-)^2}} = 0.99$$

Junctions	Computed Pressure	Observed Pressure	Y-X	Y-Y¯	X-X¯	, (Y-Y¯)^2	(X-X¯)^2	(X-X¯) * (Y-Y¯)	(X-X¯)^2 * (Y-Y¯)^2
J-7	67.5	63	-4.5	19.1	22.5375	364.81	507.939	430.46625	185301.1924
J-14	30	27	-3	-16.9	-14.963	285.61	223.876	252.86625	63941.34039
J-30	58	55.7	-2.3	11.8	13.0375	139.24	169.976	153.8425	23667.51481
J-44	19.6	22	2.4	-21.9	-25.363	479.61	643.256	555.43875	308512.205
J-61	66	63	-3	19.1	21.0375	364.81	442.576	401.81625	161456.2988
J-71	20	21.8	1.8	-22.1	-24.963	488.41	623.126	551.67125	304341.1681
J-109	85	82.7	-2.3	38.8	40.0375	1505.44	1603	1553.455	2413222.437
J-113	13.6	16	2.4	-27.9	-31.363	778.41	983.606	875.01375	765649.0627
Total	**359.7**	**351.2**	**-8.5**	**-12**	**-17**	**4406.34**	**5197.36**	**4774.57**	**4226091.219**
Mean	44.9625	43.9							
					R^2= 0.99				

APPENDIX E: Base Demand Assigned to Each Nodes

Label	Elevation (m)	X (m)	Y (m)	Base Demand (L/s)	Patterns
J-1	1,929.00	489,216.26	971,456.84	0.29	Commercial
J-2	1,950.00	489,465.72	971,856.87	0.19	Residential
J-3	1,938.00	489,973.92	971,452.51	0.24	Residential
J-4	1,932.00	489,677.00	971,061.00	0.29	Residential
J-5	1,930.00	490,439.14	971,081.77	0.23	Residential
J-6	1,926.00	490,035.00	970,692.00	0.29	Residential
J-7	1,920.00	489,612.00	970,172.00	0.23	Residential
J-8	1,924.00	489,150.06	970,530.63	0.28	Residential
J-9	1,918.00	489,117.00	969,520.00	0.19	Residential
J-10	1,921.00	488,627.00	969,857.00	0.84	Residential
J-11	1,919.00	490,585.00	970,399.00	0.16	Residential
J-12	1,920.00	491,030.00	970,112.00	0.21	Residential
J-13	1,914.00	491,539.00	969,787.00	0.13	Residential
J-14	1,927.00	490,879.40	970,752.96	0.15	Commercial
J-15	1,925.00	491,269.49	970,415.39	0.19	Commercial
J-16	1,917.00	491,668.22	970,087.70	0.12	Commercial
J-17	1,961.00	489,552.00	972,614.00	0.19	Commercial
J-18	1,956.00	489,854.00	972,388.00	0.28	Residential
J-19	1,954.00	489,093.24	972,143.94	0.24	Residential
J-20	1,949.00	489,495.00	971,900.00	0.19	Residential
J-21	1,939.00	489,998.48	971,494.20	0.22	Residential
J-22	1,937.00	490,381.00	971,978.00	0.27	Residential
J-23	1,939.00	490,759.79	972,252.10	0.12	Residential
J-24	1,927.00	491,386.10	972,066.10	0.04	Residential
J-25	1,929.00	490,850.00	971,590.00	0.24	Residential
J-26	1,931.00	490,493.52	971,121.64	0.24	Residential
J-27	1,923.00	490,908.25	970,794.83	0.22	Commercial
J-28	1,922.00	491,246.00	971,245.00	0.18	Residential
J-29	1,920.00	491,301.00	970,457.00	0.22	Residential
J-30	1,916.00	491,648.00	970,882.43	0.23	Residential
J-31	1,913.00	491,693.45	970,132.08	0.14	Residential
J-32	1,912.00	492,046.00	970,547.00	0.15	Residential
J-33	1,996.00	487,876.00	973,588.00	0.24	Residential
J-34	1,965.00	487,972.00	973,142.00	0.25	Residential
J-35	1,988.00	487,221.00	972,987.00	0.3	Residential
J-36	1,957.00	488,620.29	972,314.02	0.21	Residential

Label	Elevation (m)	X (m)	Y (m)	Base Demand (L/s)	Patterns
J-37	1,943.00	487,935.00	972,193.00	0.22	Commercial
J-38	1,953.00	489,065.86	972,116.06	0.16	Residential
J-39	1,940.00	488,565.00	971,614.00	0.26	Residential
J-40	1,935.00	487,375.90	971,636.69	0.55	Residential
J-41	2,050.00	489,345.00	975,322.00	0.66	Residential
J-42	2,045.00	488,792.05	975,450.65	0.28	Residential
J-43	2,031.00	487,474.18	974,459.51	0.19	Commercial
J-44	2,007.00	487,646.00	973,937.00	0.17	Commercial
J-45	1,995.00	488,023.00	973,456.00	0.24	Residential
J-46	1,952.00	488,909.00	972,256.00	0.13	Residential
J-47	1,950.00	489,668.00	972,019.00	0.15	Residential
J-48	1,944.00	490,030.19	971,980.70	0.09	Residential
J-49	1,989.00	489,731.37	973,369.39	0.26	Residential
J-50	1,978.00	489,602.52	972,923.00	0.19	Residential
J-51	1,927.00	488,909.00	970,520.00	0.13	Residential
J-52	1,931.00	488,581.00	970,810.00	0.37	Residential
J-53	1,913.00	491,955.00	970,837.00	0.13	Residential
J-54	1,913.00	492,234.00	971,134.00	0.06	Residential
J-55	1,929.00	490,410.37	970,982.68	0.09	Residential
J-56	1,926.00	490,598.00	970,805.00	0.09	Residential
J-57	1,923.00	490,768.00	970,660.00	0.09	Residential
J-58	1,921.00	490,651.00	970,506.00	0.06	Residential
J-59	1,924.00	490,459.00	970,662.00	0.09	Commercial
J-60	1,927.00	490,261.00	970,790.00	0.07	Residential
J-61	1,956.00	490,663.00	972,640.00	0.23	Residential
J-62	1,962.00	491,707.50	972,982.76	0.09	Commercial
J-63	1,940.00	488,925.00	971,477.00	0.22	Residential
J-64	1,953.00	489,254.52	971,988.43	0.15	Residential
J-65	1,926.00	489,344.00	970,697.00	0.18	Residential
J-66	1,922.00	489,790.00	970,370.00	0.17	Residential
J-67	1,920.00	491,397.45	971,082.72	0.16	Commercial
J-68	1,918.00	491,642.74	971,207.23	0.09	Residential
J-69	1,916.00	491,998.72	971,327.00	0.05	Residential
J-70	1,911.00	492,141.37	970,686.41	0.08	Commercial
J-71	1,953.00	488,355.78	972,741.33	0.36	Residential
J-72	2,050.00	486,960.48	974,314.82	0.16	Residential
J-73	2,033.00	487,488.19	974,229.73	0.16	Residential
J-74	1,926.00	488,858.53	970,215.23	0.1	Commercial

Label	Elevation (m)	X (m)	Y (m)	Base Demand (L/s)	Patterns
J-75	1,920.00	487,666.78	970,129.09	0.23	Residential
J-76	1,938.00	488,070.18	971,454.20	0.14	Residential
J-77	1,928.00	488,005.18	970,767.24	0.08	Commercial
J-78	1,932.00	488,906.21	970,892.48	0.18	Commercial
J-79	2,028.00	487,297.50	973,595.09	0.44	Residential
J-80	1,955.00	487,582.34	972,413.24	0.32	Residential
J-81	2,045.00	486,616.05	973,992.80	0.17	Residential
J-82	2,049.00	487,056.32	974,890.12	0.1	Residential
J-83	2,051.00	487,153.08	974,972.03	0.08	Residential
J-84	2,042.00	487,473.24	974,663.66	0.42	Residential
J-85	2,016.00	487,804.98	974,115.38	0.4	Residential
J-86	1,990.00	488,631.02	972,606.55	0.23	Residential
J-87	1,943.00	490,221.84	971,782.63	0.12	Residential
J-88	1,935.00	491,125.65	972,108.05	0.09	Residential
J-89	1,911.00	492,392.63	970,969.64	0.05	Commercial
J-90	1,918.00	491,155.27	970,838.30	0.05	Residential
J-91	1,963.00	491,312.64	972,720.16	0.19	Commercial
J-92	1,961.00	491,838.02	972,867.49	0.08	Residential
J-93	1,957.00	491,595.26	972,622.39	0.24	Residential
J-94	1,946.00	490,682.85	972,403.13	0.16	Residential
J-95	1,946.00	491,130.11	972,462.88	0.09	Commercial
J-96	1,940.00	491,145.52	972,247.36	0.03	Commercial
J-97	1,936.00	490,681.12	972,144.02	0.1	Residential
J-98	1,930.00	490,963.86	971,999.20	0.1	Residential
J-99	1,930.00	490,894.90	971,888.86	0.1	Residential
J-100	1,936.00	490,598.36	972,013.00	0.11	Residential
J-101	1,924.00	491,150.06	971,744.04	0.04	Residential
J-102	1,924.00	491,233.40	971,895.94	0.04	Residential
J-103	1,944.00	490,459.96	972,390.26	0.09	Residential
J-104	1,940.00	490,232.12	972,481.89	0.1	Residential
J-105	1,943.00	490,123.30	972,340.83	0.08	Residential
J-106	1,952.00	490,350.50	972,241.96	0.06	Residential
J-107	1,934.00	490,457.59	971,722.14	0.13	Residential
J-108	1,931.00	490,681.30	971,487.42	0.12	Residential
J-109	1,931.00	490,554.41	971,310.87	0.12	Residential
J-110	1,934.00	490,270.47	971,536.13	0.09	Residential
J-111	2,045.00	488,888.58	974,974.57	0.54	Residential
J-112	1,995.00	489,861.51	972,961.22	0.06	Residential

Label	Elevation (m)	X (m)	Y (m)	Base Demand (L/s)	Patterns
J-113	1,985.00	488,802.20	974,203.05	0.25	Residential
J-114	1,978.00	488,437.11	974,013.46	0.11	Residential
J-115	1,969.00	488,391.59	973,643.80	0.19	Residential
J-116	1,975.00	488,770.41	973,446.73	0.17	Residential
J-117	1,977.00	488,844.48	973,887.10	0.18	Residential
J-118	1,968.00	488,432.21	973,157.36	0.13	Residential
J-119	1,960.00	488,563.25	972,950.85	0.04	Residential
J-120	1,967.00	488,841.20	973,087.35	0.09	Residential
J-121	1,990.00	489,909.40	973,230.84	0.09	Residential
J-122	1,923.00	490,931.60	970,543.43	0.03	Commercial
J-123	1,938.00	492,365.92	972,523.10	0.25	Residential
J-124	1,951.00	492,682.04	973,418.58	0.13	Residential
J-125	2,035.00	487,769.13	974,430.18	0.2	Residential
J-126	1,924.00	490,968.28	971,257.73	0.05	Commercial
J-127	1,924.00	490,790.32	971,105.19	0.04	Residential
J-128	1,954.00	489,963.48	972,563.98	0.04	Commercial
J-129	1,946.00	489,959.27	972,383.42	0.02	Residential
J-130	2,025.00	486,367.29	973,736.96	0.13	Residential
J-131	1,940.00	491,450.27	972,345.45	0.04	Residential
J-132	1,920.00	487,321.66	969,580.52	0.22	Residential
J-133	1,920.00	488,224.68	969,241.06	0.23	Residential

APPENDIX F: Junctions Pressure Before and After Upgraded

Label	Elevation (m)	X (m)	Y (m)	Existing Pressure (mH_2O)	Pressure Improved (mH_2O)
J-1	1,929.00	489,216.26	971,456.84	65	58
J-2	1,950.00	489,465.72	971,856.87	43	34
J-3	1,938.00	489,973.92	971,452.51	55	46
J-4	1,932.00	489,677.00	971,061.00	57	51
J-5	1,930.00	490,439.14	971,081.77	63	54
J-6	1,926.00	490,035.00	970,692.00	63	57
J-7	1,920.00	489,612.00	970,172.00	61	61
J-8	1,924.00	489,150.06	970,530.63	57	57
J-9	1,918.00	489,117.00	969,520.00	60	61
J-10	1,921.00	488,627.00	969,857.00	54	58
J-11	1,919.00	490,585.00	970,399.00	68	64
J-12	1,920.00	491,030.00	970,112.00	75	63
J-13	1,914.00	491,539.00	969,787.00	79	69
J-14	1,927.00	490,879.40	970,752.96	69	56
J-15	1,925.00	491,269.49	970,415.39	74	58
J-16	1,917.00	491,668.22	970,087.70	79	66
J-17	1,961.00	489,552.00	972,614.00	72	49
J-18	1,956.00	489,854.00	972,388.00	77	54
J-19	1,954.00	489,093.24	972,143.94	89	46
J-20	1,949.00	489,495.00	971,900.00	88	50
J-21	1,939.00	489,998.48	971,494.20	94	57
J-22	1,937.00	490,381.00	971,978.00	96	57
J-23	1,939.00	490,759.79	972,252.10	94	55
J-24	1,927.00	491,386.10	972,066.10	112	67
J-25	1,929.00	490,850.00	971,590.00	100	43
J-26	1,931.00	490,493.52	971,121.64	98	36
J-27	1,923.00	490,908.25	970,794.83	104	44
J-28	1,922.00	491,246.00	971,245.00	105	45
J-29	1,920.00	491,301.00	970,457.00	110	47
J-30	1,916.00	491,648.00	970,882.43	109	50
J-31	1,913.00	491,693.45	970,132.08	112	53
J-32	1,912.00	492,046.00	970,547.00	113	54
J-33	1,996.00	487,876.00	973,588.00	40	54
J-34	1,965.00	487,972.00	973,142.00	55	84
J-35	1,988.00	487,221.00	972,987.00	41	57

Label	Elevation (m)	X (m)	Y (m)	Existing Pressure (mH_2O)	Pressure Improved (mH_2O)
J-36	1,957.00	488,620.29	972,314.02	46	26
J-37	1,943.00	487,935.00	972,193.00	62	41
J-38	1,953.00	489,065.86	972,116.06	43	31
J-39	1,940.00	488,565.00	971,614.00	40	40
J-40	1,935.00	487,375.90	971,636.69	65	58
J-41	2,050.00	489,345.00	975,322.00	59	60
J-42	2,045.00	488,792.05	975,450.65	72	65
J-43	2,031.00	487,474.18	974,459.51	20	22
J-44	2,007.00	487,646.00	973,937.00	30	44
J-45	1,995.00	488,023.00	973,456.00	110	74
J-46	1,952.00	488,909.00	972,256.00	46	32
J-47	1,950.00	489,668.00	972,019.00	84	50
J-48	1,944.00	490,030.19	971,980.70	89	53
J-49	1,989.00	489,731.37	973,369.39	45	26
J-50	1,978.00	489,602.52	972,923.00	55	32
J-51	1,927.00	488,909.00	970,520.00	50	53
J-52	1,931.00	488,581.00	970,810.00	45	48
J-53	1,913.00	491,955.00	970,837.00	110	52
J-54	1,913.00	492,234.00	971,134.00	110	52
J-55	1,929.00	490,410.37	970,982.68	78	53
J-56	1,926.00	490,598.00	970,805.00	81	56
J-57	1,923.00	490,768.00	970,660.00	83	59
J-58	1,921.00	490,651.00	970,506.00	85	61
J-59	1,924.00	490,459.00	970,662.00	83	58
J-60	1,927.00	490,261.00	970,790.00	80	55
J-61	1,956.00	490,663.00	972,640.00	70	70
J-62	1,962.00	491,707.50	972,982.76	49	58
J-63	1,940.00	488,925.00	971,477.00	40	40
J-64	1,953.00	489,254.52	971,988.43	25	31
J-65	1,926.00	489,344.00	970,697.00	57	56
J-66	1,922.00	489,790.00	970,370.00	61	60
J-67	1,920.00	491,397.45	971,082.72	105	47
J-68	1,918.00	491,642.74	971,207.23	107	48
J-69	1,916.00	491,998.72	971,327.00	109	50
J-70	1,911.00	492,141.37	970,686.41	111	54
J-71	1,953.00	488,355.78	972,741.33	53	31
J-72	2,050.00	486,960.48	974,314.82	1	12

Label	Elevation (m)	X (m)	Y (m)	Existing Pressure (mH_2O)	Pressure Improved (mH_2O)
J-73	2,033.00	487,488.19	974,229.73	14	19
J-74	1,926.00	488,858.53	970,215.23	50	53
J-75	1,920.00	487,666.78	970,129.09	52	58
J-76	1,938.00	488,070.18	971,454.20	60	45
J-77	1,928.00	488,005.18	970,767.24	47	51
J-78	1,932.00	488,906.21	970,892.48	45	48
J-79	2,028.00	487,297.50	973,595.09	9	22
J-80	1,955.00	487,582.34	972,413.24	72	74
J-81	2,045.00	486,616.05	973,992.80	7	17
J-82	2,049.00	487,056.32	974,890.12	28	31
J-83	2,051.00	487,153.08	974,972.03	33	35
J-84	2,042.00	487,473.24	974,663.66	66	67
J-85	2,016.00	487,804.98	974,115.38	101	93
J-86	1,990.00	488,631.02	972,606.55	74	118
J-87	1,943.00	490,221.84	971,782.63	90	52
J-88	1,935.00	491,125.65	972,108.05	103	59
J-89	1,911.00	492,392.63	970,969.64	111	54
J-90	1,918.00	491,155.27	970,838.30	107	49
J-91	1,963.00	491,312.64	972,720.16	49	58
J-92	1,961.00	491,838.02	972,867.49	52	59
J-93	1,957.00	491,595.26	972,622.39	68	63
J-94	1,946.00	490,682.85	972,403.13	80	34
J-95	1,946.00	491,130.11	972,462.88	80	34
J-96	1,940.00	491,145.52	972,247.36	86	40
J-97	1,936.00	490,681.12	972,144.02	90	44
J-98	1,930.00	490,963.86	971,999.20	95	50
J-99	1,930.00	490,894.90	971,888.86	95	50
J-100	1,936.00	490,598.36	972,013.00	89	44
J-101	1,924.00	491,150.06	971,744.04	101	56
J-102	1,924.00	491,233.40	971,895.94	101	56
J-103	1,944.00	490,459.96	972,390.26	82	36
J-104	1,940.00	490,232.12	972,481.89	86	40
J-105	1,943.00	490,123.30	972,340.83	83	37
J-106	1,952.00	490,350.50	972,241.96	74	28
J-107	1,934.00	490,457.59	971,722.14	91	46
J-108	1,931.00	490,681.30	971,487.42	94	49
J-109	1,931.00	490,554.41	971,310.87	94	49

Label	Elevation (m)	X (m)	Y (m)	Existing Pressure (mH_2O)	Pressure Improved (mH_2O)
J-110	1,934.00	490,270.47	971,536.13	91	46
J-111	2,045.00	488,888.58	974,974.57	72	65
J-112	1,995.00	489,861.51	972,961.22	39	20
J-113	1,985.00	488,802.20	974,203.05	24	24
J-114	1,978.00	488,437.11	974,013.46	30	31
J-115	1,969.00	488,391.59	973,643.80	39	40
J-116	1,975.00	488,770.41	973,446.73	32	34
J-117	1,977.00	488,844.48	973,887.10	31	32
J-118	1,968.00	488,432.21	973,157.36	39	41
J-119	1,960.00	488,563.25	972,950.85	47	49
J-120	1,967.00	488,841.20	973,087.35	40	42
J-121	1,990.00	489,909.40	973,230.84	44	25
J-122	1,923.00	490,931.60	970,543.43	83	59
J-123	1,938.00	492,365.92	972,523.10	80	81
J-124	1,951.00	492,682.04	973,418.58	56	68
J-125	2,035.00	487,769.13	974,430.18	82	75
J-126	1,924.00	490,968.28	971,257.73	101	56
J-127	1,924.00	490,790.32	971,105.19	101	55
J-128	1,954.00	489,963.48	972,563.98	72	26
J-129	1,946.00	489,959.27	972,383.42	80	34
J-130	2,025.00	486,367.29	973,736.96	12	25
J-131	1,940.00	491,450.27	972,345.45	81	80
J-132	1,920.00	487,321.66	969,580.52	52	58
J-133	1,920.00	488,224.68	969,241.06	53	58

APPENDIX G: Pipes Velocity Before and After Improvement

Label	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Existing Velocity(m/s)	Improved Velocity (m/s)
P-1	100	HDPE	130	2.23	1.31	0.78
P-2	100	HDPE	130	3.74	1.68	0.98
P-3	100	HDPE	130	3.13	1.65	0.9
P-4	100	HDPE	130	2.11	1.54	0.77
P-6	100	HDPE	130	0.24	1.32	0.53
P-7	100	HDPE	130	0.11	1.02	0.51
P-8	100	HDPE	130	-0.47	0.99	0.56
P-9	100	HDPE	130	-1.11	0.84	0.64
P-10	150	HDPE	130	2.37	0.69	0.63
P-11	150	HDPE	130	1.8	0.27	0.6
P-12	100	HDPE	130	1.16	0.2	0.65
P-13	100	HDPE	130	1.01	0.29	0.63
P-14	100	HDPE	130	0.47	0.26	0.56
P-16	80	PVC	150	3.67	0.12	1.23
P-17	50	HDPE	130	0.89	0.04	0.95
P-18	50	HDPE	130	0.29	0.48	0.65
P-19	50	HDPE	130	0.41	0.11	0.71
P-20	50	HDPE	130	0.62	0.47	0.82
P-21	50	HDPE	130	0.5	0.72	0.75
P-22	50	HDPE	130	0.47	0.58	0.74
P-23	50	HDPE	130	0.27	0.38	0.64
P-24	50	HDPE	130	0.89	0.22	0.95
P-25	50	HDPE	130	0.83	0.68	0.92
P-26	50	HDPE	130	0.41	0.65	0.71
P-28	50	HDPE	130	0.64	0.36	0.82
P-29	40	HDPE	130	0.05	0.66	0.54
P-30	50	HDPE	130	0.41	0	0.71
P-31	50	HDPE	130	0.2	0.5	0.6
P-32	50	HDPE	130	0.31	0.18	0.66
P-33	80	HDPE	130	0.52	0.28	0.6
P-34	60	HDPE	130	0.52	0.2	0.69
P-35	50	HDPE	130	0.23	0.36	0.62
P-36	50	HDPE	130	0.1	0.24	0.55
P-37	50	HDPE	130	-0.02	0.12	0.51
P-38	50	HDPE	130	0.2	0.05	0.6

Label	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Existing Velocity(m/s)	Improved Velocity (m/s)
P-39	50	HDPE	130	0.13	0.2	0.57
P-40	50	HDPE	130	0.04	0.14	0.52
P-41	50	HDPE	130	0.08	0.04	0.54
P-42	80	HDPE	130	-0.2	0.1	0.54
P-43	80	HDPE	130	-0.36	0.15	0.57
P-44	80	HDPE	130	-0.22	0.2	0.54
P-45	50	HDPE	130	-0.35	0.11	0.68
P-46	50	HDPE	130	-0.35	0.4	0.68
P-47	40	GI	120	0.42	0.4	0.83
P-48	50	GI	120	0.26	0.73	0.63
P-49	40	GI	120	0.09	0.34	0.57
P-50	50	HDPE	130	0.36	0.14	0.68
P-51	50	HDPE	130	0.32	0.3	0.66
P-53	50	HDPE	130	-0.84	0.27	0.93
P-54	50	HDPE	130	1.17	0.63	1.1
P-56	80	HDPE	130	0.95	0.4	0.69
P-57	50	HDPE	130	0.35	0.23	0.68
P-58	40	HDPE	130	0.14	0.39	0.61
P-60	50	HDPE	130	0.08	0.33	0.54
P-61	40	HDPE	130	0.49	0.18	0.89
P-62	40	HDPE	130	-0.1	0.8	0.58
P-63	40	HDPE	130	0.17	0.15	0.63
P-64	50	HDPE	130	-0.29	0.36	0.65
P-65	50	HDPE	130	0.28	0.19	0.64
P-66	50	HDPE	130	1.86	0.27	1.45
P-67	50	HDPE	130	0.68	0.45	0.85
P-68	40	HDPE	130	0.54	1.04	0.93
P-69	40	HDPE	130	1.02	0.81	1.31
P-70	50	HDPE	130	2.56	0.79	1.81
P-71	50	HDPE	130	0.43	0.69	0.72
P-72	50	HDPE	130	0.78	0.03	0.9
P-73	65	HDPE	130	-0.57	0.24	0.67
P-74	65	HDPE	130	-0.74	0.34	0.72
P-75	50	HDPE	130	-2.59	0.26	1.82
P-76	50	HDPE	130	-2.77	1.31	1.91
P-77	50	HDPE	130	-2.69	1.46	1.87
P-78	80	HDPE	130	0.17	1.4	0.53

Label	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Existing Velocity(m/s)	Improved Velocity (m/s)
P-79	250	PVC	150	6.28	0.06	0.63
P-80	100	HDPE	150	0.47	0.28	0.56
P-82	80	HDPE	130	-0.57	0.14	0.61
P-83	80	HDPE	130	1.01	0.17	0.7
P-84	80	HDPE	130	0.77	1.23	0.65
P-86	80	HDPE	130	1.76	1.15	0.85
P-87	80	HDPE	130	2.27	1.08	0.95
P-89	80	HDPE	130	0.76	0.77	0.65
P-90	80	HDPE	130	0.78	0.52	0.65
P-91	50	HDPE	130	0.27	0.57	0.64
P-27	50	HDPE	130	-0.33	0.45	0.67
P-92	80	HDPE	130	2.04	0.29	0.91
P-93	80	HDPE	130	2.81	0.26	1.06
P-94	80	HDPE	130	0.24	0.51	0.55
P-95	80	HDPE	130	0.13	0.12	0.53
P-96	80	HDPE	130	0.04	0.09	0.51
P-97	50	HDPE	130	-0.7	0.08	0.86
P-98	50	HDPE	130	0.98	0.04	1
P-99	50	HDPE	130	0.89	0.01	0.95
P-100	50	HDPE	130	-1.82	0.49	1.43
P-101	100	HDPE	130	-0.75	0.25	0.6
P-103	50	HDPE	130	2.29	0.17	1.67
P-104	50	HDPE	130	1.05	0.12	1.04
P-105	50	HDPE	130	0.64	0.09	0.82
P-106	50	HDPE	130	0.29	0.28	0.65
P-107	50	HDPE	130	0.02	0.46	0.51
P-108	50	HDPE	130	0.12	0.38	0.56
P-109	50	HDPE	130	0.29	0.44	0.65
P-110	40	HDPE	130	0.32	0.15	0.76
P-111	40	HDPE	130	0.14	0.02	0.61
P-112	40	HDPE	130	0.05	0.15	0.54
P-113	40	HDPE	130	0.06	0.3	0.54
P-114	40	HDPE	130	0.05	0.43	0.54
P-115	40	HDPE	130	0.14	0.18	0.61
P-116	40	HDPE	130	0.05	0.07	0.54
P-117	50	HDPE	130	-0.24	0.07	0.62
P-118	50	HDPE	130	-1	0.06	1.01

Label	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Existing Velocity(m/s)	Improved Velocity (m/s)
P-119	200	Ductile Iron	130	2.98	0.19	0.59
P-120	50	HDPE	130	1.02	0.07	1.02
P-121	50	HDPE	130	0.33	0.21	0.67
P-122	50	HDPE	130	0.24	0.12	0.62
P-123	50	HDPE	130	0.17	0.16	0.58
P-125	100	HDPE	130	0.13	0.86	0.52
P-126	100	HDPE	130	0.03	0.21	0.5
P-127	100	HDPE	130	1.05	0.14	0.63
P-128	50	HDPE	130	0.18	0.07	0.59
P-129	50	HDPE	130	0.04	0.09	0.52
P-130	80	HDPE	130	0.76	0.03	0.65
P-131	50	HDPE	130	0.1	0.01	0.55
P-132	50	HDPE	130	0.04	0.22	0.52
P-133	50	HDPE	130	0.04	0.15	0.52
P-135	100	Ductile Iron	130	0.39	0.04	0.55
P-136	50	HDPE	130	0.15	0.25	0.58
P-137	50	HDPE	130	0.15	0.08	0.57
P-138	50	HDPE	130	0.09	0.03	0.54
P-139	50	HDPE	130	0.02	0.03	0.51
P-140	80	HDPE	130	0.55	0.08	0.61
P-141	50	HDPE	130	0.22	0.13	0.61
P-142	50	HDPE	130	0.05	0.12	0.52
P-143	50	HDPE	130	-0.12	0.07	0.56
P-144	50	HDPE	130	0.2	0.02	0.6
P-146	200	HDPE	150	5.15	0.18	0.66
P-147	150	PVC	150	1.98	0.19	0.61
P-149	80	HDPE	130	3.94	0.04	1.28
P-150	80	HDPE	130	0.89	0.1	0.68
P-152	80	HDPE	130	1.16	0.17	0.73
P-153	50	HDPE	130	0.25	0.36	0.63
P-154	50	HDPE	130	0.14	0.34	0.57
P-155	50	HDPE	130	0.16	0.38	0.58
P-156	80	HDPE	130	0.66	0.02	0.63
P-157	50	HDPE	130	0.28	0.38	0.64
P-158	50	HDPE	130	0.14	0.21	0.57
P-159	50	HDPE	130	0.04	0.12	0.52
P-160	50	HDPE	130	-1.46	0.13	1.24

Label	Diameter (mm)	Material	Hazen-Williams C	Flow (L/s)	Existing Velocity(m/s)	Improved Velocity (m/s)
P-161	50	HDPE	130	0.14	0.22	0.57
P-163	50	HDPE	130	0.03	0.24	0.52
P-164	50	HDPE	130	0.51	0.11	0.76
P-165	50	HDPE	130	-0.04	0.04	0.52
P-166	50	HDPE	130	0.39	0.58	0.7
P-167	50	HDPE	130	0.13	0.12	0.57
P-168	50	Ductile Iron	130	0.2	0.03	0.6
P-169	50	HDPE	130	-0.03	0.49	0.51
P-81	150	PVC	150	2.62	0.04	0.65
P-172	100	HDPE	130	0.2	0.32	0.53
P-174	100	Ductile Iron	130	0.04	0.11	0.5
P-175	100	Ductile Iron	130	0.05	0.17	0.5
P-176	50	Ductile Iron	130	0.04	0.02	0.52
P-177	50	Ductile Iron	130	0.02	0.25	0.51
P-179	65	HDPE	130	1.66	0.08	1
P-181	50	HDPE	130	0.13	0.72	0.57
P-182	50	Ductile Iron	130	0.13	0.65	0.56
P-183	50	Ductile Iron	130	0.1	0.03	0.55
P-151	100	Ductile Iron	130	2.86	0.02	0.66
P-162	100	Ductile Iron	130	0.06	0.94	0.75
P-15(1)	100	HDPE	130	5.74	0.11	1.23
P-15(2)	100	HDPE	130	5.74	0.11	1.23
P-148(1)	80	HDPE	130	4.34	0.08	1.36
P-148(2)	80	HDPE	130	4.34	0.89	1.36
P-124(1)	200	Ductile Iron	130	1.72	0.61	0.55
P-124(2)	200	Ductile Iron	130	1.72	0.39	0.55
P-85(1)	80	HDPE	130	0.54	0.39	0.61
P-85(2)	80	HDPE	130	0.54	0.54	0.61

APPENDIX H: Household survey questionnaires

Greetings, responder!

This questionnaire's objective is to produce pertinent data that can be used to assess the adequacy of the water distribution system in Dukem Town. Therefore, the information you will provide is very important for the academic research required for the fulfilment of the Masters of Science (M.Sc.) in Water Supply and Environmental Engineering at Adama Science and Technology University School of Civil and Architecture, Department of Water Resource Engineering.

The study is solely carried out for academic purposes, and no other use will be made of the responses. Your information is absolutely necessary for the study to be successful. As a result, we respectfully ask that you respond to all of our inquiries and provide accurate and thorough information about the problems.

The number of sample used for this research will be 376 households

Part one: Household socioeconomic characteristics

1. Name of Kebele (Admin. Unit) ....……………….......
2. Gender
   a) Male b) Female
3. What is your age? ………… years
   a) 11-20
   b) 21-30
   c) 31-40
   d) 40-50
   e) Above 51
4. What is your family size? ……… persons
5. Educational level
   a) Illiterate
   b) Able to read and write
   c) Primary school
   d) Secondary school
   e) Above grade
6. Source of income
   a) Business/peaty trade
   b) Farming
   c) Daily labor

d) Job holder/ government employee
e) Retired -If others, specify

Part two: Access to water source and consumption of water by households

1. Which source of drinking water you use?
   a) Surface source
   b) Ground water source
   c) Others
2. What types of pipe system using?
   a) House Connection
   b) Yard Connection
   c) Public Fountain
   d) Others____
3. On average how frequently do you <u>receive piped water</u>?
   a) Continuously/daily
   b) Twice a day
   c) Once a day
   d) Twice a week
   e) Once a week
   f) One time in 2 weeks
4. On the days that you get water, how many <u>hours</u> do you usually <u>get water</u> for?
   a) Full day
   b) Half day
   c) 3- 5 h
   d) 1-3 h
   e) Less than 1 h

Part 3 Household attitude towards Affordability to pay

1. Does the price you are paying for water commensurate with your economic capacity
   a) Yes
   b) No
2. If Q1 YES, what is your judgment on the water tariff?
   a) Very expensive
   b) Expensive
   c) Fair
   d) Cheap
   e) Very cheap

Part Four: Customer satisfaction along with general water supply service

1. Is the quantity of water that you receive (from your main source of water) adequate?

   a) Yes b) No

2. If your answer for Q1 is 'No', what is the main reason limiting access to sufficient quantities of water needed?

   a) Water is not available from source
   b) Infrastructure problem
   c) Water is too expensive
   d) Source is not accessible

3. How many <u>liters of water</u> do you use per day?

   a) 10-25
   b) 26-35
   c) 36-50
   d) Above 51

4. At what distance are you getting drinking water?

   a) Less than 100m
   b) 100m-250m
   c) 250-500m
   d) Above 500m

If others, specify____

5. The <u>quality</u> of water that you receive (from piped water supply) is

   a) Very clean
   b) Clean
   c) Somewhat clean
   d) Not clean at all

If others specify____

6. Overall satisfaction level of existing water supply systems of the town is?

   a) Very satisfactory
   b) Satisfactory
   c) Less Satisfactory
   d) Unsatisfactory