EVALUATION OF WATER DISTRIBUTION SYSTEM AND ITS IMPACT IN HA FOSO, BEREA, LESOTHO.

BY

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DISSERTATION SUBMITTED TO THE NATIONAL UNIVERSITY OF LESOTHO WATER INSTITUTE IN PARTIAL FULLFILMENT OF THE REQUIREMENTS FOR THE

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Abstract

The interplay between urbanization, water demand and supply, and resource management is a critical issue, particularly as population concentration intensifies, with the implications for peri-urban areas. Rapid urbanization in Lesotho, for instance, has exerted pressures on the water infrastructure network, particularly in newly developing peri-urban communities like Ha Foso, where water supply challenges have become an issue. This study, therefore, evaluates the performance, adequacy, and reliability of Ha Foso's water distribution system. EPANET software was used to conduct hydraulic analysis assessing parameters such as pressure levels, flow rates, and network efficiency, among others. Complementing the technical analysis, quantitative and qualitative data were obtained from a sample of 270 households, while participant interviews were conducted with water consumers and utility personnel. Logistic regression analysis was used to explore the relationship between infrastructure performance and users' satisfaction, providing a robust analysis for understanding the system's impact on the community. The study identifies systemic inefficiencies in the distribution network, such as low water pressure as well as low frequency, duration, shortage of, and less reliable water supply, and dissatisfied consumers. By integrating technical information (through assessments) with community perspectives, this study provides innovative solutions, such as adding booster pumps in households that receive low pressure for water infrastructure management. It also suggests measures, including installing pressure-reducing valves in high-pressure zones to protect infrastructure for improved water access and resilience of the water distribution network, towards achieving equitable and sustainable water resource management.

Keywords: Ha Faso, Water Reliability, Water Supply Infrastructure, EPANET Software, Peri-urban communities

Declaration

The work contained in this dissertation was carried out and completed by Ts'epang C. Mofolo, 200501077, at the National University of Lesotho Water Institute. I hereby declare that this study constitutes my original work and has never been submitted for the award of a degree or diploma to any other University. To the best of my knowledge, this dissertation contains no material written by another person except where due reference is made in the dissertation itself.

Signature ………………… Date: 9th October 2025

As the candidate's supervisor, I certify the above statement to be correct to my knowledge and have recommended this dissertation for submission.

Professor Musibau O. Jelili …………………… Date:

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Table of Contents

List of Figures

List of Tables

List of Plates

Acronyms and Abbreviations

ANSD	National Agency for Statistics and Demography
CUET	Chittagong University of Engineering and Technology
CWS	Continuous Water Supply
DMA	District Metered Areas
EPA	Environmental Protection Agency
EPANET	Environmental Protection Agency NETwork
GIS	Global Information Systems
GMWSP	Greater Maseru Water Supply Project
HSTU	Hajee Mohammad Danesh Science and Technology University
IWS	Intermittent Water Supply
KPI	Key Performance Indicator
NRW	Non-Revenue Water
OECD	Organization for Economic Cooperation and Development
OFID	OPEC Fund for International Development
OPEC	Organization of the Petroleum Exporting Countries
PIPE-FLO	Piping Flow Analysis/Piping Flow Optimization
PRV	Pressure-Reducing Valves
QGIS	Quantum Geographic Information System
SCADA	Supervisory Control and Data Acquisition
SSA	Sub-Saharan Africa
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNICEF	United Nations International Children's Emergency Fund
WASCO	Water and Sewage Company
WASH	Water Sanitation and Hygiene
WaterCAD	Water Computer-Aided Design
WDN	Water Distribution Network
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1 Preamble

Water is a basic necessity of life. There are different sources of water supply to households and industries including public tap water, groundwater, and collected rainwater. Although public tap water is frequently seen as the best form of water supply in every home, the level of service this system offers varies greatly. The percentage of people worldwide who have access to a better supply of drinking water generally went from 76% to 91% between 1990 and 2015, while the percentage who have piped water at home rose from 44% to 58% (WHO/UNICEF, 2018). However, not all improved sources, including piped ones, necessarily deliver safe and reliable water (Shaheed *et al*, 2014). Using data from the Rapid Assessment of Drinking Water Quality conducted by WHO and UNICEF in five countries of Bangladesh, China, Ethiopia, Jordan and Nigeria, Onda *et al* (2012) projected that 28% of people on earth drank contaminated water in 2010, a far greater percentage than the 12% who drank from unimproved sources in 2004. Additionally, piped water systems frequently encounter difficulties such as low operating efficiency, high rates of water loss, and insufficient cost recovery, which result in substandard service (Savedoff, 1999; McIntosh, 2003).

Water scarcity world over affects two to three billion people annually for at least one month, which puts their livelihoods—particularly those related to food security and access to electricity in serious danger. Water scarcity in urban areas is expected to quadruple globally by 2050, from 930 million in 2016 to 1.7–2.4 billion people with inadequate or poor access to water in the world (Bonazzi, 2023). The situation in the countries of the global south is similar, if not worse than the global average. For example, the South African Intermittent Water Supply (IWS) affected population increased by over 26% between 2008 and 2017, outpacing the population growth of about 12% during that same period. Furthermore, in 2017, IWS caused harm to 22 million people in South Africa. The results of a survey by Loubser (2023) showed that 65 out of 231 municipalities in South Africa had intermittent water supplies in 2017 and that the frequency of IWS has been increasing over time, and may continue to increase within the foreseeable future. The findings show how widespread IWS is in South Africa (Loubser, 2023).

Water, being a major resource and source of foreign exchange to Lesotho, has been of priority attention to the nation over time. Yet, the problem of water supply to some places in the country remains an issue. The Water and Sewage Company (WASCO) in Lesotho began notifying the public about water disruptions at Ha Foso and the adjoining village of Marabeng as early as 2018. Consumers were notified that there would be regular shortages of water from October 22 to October 26, 2018, in the two villages. That amounted to five days without regular supplies. The connectivity projects that were carried out during this time as part of the network extension project were cited as the primary cause. The Lesotho government requested financial support from the Organization of the Petroleum Exporting Countries (OPEC) Fund for International Development (OFID) in 2003 to expand distribution networks and repair water infrastructure in Maseru, the country's capital. In the subsequent project, thousands of households had meters installed, along with 300 kilometers of pipeline and connections. With a combined storage capacity of approximately 3,750 cubic meters, two new reservoirs were constructed, and two existing reservoirs were expanded. One pumping station was fully renovated, and two more were built. In spite of all the above, Lesotho has faced several challenges to its economic growth, such as scarcity of natural resources, susceptibility to drought, and severe land scarcity.

Ha Foso emerged due to encroachment onto agricultural land brought about by the paucity of land. Water is one of the most valuable natural resources in the nation, notwithstanding the scarcity of other resources. Water as a resource provides the 2.1 million residents of Lesotho with wealth and success. The unequal distribution of water resources and the absence of a sufficient supply infrastructure, however, may still threaten the nation's socioeconomic advancement. Safe drinking water remains unaffordable for a large number of people living in both rural and urban areas. There are numerous trade-offs in Lesotho's water industry, such as a decrease in water security and supply for both urban and rural populations. The infrastructure required for local communities to take advantage of Lesotho's water supply is quite inadequate. Because of this, Lesotho's population has restricted access to a resource that has historically been abundant in the area (Acosta, 2021). Even though water is cited as one of the most valuable and abundant natural resources in Lesotho, the analysis of the scientific literature shows that, compared to other regions or nations, continuous Water Distribution Systems (WDSs) and intermittent WDSs have received significantly less research attention in Lesotho. This study, therefore, evaluates the water distribution system and its impact on the frequency, adequacy and reliability of water supply in Ha Foso, Berea, Lesotho.

1.2 Statement of the Research Problem

Access to safe and adequate water is a critical issue affecting households and industries worldwide, with significant disparities across regions. Globally, approximately 2.2 billion people lack access to safe drinking water, and 3.5 billion people are without access to a safe toilet. This deficiency contributes to over 1 million deaths annually due to health impacts alone (Water.Org, not dated). In sub-Saharan Africa, the situation is particularly dire. The region is the only one globally where the number of people without access to basic drinking water services is increasing. In 2020, about 387 million people in sub-Saharan Africa lived without such access, up from 350 million in 2000 (World Bank, 2024). This lack of access is linked to the transmission of diseases such as cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio (WHO, 2023).

Focusing on Southern Africa, countries like Lesotho, Namibia, and South Africa have varying levels of access to improved water sources. Lesotho, for instance, has one of the highest rates of access to clean water in sub-Saharan Africa, with 72% in urban areas and 63% in rural areas (Stockholm Environment Institute, 2016). Despite that, the situation in some rural and peri-urban communities like Ha Foso, Berea, Lesotho, is also not encouraging, as residents are experiencing significant challenges, especially with the water distribution system, leading to inconsistent supply and frequent disruptions. The existing water distribution system faces significant challenges that affect its performance and ability to meet the needs of the community. Issues such as inconsistent water supply, frequent outages have created a situation that undermines the quality of life for residents who rely on a stable water supply for daily needs such as drinking, cooking, and sanitation. Therefore, there is an urgent need to evaluate the current water distribution system in Ha Foso to identify systemic weaknesses, assess the impact of recent developments on water supply frequency, adequacy and reliability, and propose actionable strategies for improvement. Such issues as the condition and performance of water supply infrastructure/distribution network, how these impacts the frequency, adequacy, and reliability of water supply, actions being taken, or already taken, the extent of success, and what needs to be done to improve water supply situation in the area, among others, are of concern to this study. The study shall use EPANET model to analyze and model water supply system in the area. EPANET is a widely used, open-source hydraulic modeling software developed by the US Environmental Protection Agency (EPA) that simulates and analyzes the behavior of water distribution systems.

1.3 Hypothesis

There is no significant relationship between water supply infrastructure and/or distribution network on one hand, and frequency, adequacy and reliability of water supply in Ha Foso, Berea, Lesotho, on the other.

1.4 Research Questions

i) What is the current condition of the water supply infrastructure and distribution network in the study area?
ii) How frequent, adequate and reliable is supply of water in the study area?
iii) How does infrastructure condition/distribution network affect the frequency, adequacy and reliability of water supply in the area?
iv) What are the key factors responsible for, and effects of poor water supply in the area?
v) How can the water supply infrastructure and distribution network be improved upon for a better access to water supply in the area?

1.5 Aim and objectives

The main objective (aim) of this study is to evaluate the water distribution infrastructure/ network and its impacts on the frequency, adequacy, and reliability of water supply in Ha Foso, Berea, Lesotho.

The specific objectives are:

i) Appraise the existing water distribution infrastructure system/network in the area using EPANET.
ii) Examine the frequency, adequacy, and reliability of water supply in the area.
iii) Analyze the relationship between water supply infrastructure/distribution network, on one hand, and the frequency, adequacy, and reliability of water supply, on the other, in the area.
iv) Analyze key factors responsible for, and effects of, poor water supply in the area.
v) Identify strategies by which water supply infrastructure/distribution network can be upgraded for improved frequency, adequacy, and reliability of water supply in the area.

1.6 Data Validity and Reliability

Data reliability and validity, particularly in studies assessing water supply systems are essential elements in guaranteeing the integrity of research findings. Reliability is the consistency of the data throughout time or across several measurements, whereas validity is the degree to which the data accurately reflects the concepts being measured (Cresswell, 2003). In the context of this study, data validity would be assessed by examining whether the instruments and methods used for data collection effectively capture the true state of water supply conditions. This includes ensuring that survey questions are clear, relevant, and aligned with the study's objectives. For instance, in this study, it was guaranteed that the data collection methods accurately measured parameters such as water distribution network performance in terms of frequency, adequacy, and reliability of water supply by validated consumer surveys.

Reliability, on the other hand, is the consistency of a measure or the ability to obtain similar results under repeated trials under the same conditions (Carmines, 1979). This can be achieved through various means. In the context of water distribution modeling in this study, reliability was conducted by 1. running the results of the model multiple times under the same conditions to ensure the consistency of simulation, ensuring that the findings were robust and reproducible, and 2. ensuring that data collectors were trained to minimize variability in data collection processes. Additionally, employing multiple sources of data—such as combining quantitative surveys with qualitative interviews—can enhance reliability by providing a more comprehensive view of water supply issues.

Ultimately, ensuring both validity and reliability in this study was paramount for drawing meaningful conclusions regarding water supply frequency, adequacy, and reliability.

1.7 Ethical Considerations

Participants received a comprehensive consent form that clearly and concisely explained the study. They were able to decide whether or not to participate after having the opportunity to ask questions. Participants had the option to withdraw at any moment without giving a reason; this was made very clear in the consent form and throughout the interview process. There was no coercion to continue participating in the study if, for any reason, they wished to stop. Participants' privacy was safeguarded, and all information gathered was kept confidential. No personally identifiable information was obtained.

CHAPTER 2: LITERATURE REVIEW

A thorough summary of previous research on water supply and water distribution/supply networks (WDN) was considered in this section. It will look at the water distribution infrastructure system/network, the relationship between the water supply infrastructure/distribution network and its performance (frequency, adequacy, and reliability) on water supply, key factors responsible for, and effects of poor water supply, and EPANET as a water distribution modeling software. This chapter draws lessons from empirical studies that have used EPANET in the past, its shortfalls, and benefits.

2.1 Water Distribution Infrastructure System/Network

As stated by Palleti *et al* (2014), water distribution networks (WDNs) comprise a system of pipelines, reservoirs, pumps, valves, storage tanks. The WDN is a group of infrastructure elements that supply customers with predetermined water volumes at predetermined pressures. These systems are commonly represented as graphs, with pipes represented by links and nodes signifying connections between pipes, hydraulic control components, consumers, and sources (Ostfeld, 2015 in Kyriakides and Polycarpou, 2014). An effective water supply is necessary for building a new water distribution network or enlarging an existing one since it is crucial to provide end users with drinking or potable water (Alperovits and Shamir, 1977).

The behaviour of a water distribution network is influenced by the system layout, customer needs, and the physical principles characterizing the flow connections in the pipes and the hydraulic control devices (Ostfeld, 2015). As the last line of defense against contamination, distribution systems make up the great majority of the water systems' physical infrastructure. Vamsi *et al* (2021) state that a distribution system should typically fulfil the following requirements. It should have the capacity to supply sufficient water at sufficient pressure throughout the entire area provided. It should meet the water supply's needs for putting out flames. It ought to be trustworthy. Its construction, design, and layout should all be economical. It should be simple to use and repair.

2.2 Effects of Water Supply Infrastructure on Reliability, Adequacy, and Frequency of Water Supply

Water supply is reliable if it is provided in time and with the quality and quantity required by the user (Alzahrani *et al*, 2024). Reliability considerations are an integral part of all decisions regarding the planning, design, and operation phases of water distribution systems. The complement of the likelihood that a water distribution system would fail—a failure being the system's incapacity to meet the demands of its customers—is the system's reliability (Ostfeld, 2015). Therefore, inadequate water supply, infrastructure failures (such as pipe ruptures, pump failures), equipment failures, leaky pipes, pressure management issues, operational issues, water quality issues, and contamination are all signs of a water distribution network failure

(Alzahrani *et al*, 2024).

Intermittent water supply (IWS) is another sign that a system is failing, and it is a widespread issue affecting many regions, particularly in developing countries. The causes of IWS are multifaceted, involving a combination of environmental, technical, financial, and social factors.

Other consequences of IWS are summarized as deficiencies associated with IWS in Figure 1 below. Figure 1 serves as a comprehensive overview of the multifaceted challenges posed by IWS. Social deficiencies highlight issues such as costs in storage tanks, pumps, and uneven distribution, with disadvantages that may include customer dissatisfaction and inequitable access to water, which can lead to social unrest and a lack of trust in water service providers. Technical deficiencies point to infrastructure problems, including pressure deficits, aging pipelines, and inadequate maintenance, which contribute to high levels of water loss and unreliable service delivery. Economic deficiencies indicate that intermittent supply can lead to increased operational costs for utilities, as well as economic burdens on households that may need to invest in alternative water sources or storage solutions. Health deficiencies, on the other hand, are risks of significant concern, as intermittent supply often results in water contamination and limits access to safe drinking water, leading to public health issues.

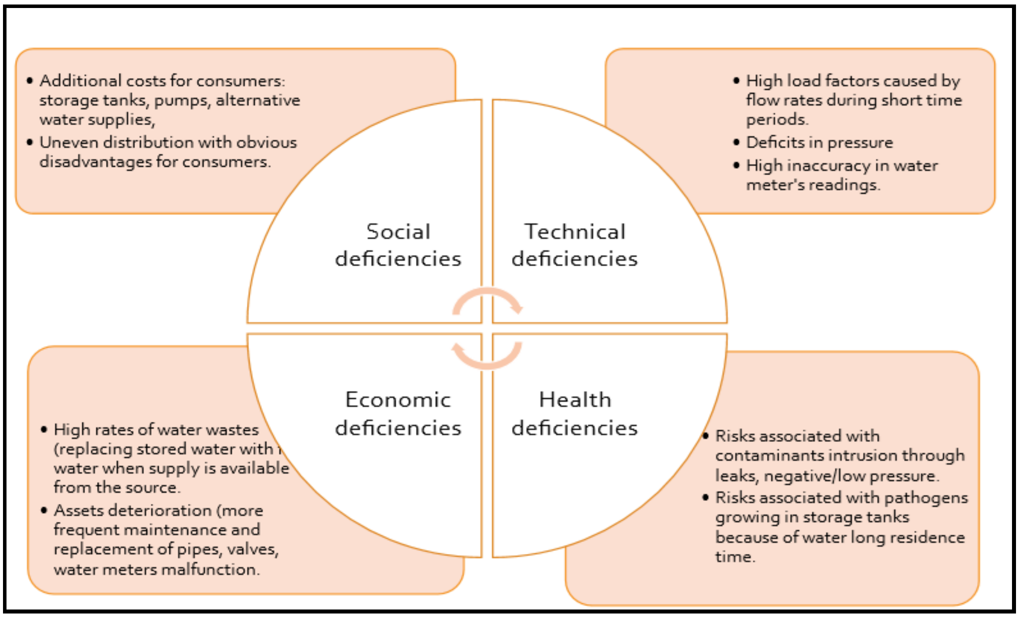

Figure 1: Deficiencies of IWS (Zyoud, 2017)

2.3 Water Distribution System Evaluation: Hydraulic Modeling (EPANET)

EPANET is a software application for understanding the movement and fate of drinking water constituents within a drinking water distribution system. EPANET can be used to design and size new water infrastructure, retrofit existing aging infrastructure, optimize operations of tanks and pumps, reduce energy usage, investigate water quality problems, and prepare for emergencies (EPA, 2024). The EPANET 2.0 upgrade introduced critical technical improvements that enhanced the accuracy and scope of simulations. The software developed by the U.S. Environmental Protection Agency is adopted because it is intended for the general public and educational use, and it is available free online. It has the capacity to analyze an unlimited number of pipes and tanks. EPANET has become a popular tool in analyzing complex and simple water distribution networks in both developed and developing countries of the world. EPANET is a computer program that performs extended period simulation of hydraulic and water quality behaviour within pressurized pipe networks (Ramezanianpour and Ali, 2023). A network consists of pipes, nodes (pipe junctions), pumps, valves, and storage tanks or reservoirs.

The water flow in each pipe, the pressure at each node, the water level in each tank, and the concentration of a chemical species across the network are all monitored by EPANET. In order to better understand the movement and destiny of drinking water elements inside distribution networks, EPANET was created as a research tool. It can be applied to a wide range of distribution systems analytical tasks. It is employed to perform the hydraulic analysis of the research area's distribution network (Ramana *et al*, 2015). It can analyze networks made up of pipes, nodes, pumps, valves, and storage tanks and runs on Windows. The program supports research on the movement and fate of drinking water constituents throughout distribution networks and tracks water flow, pressure, and tank levels (Mehta *et al*, 2024).

The program adjusts to different demand patterns at each node, accounts for minor losses from bends and fittings, and handles changing needs over time. EPANET's user-friendly Windows interface simplifies the process of building and modifying pipe network models. It offers resources for data visualization and reporting (Environmental Protection Agency, 2021). This review provides a theoretical framework for future research on water distribution systems by synthesizing empirical results pertaining to WDS and system design.

2.3.1 Input Parameters - Junction and Pipe Report

Junctions are the places where water enters or exits a network, and links join (Mehta *et al*, 2024). Water is transported from one location in the network to another via pipes. All pipes are assumed to be full at all times for EPANET to operate. According to Mehta *et al* (2016), the flow direction is from the end at the higher hydraulic head to that at the lower head.

EPANET, a widely used software for modeling water distribution networks, has been employed in various studies globally, including in South Africa.

In South Africa for example, EPANET has been utilized for designing efficient water distribution networks and pressurized irrigation systems. Its application in these areas underscores its versatility and effectiveness in addressing the unique challenges of water distribution in the region (EPA, 2021). Additionally, a methodological approach integrating open-source software like QGIS and EPANET has been developed to evaluate existing municipal water infrastructure in developing countries, with a case study focusing on Swakopmund, Namibia. This approach highlights the potential of EPANET in assessing and improving water distribution systems in similar contexts (Muller *et al*, 2020).

Globally, EPANET has been applied in various contexts, such as analyzing water distribution systems in rural areas and optimizing water supply networks in academic institutions. These studies demonstrate EPANET's flexibility and reliability in different settings, which may inform its application in South Africa (Muller *et al*, 2020; Srivas *et al*, 2023). While specific empirical studies directly comparing EPANET to other tools in South African water supply studies are limited, its extensive use in the region indicates a level of preference among researchers and practitioners. The software's ability to model complex networks accurately and its cost-effectiveness contribute to its widespread adoption.

The rest of the input parameters in EPANET are summarized in the diagram below.

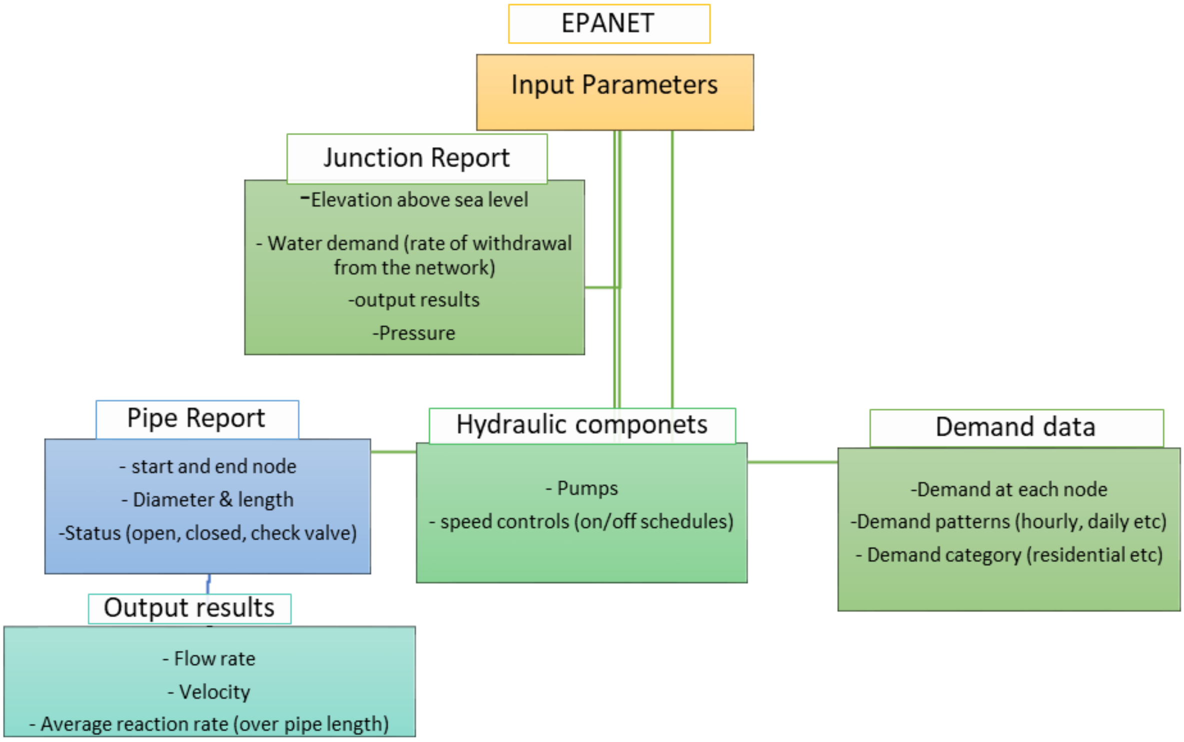

Figure 2: Input parameters in EPANET (conceptualized by the author)

2.4 Key Factors Responsible For, and Effects of, Poor Water Supply

Communities all around the world struggle with access to a consistent supply of water, especially in places where demand frequently outpaces infrastructural capacity. Intermittent water supply (IWS), which is defined by erratic delivery schedules and insufficient volumes to satisfy customer demands, is one way that a poor water supply might appear. Numerous issues, such as poor infrastructure upkeep and water companies' budgetary limitations, are to blame for this predicament. IWS has far-reaching effects on social justice, public health, and economic stability in addition to water availability. Developing successful interventions that improve water distribution networks and provide sustainable access to this crucial resource requires an understanding of the causes of inadequate water supply and its consequences. By investigating these patterns, this study seeks to bring some insights into the root causes of inadequate water supply and the wide-ranging effects it has on impacted populations.

2.4.1 Intermittent Water Supply

Water that is not always available is referred to as an "intermittent" water supply. The water supply's predictability or unpredictability in such a system may have a significant effect on consumers (Galaitsi *et al*, 2016). An unreliable piped urban water supply service that does not offer water to customers every day of the week or twenty-four hours a day is commonly referred to as an IWS (Charalambous & Laspidou, 2017; Simukonda *et al*, 2018). Galaitsi *et al* (2016) suggest three categories to label the various kinds of intermittencies: (1) Predictable, similar to continuous water supply (CWS) systems, in which customers are informed of the delivery schedule and each receives enough water to suit their needs. (2) Irregular, meaning that although the user can get enough water, the supply schedule is unpredictable, similar to anticipated intermittency. (3) Unreliable; there is typically insufficient water and little to no information on when the water supply will occur. The core of this study is the unreliable intermittency.

2.4.2 Water Distribution Infrastructure Performance

The term "water infrastructure" refers to the collection of facilities and installations required for the development and management of water resources, including the collection, removal, treatment, and disposal of sewage and wastewater as well as the delivery, treatment, supply, and distribution of water to its users (United Nations Economic and Social Commission for Asia and the Pacific UNESCAP, n.d.). Many regions suffer from inadequate infrastructure due to insufficient investment in water systems, resulting in an inability to fulfil present and future demands. This insufficiency leads to uneven water supplies and heightened vulnerability to shortages. The problem is made worse by ineffective management techniques and weak institutional frameworks, which make it more difficult to optimize water distribution and fix issues like leaks or unauthorized connections. Furthermore, improper management of over-exploitation of water resources leads to environmental deterioration, which further reduces the availability and quality of water. Furthermore, many nations have poor reservoir capacity to renewable water resource ratios, which restricts their potential to retain water during rainy seasons for usage during dry ones (UNESCAP, 2006).

2.4.3 Design and Operational Challenges

The design of WDNs plays a crucial role in determining their resilience and efficiency under poor supply conditions. Studies have highlighted that many existing systems are not optimized for IWS scenarios, leading to issues such as low pressure and inequitable distribution among users (Kumpel and Nelson, 2016). The operational challenges are compounded by the need for utilities to manage fluctuating demands effectively while maintaining service quality. Vairavamoorthy *et al*. (2007) highlighted the inefficiencies in pressure management within IWS, emphasizing the need for robust hydraulic modeling tools like EPANET to predict flow dynamics under intermittent conditions. Mala-Jetmarova *et al*, (2018) explored key design considerations in water distribution systems, including hydraulic performance and reliability. In their study, hydraulic performance focused on ensuring adequate pressure and flow throughout the network. Reliability emphasized the need to build resilience against failures and uncertainties, ensuring that the system can effectively handle disruptions and maintain service under varying conditions.

2.4.4 Economic and Health Impacts of Poor Water Supply

Poor water supply has serious repercussions because it exposes households to waterborne diseases that can be fatal for vulnerable people (Kumar *et al*. 2022; Adams 2018). In households without alternative sources, members must spend a greater portion of their time fetching water from various sources (Choudhuri and Desai, 2021). For instance, in rural Senegal, women and children walk 500 m to 1 km on average to obtain potable drinking water, taking an average of 30 minutes to an hour (NASD, 2021). Concurrently, water fetching has a high opportunity cost, since the activity reduces the time available for income-generating activities, employment, and educational pursuits (Adams 2018; Choudhuri and Desai 2021; Ortiz-Correa *et al*. 2016). Additionally, it increases the gender inequality gaps that exist in the global South by exposing women to sexual harassment (Dickin *et al*. 2021).

2.4.5 Limited Financial and Human Resources

Sub-Saharan Africa's (SSA) water infrastructure faces severe financial difficulties, with underfinancing being a major problem. Because of SSA's small government budgets and reliance on foreign funding, which is frequently erratic and dwindling over time, the region's water infrastructure systems are underfunded. Compared to other infrastructure sectors, the water sector attracts only 6% of global infrastructure investments (George-Williams *et al*, 2024). A 2018 report of the Organization for Economic Cooperation and Development (OECD) highlights that the money received from the 3Ts—taxes, tariffs, and transfers—is sometimes insufficient to pay for all of the expenses associated with water infrastructure, especially in developing nations. This deficit leads to rationing and unequal access to water since it causes inefficiency, subpar service, and utilities' incapacity to recoup costs (OECD, 2018). Koppen *et al*. (2009) also point out that insufficient funding for water infrastructure in developing nations frequently leads to malfunctioning systems that are unable to satisfy rising demand. They talk about how marginalized groups are disproportionately affected by inefficiencies like leakage, waste, and unstable supplies caused by an inability to maintain or modernize infrastructure.

2.5 Empirical Review

A lot of studies have been carried out on the quality of water supply, distribution network performance, and related subjects. In spite of that the problem of inadequate access to potable water for drinking and other purposes is still a serious one, if not mounting. One of the less embraced and most recent methods of analyzing water supply infrastructure and distribution network, especially in this part of the global south, especially in Lesotho, is with the use of EPANET, and the review of empirical studies in this study is, therefore based on it. Adeniran and Oyelowo (2013) used EPANET for Water distribution analysis at the University of Lagos, Nigeria. The WDN's design was predicated on the need for water, minor losses, fire demand, and population. The following data were gathered from the records of the various departments and units of the University of Lagos Water Network to conduct the analysis and simulation of the water network: population data, water supply records from 1991 to 2012, and direct sample head counts of the various sectors to ascertain the water demand at each distribution network node. The EPANET platform was given distribution network parameters, including pipe diameters, lengths, node counts, and nodal altitudes. The EPANET data made it abundantly evident that in practically every scenario, the current supplies at the nodal sites were insufficient to meet the demands.

This suggested that the water supply sources needed to be upgraded in order to satisfy the current demand, and that additional sources needed to be added in order to enhance the system's supply. The EPANET map also revealed that 36 of the 43 nodes had pressure heads that were less than the 9.0 m minimum permitted by law. This suggested that the network's pressure was generally low and inefficient. In the same study, EPANET was used to investigate the current flow and velocity situations in the pipes under the current demand conditions, and the software revealed that velocities remained within acceptable limits across the network (Adeniran and Oyelowo, 2013).

The case study in "Using EPANET for Modelling Water Distribution Systems with Users Along the Pipes" by Farina *et al* (2014) examines how EPANET can be used to better properly model water distribution networks by taking into account user demands that are distributed throughout the pipes as opposed to just at nodes. The hydraulic behaviour of water distribution systems was modelled using EPANET. The authors used an iterative process in which they distributed the overall demand among consumers positioned along the pipes and gave the pipes geometric properties (length, diameter, and roughness). A number of stages were engaged in the simulation, including the assignment of initial geometric parameters, user demand distributions, and simulations utilizing EPANET to determine discharge levels. They found out that EPANET may be used to improve water distribution system modelling by taking user needs along pipes into account. It recognized the trade-offs associated with computing efficiency while highlighting the significance of correct demand representation for enhancing system performance evaluations.

In another study, Magabatela (2024) uses EPANET to assess and enhance Tswelopele Village's water distribution system in Gauteng, South Africa. The study intends to address the difficulties the current network has, especially in providing enough water supply and allowing for more household connections. The hydraulic performance of the current water distribution network was modelled and simulated using EPANET, which included the following steps: 1. modelling the current network by configuring the original Tswelopele water distribution network with information on pipe dimensions, materials, and current node pressures, 2. pressure analysis using simulation to evaluate nodes for pressure levels and identified those that dropped below the permissible minimum threshold, and 3. suggested improvements to support an extra 35 residential connections while satisfying future water demands.

Although only one node was found to have pressure below the minimum acceptable level, the analysis found multiple shortcomings in the current water distribution system related to pressure issues. Other factors, including leaks and illegal connections, were suspected to be responsible for the irregular water supply. Inadequate infrastructure coverage was revealed by the fact that only 54 of the 89 residences in Tswelopele Village were connected to the current network.

According to the results of the EPANET analysis, additional research was required to determine the other possible sources of problems with the water supply, even though pressure levels were typically adequate. Trial-and-error and optimization findings supported the suggested improvements to enhance service delivery for more households. In the end, the study emphasized how crucial it is to use sophisticated modelling tools, such as EPANET, to guide infrastructure upgrades in water distribution networks. In summary, this case study illustrated the advantages of incorporating optimization software into conventional modelling techniques and showed how EPANET can be utilized to efficiently analyze and optimize water distribution systems, providing important insights into performance and areas for improvement (Magabatela, 2024).

A not so different study in Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur, Bangladesh examined how EPANET was used to assess and modify the water distribution system at HSTU. The study highlights the difficulties in providing for the population of the university due to insufficient water delivery infrastructure. The HSTU water distribution network was modelled and examined using EPANET. Data gathering was the first step in the process, during which important details including the campus layout, population distribution, water demand, elevations, and pipe lengths were acquired.

A model of the current network in EPANET was created using this data, taking into account crucial elements like inflows and outflows from overhead reservoirs. Critical hydraulic parameters, such as pressure head, flow rates, and head losses across the network, were then assessed using a long-term simulation. Design suggestions were developed to improve the water distribution system's performance, guaranteeing increased dependability and efficiency, based on the simulation findings. The current water distribution system has a number of shortcomings, according to the report. Many buildings were forced to rely on individual suction pumps because the current network was found to provide insufficient coverage, leaving areas of the campus underserved.

Furthermore, water supply was hampered by inadequate pressure in some locations, which had a major impact on the service's dependability. A reform of the water distribution system will greatly improve service delivery throughout the HSTU campus, according to the results of the EPANET investigation. The suggested upgrades sought to successfully handle future demands while guaranteeing sufficient pressure levels and coverage for every building.

In summary, this case study shows how water distribution networks may be efficiently analyzed and designed using EPANET. It draws attention to serious flaws such as inadequate pressure in certain areas on campus, uneven water distribution, and insufficient coverage in current systems and offers practical advice that helps direct infrastructure upgrades to satisfy the rising need for a steady supply of clean water (Hossain *et al*, 2021).

Masum *et al* (2020) studied and modeled the water distribution system of Chittagong University of Engineering and Technology (CUET) using EPANET 2.0. The study focused on assessing the distribution system's reliability, including simulations of pressure variations throughout the network. Similarly, Hossain *et al* (2021) conducted an extended-period simulation of a water distribution network at Hajee Mohammad Danesh Science and Technology University in Bangladesh. The study utilized EPANET to analyze various hydraulic parameters, including pressure head and flow rates, demonstrating its application in ensuring sustainable water supply under varying demand conditions. Research utilizing modeling tools like EPANET has shown promise in simulating various operational scenarios for WDSs under intermittent supply conditions. These models can help identify critical points within the network where improvements can be made to enhance reliability and equity in water distribution (Zyoud, 2017).

2.6 Research Gap

While many studies have seemingly been conducted using EPANET in various regions, there is a lack of focused research specifically addressing the unique challenges faced by water distribution networks in Lesotho. This includes understanding the infrastructural factors that influence water supply. Additionally, existing studies often did not thoroughly assess the physical condition of infrastructure components (e.g., pipes, pumps) when using EPANET.

Understanding the state of existing water distribution network is critical for effective planning and prioritization of upgrades. Also, research in Lesotho could benefit from a comprehensive approach that considers hydraulic modeling.

2.7 Conceptual Framework

The conceptual framework offers a structured approach for utilizing EPANET to assess a water distribution network. It lists the essential elements, procedures, and interconnections existing among variables of the research, and capable of providing a guide to conduct a thorough evaluation of system performance. The approach guarantees a methodical assessment to pinpoint inefficiencies and provide practical improvements by combining data gathering, model creation, performance analysis, and scenario testing.

This method connects technical evaluations with workable ways to improve water distribution networks.

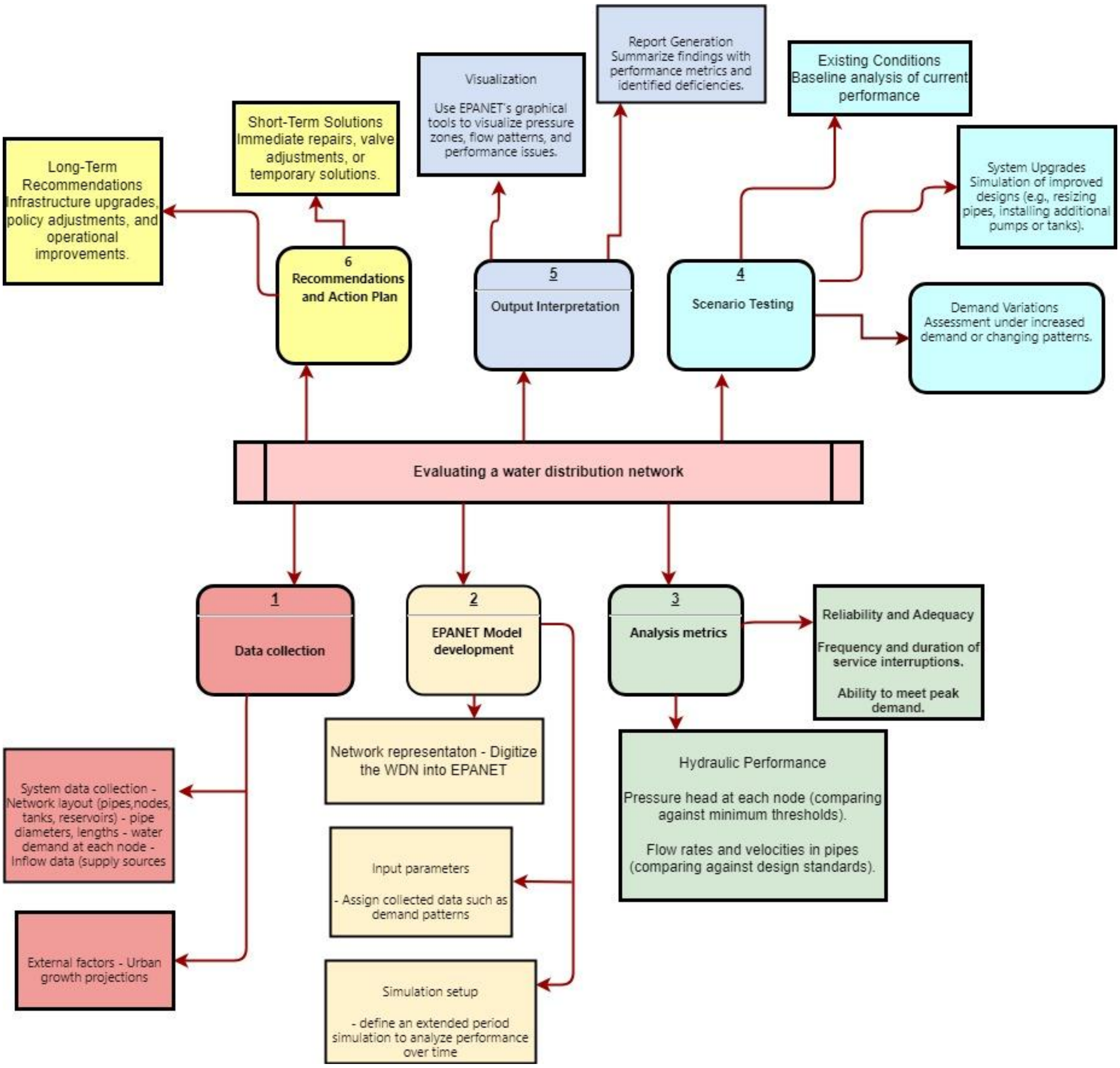

Figure 3: Conceptual Framework (conceptualized by the author)

2.7.1 Key Components of the Framework

In the framework for evaluating a water distribution network (WDN), several key variables are interrelated, dynamically influencing one another. The primary relationships emerge between data collection, model development, performance metrics, scenario testing, and recommendations.

The data collection phase establishes the foundation for the analysis by gathering information on network layout, pipe characteristics, water demand at each node, inflow sources, and external factors like urban growth. These variables are interdependent; for instance, water demand at each node directly influences inflow requirements, while pipe diameters and lengths determine flow rates and pressure conditions.

This collected data feeds into the EPANET model development, where input parameters such as demand patterns and network layout are assigned. The reliability of the model is highly dependent on the accuracy of the input data—errors in demand estimation or pipe characteristics can lead to misleading performance assessments. Once the model is developed, the hydraulic performance metrics—including pressure head, flow rates, and velocities—become key dependent variables. These performance indicators are influenced by the physical characteristics of the network, the assigned input parameters, and the accuracy of simulation settings. For instance, low pipe diameters may result in reduced flow rates and higher-pressure losses, which in turn affect the system's ability to meet demand. The relationship between scenario testing and performance metrics is crucial. Scenario testing alters certain variables, such as increasing demand or simulating pipe failures, to observe their impact on performance. A rise in demand may lead to lower pressures at critical nodes, highlighting potential weaknesses in the system. Conversely, improving pipe capacity or adding pumps in simulations can demonstrate ways to enhance reliability.

The output interpretation phase is directly dependent on both performance metrics and scenario testing. By analyzing the results, the framework identifies deficiencies in the network, such as areas with low pressure or insufficient flow. These findings guide the formulation of recommendations and action plans, where short-term solutions (such as valve adjustments) are linked to immediate deficiencies, while long-term strategies (such as infrastructure upgrades) are shaped by projected demand growth and persistent network issues.

Finally, the system upgrades phase creates a feedback loop, where implemented changes (e.g., pipe resizing or pump installations) modify the input parameters of the model, requiring a reassessment of performance. This cycle of data collection, modeling, testing, and improvement establishes a continuous relationship among the variables, ensuring an evolving and adaptive approach to water distribution network management.

In summary, the variables in this framework are deeply interconnected, forming a chain of cause-and-effect relationships. Data collection defines model inputs, which influence hydraulic performance. Scenario testing modifies key factors, affecting performance metrics and output interpretation. The analysis then informs recommendations, which, when implemented, alter system conditions and create new input variables for ongoing assessment and refinement.

CHAPTER 3: METHODOLOGY

The study utilized a mixed-methods approach, integrating both quantitative and qualitative methodologies. This approach allowed for a comprehensive analysis of water supply systems by capturing numerical data on water distribution patterns while also exploring the lived experiences of affected communities. Data collection techniques were through surveys, interviews, and field observations. Surveys quantified water access and usage patterns, while semi-structured interviews provided deeper insights into community perceptions and experiences related to water supply. Additionally, field observations assessed infrastructure conditions and operational practices in water distribution systems. Analytical strategies of quantitative data were done through statistical analysis to identify trends and correlations, while qualitative data was through thematic analysis to extract key themes and insights. Detailed information about this methodology was provided objective by objective.

3.1 Research Methods

This study used a mixed-methods approach. A mixed-methods approach is a research methodology that integrates both qualitative and quantitative research methods to provide a more comprehensive understanding of complex phenomena. This approach leverages the strengths of each method while compensating for their respective limitations, allowing researchers to explore multifaceted issues more effectively (Saraswati and Devi, 2023).

With mixed-methods approach, researchers can capture a wide range of information, including numerical data (e.g., survey results) and descriptive insights (e.g., interviews), providing a fuller picture of the phenomenon being studied (Damyanov, 2023). The methodology will encompass the gathering and analysis of both qualitative and quantitative data to understand the operational difficulties, consumers' experiences, and performance of the water distribution system. Examining previous water supply data, maintenance logs, client complaints, and infrastructure performance are important elements in understanding the effectiveness and sustainability of WDN. To simulate network behaviour and pinpoint inefficiencies, the data will be supplemented with field observations, and interviews with important stakeholders. EPANET software was used to simulate the hydraulic performance of the water distribution system, allowing for the identification of inefficiencies such as pressure drops, flow imbalances. This comprehensive research approach and strategy, are similar to those of previous studies that have successfully integrated qualitative and quantitative methods to enhance WDS performance (e.g., the review of the quantitative resilience methods in water distribution networks by Shuange *et al* (2019), will offer a thorough foundation for addressing problems with intermittent water supply.

While other water modelling software, such as WaterCAD, InfoWater, PIPE-FLO, etc., do exist for water distribution modelling, the researcher chose EPANET over them. This is because of its open-source nature and robust simulation capabilities that make it a preferred choice for analyzing hydraulic and water quality behavior within pressurized pipe networks, and because of its extensive use to simulate pressure variations and water age in distribution systems (Rossman, 2000).

3.2 Appraise the Existing Water Distribution Infrastructure System/Network in the Area Using EPANET

The appraisal of an existing water distribution infrastructure system using the downloaded EPANET Software Version 2.0 involved a systematic methodology encompassing data collection, model creation, calibration, simulation, and performance analysis. The process began with the gathering of comprehensive data about the distribution network, including pipe diameters, lengths, materials, elevations, and operational details such as pump characteristics, valve settings, and storage tank levels (Rossman, 2000). Demand data for residential usage were also collected and allocated to corresponding nodes, taking into account both spatial and temporal variations in consumption patterns.

After assembling the necessary data—such as (1) pipe specifications (diameters, lengths, and materials of all pipes in the network), (2) node information (locations and types of nodes, including junctions and storage tanks), (3) operational parameters (pump characteristics, including types, capacities, operational curves, and settings for all pumps in the system), (4) demand data (residential usage patterns, including weekly and seasonal demand profiles, peak usage times, and variations in consumption across different nodes), and (5) storage tank levels (capacity and operational limits, including maximum and minimum levels to assess supply availability under varying demand scenarios)—the EPANET model was constructed by accurately mapping the network layout and inputting the operational parameters. Initial simulations were run to check for data consistency and identify any errors in the network structure. Calibration, a crucial process in modeling water distribution systems, was performed, during which the outputs generated by the simulations—such as flow rates and pressure levels—were systematically compared against actual field measurements obtained from the real-world system (standard flow measurements). This step ensured that the model accurately reflected the physical characteristics and operational behaviors of the water distribution network. Discrepancies were minimized by adjusting demand allocations or other network parameters, such as storage tank levels, until the model accurately reflected real-world conditions (Bentley Systems, 2021). Once calibrated, hydraulic simulations were conducted to evaluate system performance. Key performance indicators—such as pressure distribution, flow rates, and velocity—were analyzed to identify areas of concern, including low-pressure zones, high head loss locations, and potential stagnation points (Awe *et al*, 2019). EPANET simulations enabled the appraisal of the network's ability to meet varying demand scenarios, including peak consumption periods and emergency conditions, in order to assess reliability and resilience (Trifunovic, 2020).

3.3 Examining the Frequency, Adequacy, and Reliability of Water Supply

Examining the water supply's frequency (how often water was delivered to consumers within a given period), adequacy (sufficiency of water supply to meet demand), and reliability in the study area required a comprehensive methodology incorporating qualitative and quantitative analyses. This methodology evaluated the operational performance of the water distribution system. The process included data collection, model simulation, and statistical analysis to assess how the water supply system met the demands of the Ha Foso community. Data collection was the first and most critical step in evaluating water supply performance. The accuracy of the analysis depended on the quality and comprehensiveness of the collected data. Data were collected on water supply frequency through surveys and/or records from the water utility company, ensuring a comprehensive understanding of how often water was delivered to consumers in the study area. Water supply adequacy was determined by the ratio of actual supply to demand and through assessments of service levels in terms of pressure and quantity. Household surveys were also used to gather information on consumers' perceptions of water supply frequency, adequacy, and reliability. Engaging consumers through community surveys captured their perspectives on water access and reliability. This was an essential step in evaluating the performance of the water distribution infrastructure.

These surveys, which included interviews with officers of the water company, provided critical qualitative and quantitative data that helped bridge the gap between technical assessments and the lived experiences of end users. The qualitative and quantitative data included information such as: 1. Customer satisfaction, based on consumer feedback regarding the reliability, adequacy, and responsiveness of water services. 2. Narratives on service challenges, reflecting personal experiences of consumers and officers of the water company concerning difficulties in accessing water, such as waiting times and stories detailing how unreliable or inadequate water supply affected household activities.

This was done through the development of a structured questionnaire that included both closed and open-ended questions. The Likert scale was used in this instance. According to Alabi and Jelili (2023), the Likert scale remained indispensable for researchers in various fields. Similarly, clear and well-defined verbal labels for each category enhanced respondents' understanding and improved the quality of responses. Examples of questions included: "On a scale of 1–5, how would you rate the reliability of your water supply?" (1 = Very unreliable, 2 = Unreliable, 3 = Neutral, 4 = Reliable, 5 = Very reliable), "How often did you experience interruptions in your water supply?" (Options: rarely, monthly, fortnightly, weekly, and daily), and "What concerns did you have regarding the adequacy of your water supply?" (Open-ended), among others. The target population was determined by identifying the demographic groups to be surveyed, ensuring representation across different user categories (e.g., residential, commercial). Distribution channels for the questionnaires were based on accessibility and convenience for respondents. Online surveys used platforms like Kobo Collect to reach tech-savvy users, while paper surveys were distributed door-to-door or at community events for those without internet access.

To analyze the data collected for evaluating the frequency, adequacy, and reliability of the water supply in the Ha Foso community, a systematic approach incorporating both quantitative and qualitative analytic methods was applied. The data were categorized into quantitative (numeric variables) and qualitative (non-numeric perceptions) types. Descriptive analysis was used to summarize key data points such as the average number of interruptions per week, average hours of water availability, and the percentage of households relying on alternative sources of water. For instance, measures of central tendency—such as the mean, median, and mode of service interruptions—were calculated to provide insights into the stability of the water supply in the Ha Foso community. For the data on the frequency of interruptions (e.g., how often water was unavailable), a frequency distribution was used to classify the interruptions into categories such as "daily," "weekly," or "monthly." This allowed for the identification of common occurrences and outliers, which pointed to underlying infrastructure problems. Regression analysis was applied to determine the relationship between infrastructure characteristics (e.g., pipe material and age) and the frequency of interruptions or the adequacy of the water supply. This approach mirrored the study by Pérez-Padillo (2023), which discussed the application of regression analysis to examine how infrastructure characteristics—such as pipe material and age—influenced water service performance. By using multiple regression models, the study assessed the degree to which independent variables (e.g., pipe condition, network coverage) influenced dependent variables such as frequency and adequacy.

Content analysis was used. It involved systematically categorizing the text-based responses from surveys to identify recurring themes related to the reliability, adequacy, and quality of water supply. For instance, the study by Koutiva *et al* (2017) applied content analysis to explore user experiences with urban water supply systems. The study identified themes such as service interruptions and customer satisfaction, contributing to a deeper understanding of the human dimension of water management. Thematic coding helped analyze qualitative responses by categorizing data into themes such as “satisfaction with supply,” “water quality,” and “frequency of interruptions.” This approach aided in capturing the human dimension of water supply reliability and adequacy, offering deeper insights into user experiences

(Maxwell, 2013). The study by Jowsey *et al* (2021) focused on qualitative data gathered from community surveys about water supply challenges. Thematic coding in that study was used to identify patterns related to satisfaction levels and service reliability. Once both the quantitative and qualitative data were analyzed, the findings were integrated. For example, the statistical analysis of water supply frequency was corroborated with consumer narratives that explained the reasons behind interruptions. Likewise, consumer feedback on water adequacy was cross-referenced with pressure and supply data to assess whether the technical system matched user perceptions.

Key performance indicators (KPIs) for water supply frequency, adequacy, and reliability were calculated based on the data. These included the frequency of interruptions—this KPI reflected the average number of interruptions per week; water availability—calculated as the ratio of hours the water was available per day to the total number of hours in a day; and the adequacy ratio—the ratio of the actual water supply (measured in liters per capita per day) to the required demand. The concept generally refers to the adequacy of water supply and sanitation services relative to the needs of the population, particularly in emergencies (WHO, 2021). These KPIs served as the foundation for performance assessments and assisted in concluding the reliability and adequacy of the water supply system in Ha Foso. The final step involved synthesizing the findings into actionable insights. These insights will guide recommendations for improving water supply infrastructure in the study area.

3.4 Analysis of the Relationship Between Water Supply Infrastructure/Distribution Network and Its Performance on Water Supply

To explore the relationship between water supply infrastructure and the frequency, adequacy, and reliability of water supply, a systematic methodology was employed to assess how infrastructure elements such as pipe condition, network coverage, and operational settings affected water supply outcomes, with a focus on the frequency of interruptions, adequacy of supply, and reliability of service. The approach involved data collection, model development, descriptive statistical analysis, and interpretation of the relationship between infrastructure metrics—such as the physical state of pipes within the distribution network, including factors like age, material type, and network coverage (measuring the extent of the water distribution network in relation to the population it served), and flow rates—and water supply performance (frequency, adequacy, and reliability).

The examination of the relationship between infrastructure and water supply involved data collection from multiple sources, including the water utility and consumer feedback. Data on infrastructure characteristics—such as pipe material, pipe age, pump efficiency, and network coverage—were collected directly from the utility company’s records. These characteristics were essential for understanding how infrastructure impacted water distribution and supply. Additionally, field measurements of water flow, pressure, and velocity at key points in the distribution network provided data to assess the current state of the network system (Rossman, 2000).

To capture water supply outcomes, data were collected on water interruptions (frequency and duration), water pressure, and the sufficiency of supply to meet demand. Surveys and questionnaires were administered to households and water users to understand their experiences with water service, including perceived reliability, frequency of interruptions, and satisfaction with water adequacy (Mantey *et al*, 2024). Once the data had been collected, it was processed and analyzed using a combination of statistical techniques along with data from household surveys and results from hydraulic modeling software such as EPANET. Analysis was employed to assess the relationship between infrastructure characteristics and water supply outcomes. For instance, the relationship between pipe age or material and the frequency of service interruptions was explored. This was done to corroborate or negate a hypothesis by van Zyl (2014) that older or poorly maintained pipes may lead to higher frequencies of interruptions due to failures or leaks. The relationship between network coverage (e.g., the percentage of the area covered by the water distribution system) and the adequacy of supply was also analyzed to determine whether increased coverage improved water supply adequacy, as was observed in a study by Henok *et al* (2018). To identify and quantify the relationship between multiple infrastructure characteristics and water supply outcomes, multiple linear regression analysis was conducted. For example, the frequency of interruptions (dependent variable) was modeled as a function of infrastructure predictors such as pipe material, age, and pump efficiency (independent variables). This regression model allowed for the identification of the infrastructure variables that most significantly impacted the frequency of service disruptions and was extended to assess other outcomes such as the adequacy and reliability of water supply (Pérez-Padillo, 2023).

Infrastructure metrics (e.g., pipe material) were treated as the independent variables (predictors) because they were expected to influence or explain variations in the water supply outcomes. Network coverage was measured as a percentage or a ratio of the area covered by the infrastructure relative to the total area (e.g., 80% of the region covered by the pipeline network). It had a meaningful zero (no coverage) and consistent intervals between values. Water supply outcomes (adequacy and frequency) were treated as the dependent variables. Adequacy was measured ordinally, as it was categorized using terms such as "low," "medium," or "high," which represented an ordered ranking of water supply adequacy. The distance between these categories was not guaranteed to be uniform (i.e., the difference in adequacy between "low" and "medium" might not have been the same as between "medium" and "high").

3.5 Analyze Key Factors Responsible For, and Effects of Poor Water Supply

To identify and analyze the key factors that contributed to poor water supply and to evaluate its effects on the community, the methodology involved data collection on the primary causes of inadequate water supply (e.g., infrastructure performance and operational challenges), as well as on the effects of poor water supply on communities—such as impacts on quality of life and economic productivity. Operational challenges were considered in this study as difficulties in the day-to-day management, maintenance, and functioning of water supply systems. The identified key factors included: 1. Maintenance – this encompassed delayed repairs or replacement of damaged pipelines, and inadequate upkeep of pumps, valves, and water treatment facilities. 2. Funding and resource allocation – this referred to budget constraints affecting regular maintenance and system upgrades, as well as limitations in the workforce available for system monitoring and repairs. Infrastructure performance in this analysis was assessed on the basis of pump and equipment failures, such as frequent breakdowns of water pumps or generators due to poor maintenance or overuse, and the lack of spare parts for timely repairs.

3.5.1 Effects of Poor Water Supply

The effects of poor water supply referred to the negative consequences that arose when water availability, quality, or reliability did not meet the needs of a population. These effects impacted multiple aspects of daily life, public health, economic productivity, and environmental sustainability. The effects of poor water supply on communities were reflected by: 1. Quality-of-life impacts—examples of how inadequate water supply affected quality of life were analyzed using measures such as the time and effort spent fetching water (e.g., long distances to access water sources). 2. Increased household costs—spending on alternatives such as bottled water or water delivery services was considered. Surveys were designed to gather both quantitative and qualitative information from households and water utility managers regarding the frequency of water shortages (continuous), with questionnaire items such as: "On average, how many hours per day was water unavailable in your household?", "How many days per week did your household experience water shortages?" For access challenges, questions were asked such as: “Rank the following challenges in accessing water in your area: distance to source, cost of water, or service reliability," and "What percentage of your household income was spent on securing water from alternative sources?" Focus Group Discussions (FGDs) collected qualitative data to explore the social and emotional impacts of poor water supply. Discussion topics included: Time spent fetching water (e.g., "How did time spent on water collection affect other daily activities, such as work or school?") Coping mechanisms (e.g., "What alternative strategies did you use when the water supply was unavailable?") Perceived quality of life (e.g., "How did poor water supply impact economic conditions in your household?").

The effect on quality of life (time spent fetching water) was analyzed by performing a regression analysis to determine how far households had to travel (independent variable) and how this distance affected other activities, such as work hours lost (dependent variable). This analysis provided a ranked list of operational and infrastructure factors contributing to poor water supply and quantified impacts on households, including financial burdens and reduced productivity. Key factors responsible for poor water supply were analyzed using views from water utility personnel as qualitative data. The independent variables were maintenance delays and resource allocation issues (e.g., workforce sufficiency and budget constraints). Workforce sufficiency reflected the adequacy of human resources available for system monitoring and repair and was measured using an interval-like ordinal scale, where: 1 = Severely insufficient, 2 = Insufficient, 3 = Moderately sufficient, 4 = Sufficient, 5 = Very sufficient. For the analysis of infrastructure performance, the study conducted a correlation analysis to assess the impact of pump and equipment failures on water supply reliability (e.g., interruptions).

3.6 Identify Strategies by Which Water Supply Infrastructure/Distribution Network can be Upgraded for Improved Frequency, Adequacy, and Reliability of Water Supply

To develop strategies for upgrading water supply infrastructure, the methodology systematically evaluated the existing system, identified deficiencies, and proposed solutions that addressed key performance metrics (frequency, adequacy, and reliability) by assessing the current infrastructure and its performance. This assessment was carried out by collecting infrastructure inventory data, including details on the existing pipe network (age, material, diameters, lengths), pumps, valves, storage tanks (capacity, efficiency, condition), and coverage area. Operational data—such as current pump schedules, flow rates, pressure levels—alongside maintenance records (frequency of repairs, failures, and replacements) and historical performance data (e.g., water loss, interruptions) were collected to support strategy development. Additionally, demand data on current and projected residential water needs and temporal variations (hourly, daily, seasonal) were gathered.

To evaluate performance, the study conducted hydraulic simulations using EPANET software. These simulations assessed the system under various conditions, focusing on pressure levels (identifying zones with low or fluctuating pressure), flow rates (detecting bottlenecks or areas with insufficient supply), and system reliability (analyzing performance during peak demand, emergencies, or component failures). The key performance metrics analyzed were: Frequency, by evaluating interruptions in water supply and their causes (e.g., pump failures, pipe bursts); Adequacy, by assessing whether the volume of water supplied met demand; and Reliability, by evaluating the system's resilience under different scenarios. These strategies were analyzed through simulation modeling in EPANET to assess how proposed upgrades would impact hydraulic performance, pressure distribution, and overall system reliability under varying demand conditions. Perspectives from consumers and water company personnel were also incorporated to identify strategies for improving the water supply system in the area. Consumers were asked to rate specific strategies based on their perceived importance using the Likert scale.

3.7 Study Area

Ha Foso is a village located along the A1 Main Road between Ha Mabote and Berea villages in Berea District. It is located at 29˚16' 00'' S and 27˚34'00E, at an elevation of 1561m (https://mapcarta.com/W261547359). Major infrastructure components include two reservoirs to supply both villages of Ha Foso and a neighboring village of Marabeng. Ha Foso, an emerging peri-urban area in the Berea district of Lesotho, faces significant water supply challenges due to rapid urbanization and inadequate infrastructure. Historically an agricultural region, Ha Foso has transformed into a residential hub, leading to a growing population and increased water demand. The area, which falls under the Maseru M.C Berea Municipal Council, relies on the city's water reservoir at *Sehlabeng sa Thuoathe* for its supply. However, the current system struggles to meet the needs of the community, resulting in inconsistent and often insufficient water availability. According to the Bureau of Statistics (2019), this village has seen an increase in population, with a record of 102 in 2016 population census, according to the Bureau of Statistics Village List of 2016. This population is projected to be 108 in 2025 using the Malthusian (Exponential) Growth Model, $P(t)=P_0e^{rt}$.

Where:

$P(t)$ = The Population size at a future time t

P_0 = The Initial Population size (at time t=0)

e = Euler's number (the base of the natural logarithm, approx. 2.71828)

r = The constant Intrinsic Rate of Natural Increase (birth rate minus death rate)

t = The Time elapsed

Initial Population (P_0): 102

Growth Rate (*r*): 0.65%, or 0.0065 in decimal form.

Time (t): 2025−2016=9 years.

$P(9) = 102 \times e^{(0.0065\times 9)}$

$P(9) = 102\times e^{0.0585}$

$P(9) \approx 102\times 1.060245$

$P(9) \approx 108.1449 = 108$

As recent as January 2024, residents of Ha Foso *Potoloha* and neighboring villages reported severe water shortages and contamination issues. Since the beginning of the festive season (November to December) in 2023, many households experienced brown, foul-smelling water flowing from their taps, rendering it unsafe for drinking, cooking, or cleaning. This forced residents to purchase drinking water or fetch it from unaffected areas, placing a significant financial burden on already struggling families.

WASCO initiated efforts to address the crisis, including a recent plan to provide 24-hour water supply to Ha Foso and another village on alternating days. However, this remained a temporary solution, as the underlying infrastructure and resource limitations persist. Reports indicate that water supply is often cut off before all households can access it, exacerbating the inequities in distribution.

The study area has 4 boreholes and a proposed line running through it as part of the Greater Maseru Water Supply Project (GMWSP). The project is for building new water transmission lines and other infrastructure in the peri-urban areas of the capital Maseru to help serve the city's growing population. Clean drinking water will be provided to an estimated 120,000 people. This will help reduce the spread of waterborne diseases, improve living conditions, and save households the considerable cost of purchasing water (OFID, 2017). Figure 6 below shows the map of Ha Foso and the delineated study area.

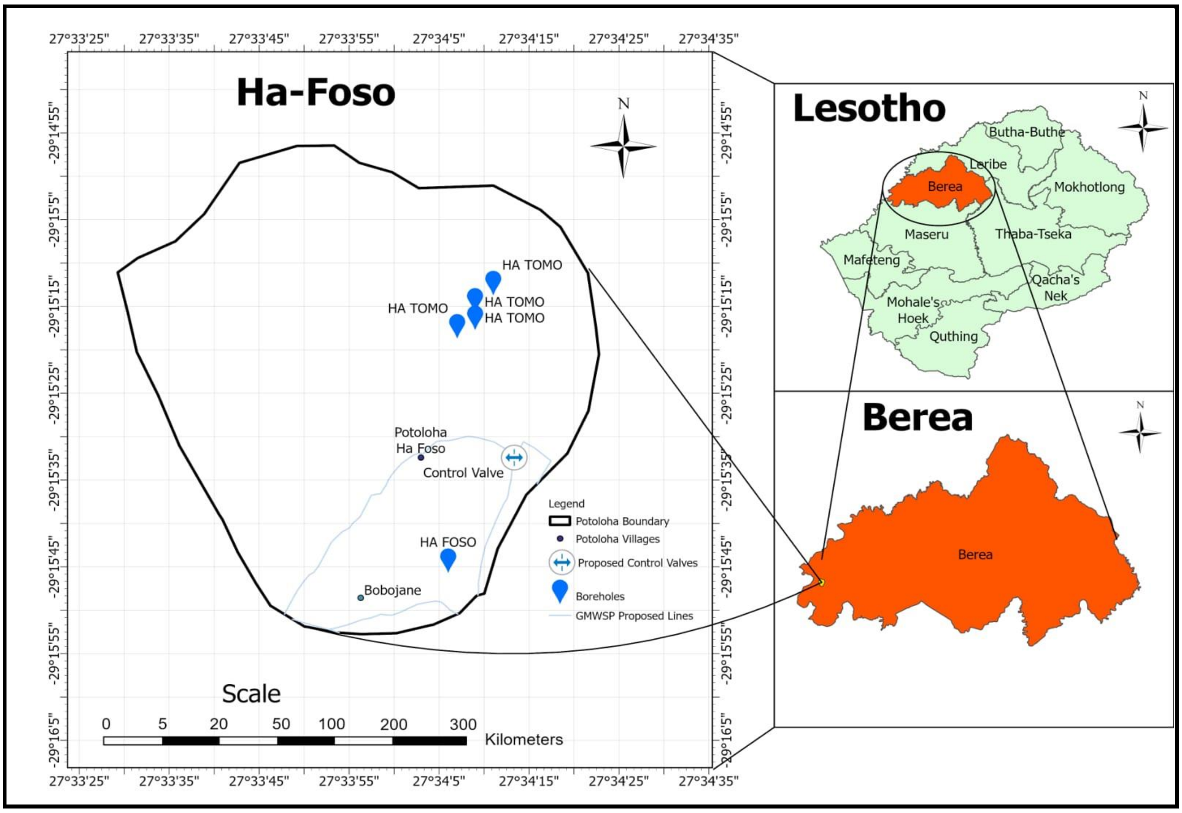

Figure 4: Map of Ha Foso (Conceptualized by the author)

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter presents data collected to examine the frequency (how often water is delivered to consumers within a given period), adequacy (the sufficiency of the water supply to meet demand), and reliability of the water supply. Consumers were engaged through community surveys to capture their perspectives on water access and reliability. Customer satisfaction, based on consumer feedback regarding the reliability, adequacy, and responsiveness of water services, as well as personal experiences of inadequate water supply affecting household activities, is captured in this chapter. Key factors responsible for, and effects of, poor water supply on the health of household members and financial burdens on alternative sources were explored. Strategies by which water supply infrastructure/distribution network can be upgraded for improved frequency, adequacy, and reliability of water supply were looked into through the perceptions of respondents. The water distribution network, drawn in EPANET, is also analyzed and discussed based on the pressure and flow of water in distribution pipes. The data for all these variables are presented objective by objective in the subsections that follow. An overview of the physical parameters of the Ha Foso water distribution network is first discussed, followed by the examination of the socioeconomic characteristics of the respondents/residents.

4.1 Overview of Ha Foso WDN

This section provides a visual overview of the key physical components that constitute the Ha Foso water distribution network. Moving beyond schematic diagrams, the photographic plates presented here serve as a ground-truthed inventory and baseline record of the system's infrastructure. These images (all conceptualized by the author) capture the actual field conditions, providing critical context for the network's operation and any subsequent analysis. These photographs establish the tangible framework of the network, forming a vital reference for understanding its physical state and operational context. Ha Foso is supplied with water from the High North Reservoir, illustrated by Plate 1 below. In a water distribution network, a chamber, as shown in Plate 2, provides protected access to key components of the system that need to be operated, maintained, or monitored, such as control valves. Plate 3 shows the manhole as a physical component of the Ha Foso water distribution network. This is a crucial piece of infrastructure that makes the entire buried water system maintainable, repairable, and monitorable. The pipeline marker, illustrated by Plate 4, provides information on the pipeline route from the reservoir to a water serviced study area of Ha Foso.

Plate 1: High North Reservoir

Plate 2: Chamber

Plate 3: Manhole

Plate 4: Pipe Marker

4.2 Socioeconomic Characteristics of Respondents

The most significant proportion of the respondents (40%) falls within the 31-45 age range. This may suggest that individuals in their early to mid-career and family-raising years are the most represented in this survey. Respondents between the ages of 46 and 60 make up the second-largest group (28%). This suggests that older working persons and those approaching or starting retirement are well represented. Young individuals (18–30 years old) make up 20% of the respondents, which represents a younger working population segment and possibly new homes.

According to this age profile, the study probably represents the opinions of a sizable portion of the adult population, who are probably directly in charge of managing household water and have long dealt with water supply issues. Their perspectives and experiences might help determine the long-term effects and possible fixes for Ha Foso's water problems.

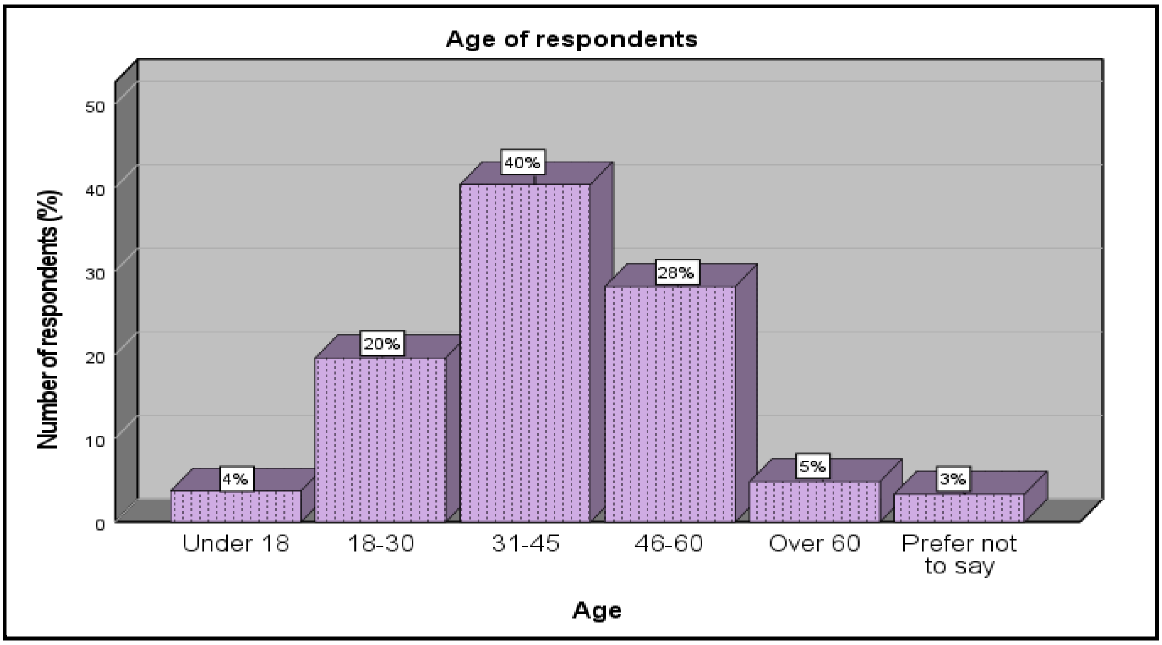

Figure 5: Age of respondents

4.2.1 Gender

The vast majority of respondents (77%) were female, making up the bulk of respondents. This suggests that the survey's participation was significantly skewed towards women. Male respondents comprise a lower portion of 22%, a significantly lower portion of the total. A very tiny percentage of 1% of respondents decided to withhold their gender. Figure 6 makes it evident that women make up the majority of the perspectives and experiences recorded in this water supply study in Ha Foso. There could be some reasons for this notable gender disparity in the sample of respondents. Women are frequently in charge of handling traditional gender roles (household duties) involving water, such as fetching, controlling its usage, and handling the fallout from inadequate supplies, in various communities, including maybe Ha Foso. They may therefore, be more immediately impacted by water-related concerns and more inclined to take part in a survey regarding them.

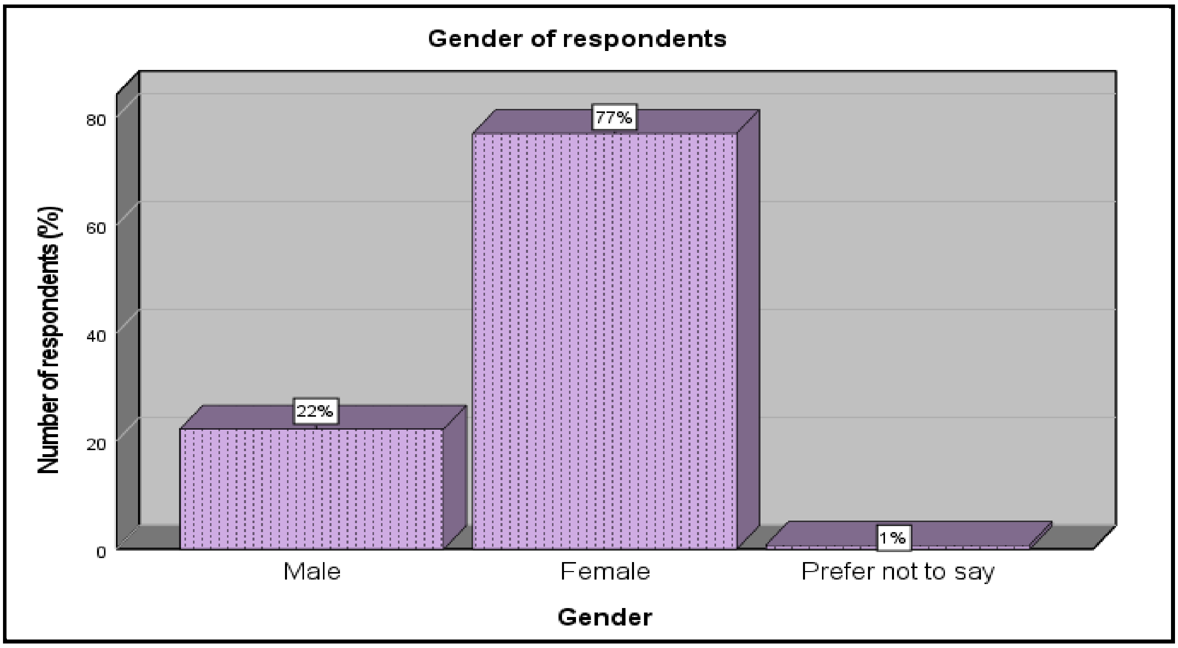

Figure 6: Gender of respondents

4.2.2 Occupation of Respondents

Not less than 66 % of the respondents were "Employed/Self-employed." This suggests that the study mostly gathered responses from those who are actively involved in business or work. A significant portion of those surveyed (23%) were "Unemployed." This implies that a sizable portion of the unemployed was surveyed. About 9% of the respondents were in the category of "Student/Apprentice,"- which represents the youths and future workforce. The percentage of respondents who are retired is under 2%. The employed/self-employed group's concerns might relate to the impact of water supply on their livelihoods, businesses, and overall economic productivity. Reliable water access is often crucial for various economic activities. The unemployed group might be particularly vulnerable to the economic burdens associated with poor water supply, such as the cost of alternative sources or the impact of water-related illnesses on their ability to seek employment. The viewpoints of students and apprentices center on how the availability of water affects their living circumstances and possibly their prospects for the future in the community. Although a tiny group, the longer-term experiences of the retired with the water delivery system may offer important historical context.

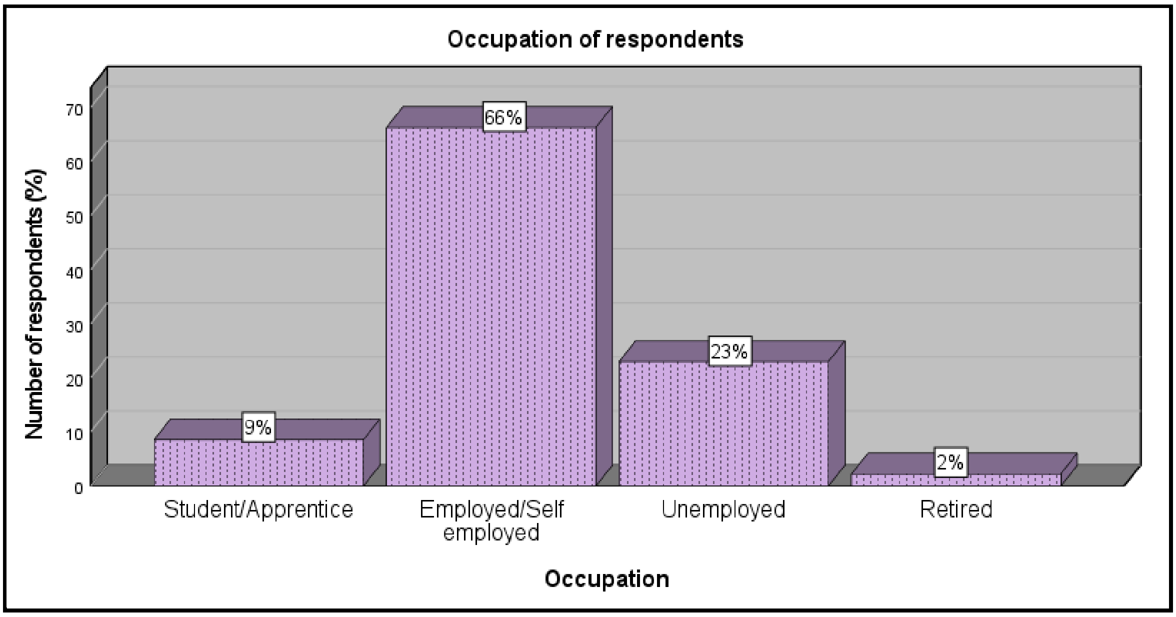

Figure 7: Occupation of respondents

4.2.3 Years of Residency of Respondents

Figure 8 illustrates the length of time the respondents have resided in Ha Foso.

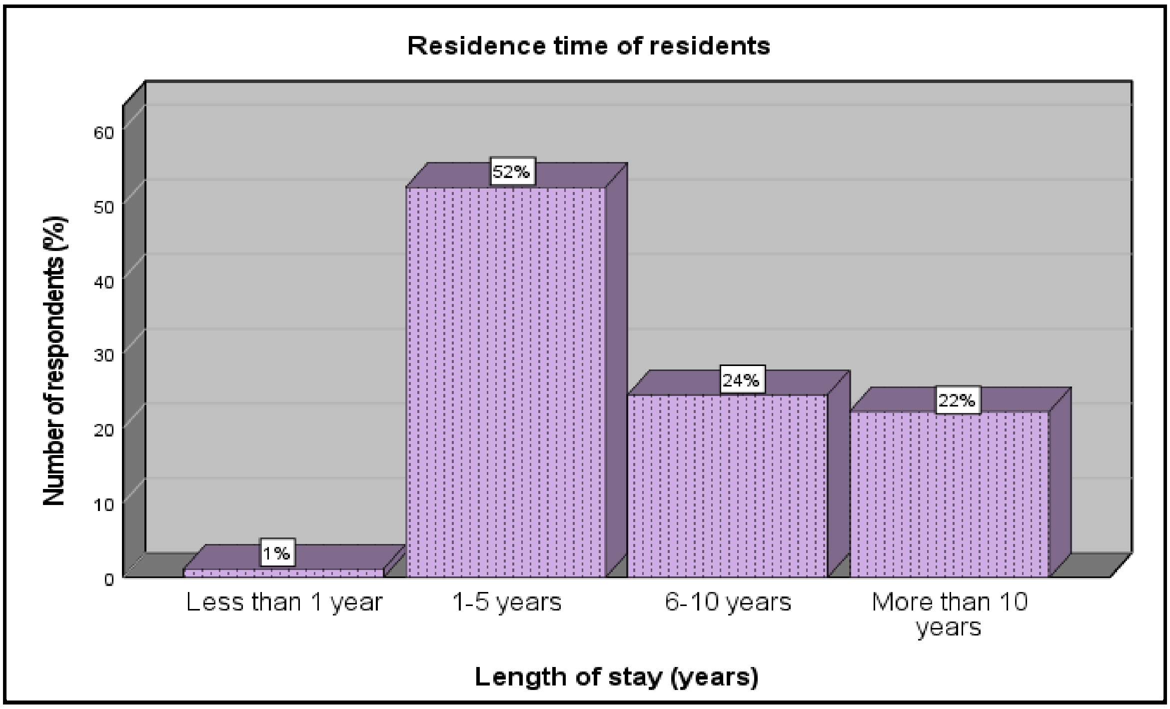

Figure 8: Residence time (years)

The most significant portion of the respondents (52%) has lived in Ha Foso for a period of 1 to 5 years. This suggests a period of significant household formation within the recent past. A considerable percentage of respondents have lived in Ha Foso for longer periods - 24% for 6-10 years and 22% for more than 10 years. This indicates a strong presence of longer-term residents within the surveyed population. Merely 1% of the participants reported having lived in Ha Foso for less than a year. This implies that the experiences of people with at least some established history in the community were the ones that the survey mainly recorded.

4.3 Appraise the Existing Water Distribution Infrastructure System/Network in the Area Using EPANET

This section presents an appraisal of the existing water distribution infrastructure system within the study area using EPANET 2.0, a robust hydraulic modeling software developed by the US Environmental Protection Agency. The appraisal aims to evaluate the current performance and operational efficiency of the water supply network, focusing on pressure and flow rate. This assessment provides key insights into the adequacy, reliability, and responsiveness of the existing system under varying demand conditions.

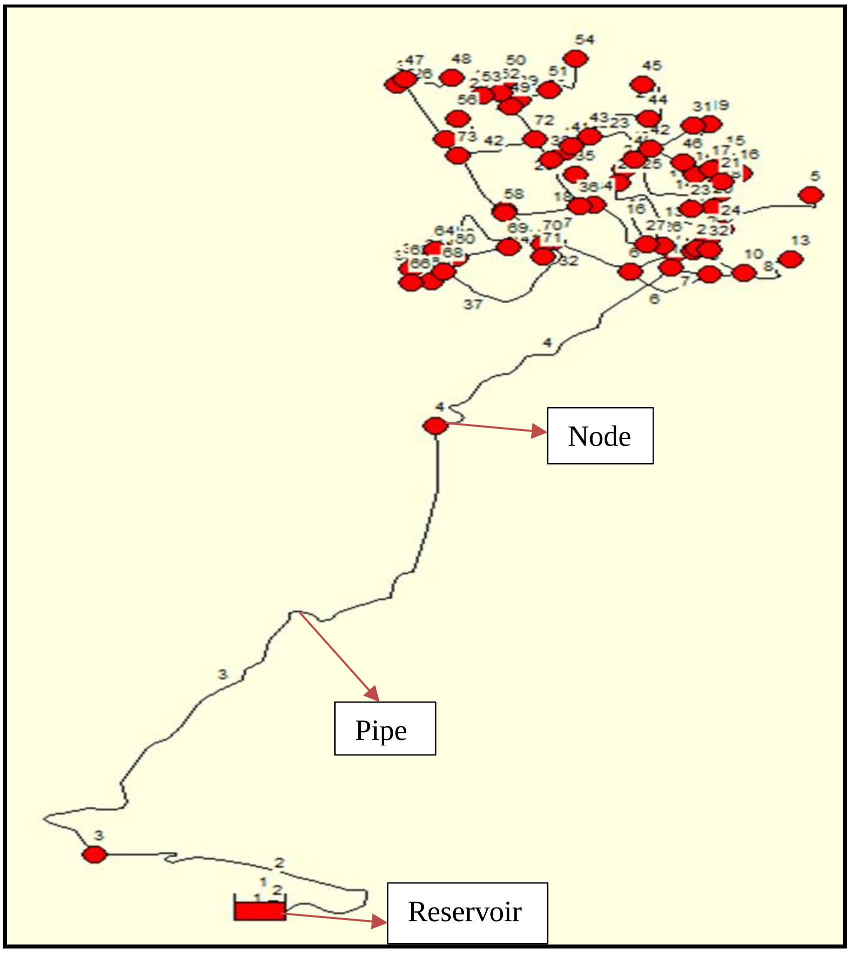

Figure 9: Distribution network of Ha Foso (nodes and pipes)

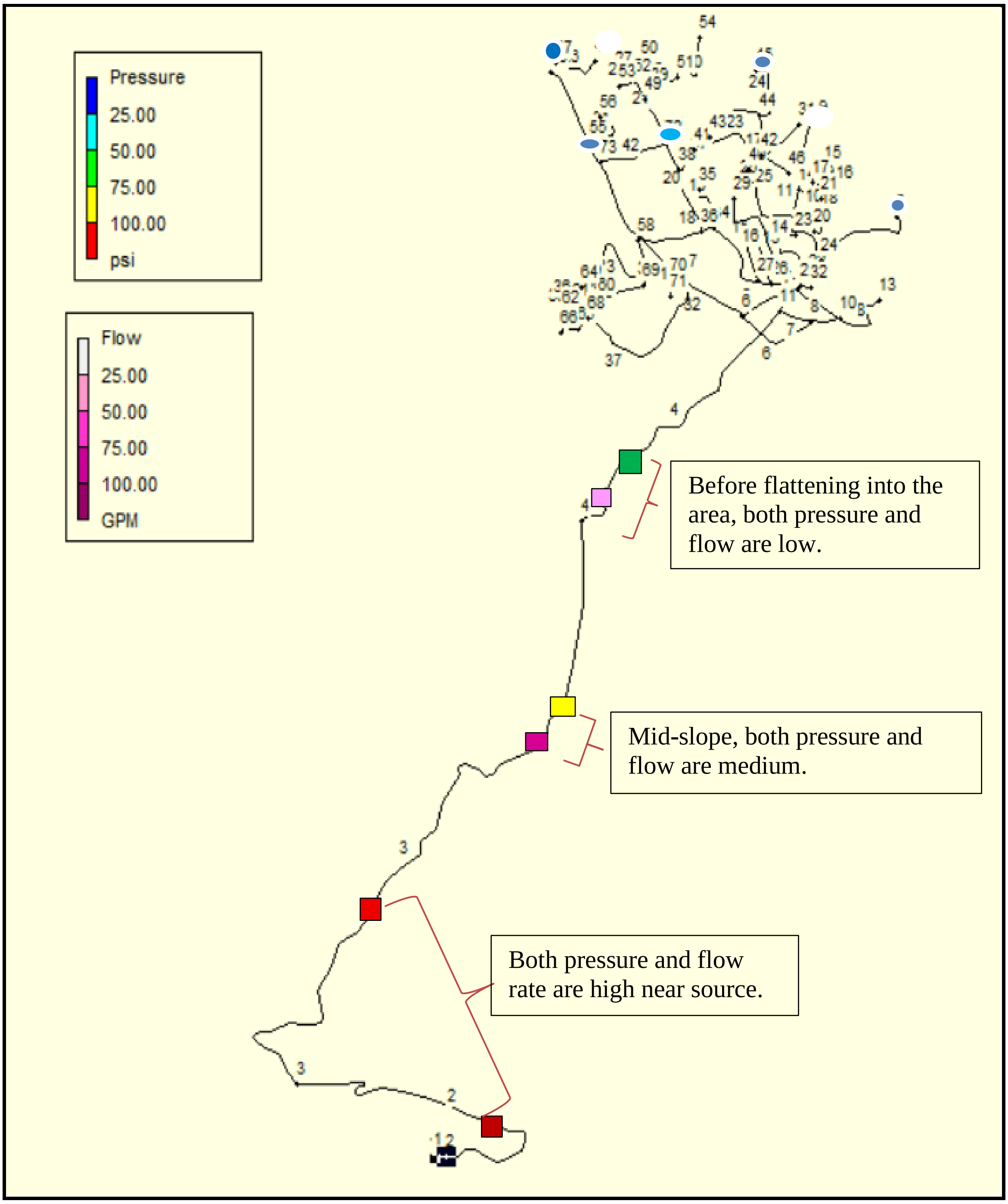

Figure 10: Distribution network of Ha Foso (Pressure and flow)

Figure 10 above illustrates the water distribution network pressure, the force exerted by water within pipes, measured in pounds per square inch (psi, used in EPANET as the default unit). 25 psi is the minimum pressure as denoted by blue dots, and the flow rate by white dots. 50–75 psi is the optimal operational range, illustrated with a green box, while flow rate is shown with a pink box, mid-slope of a pipeline route. This is where the pipeline begins to flatten out into the study area. 100 psi and 100 GPM (It is a unit of flow rate and is the default flow unit in EPANET) are high pressure and high flow rate, illustrated by the light red box and dark red box, respectively. These parameters are at a high elevation, near the reservoir, where water gravitates from. High pressure and high flow rate risk pipe bursts, leaks, or valve damage. According to the Washington Suburban Sanitary Commission (WSSS) Pipeline Design Manual of 2019, where the pressure at the connection during the maximum-day demand flow rate is between 20 and 25 psi, the installation of booster pumps by the building owner will be required. Furthermore, connections with more than 80 psi during high hydraulic grade conditions will be required to be fitted with an individual pressure-reducing valve. If pressures at connections drop to 20–25 psi during maximum-day demand (peak usage), Ha Foso's system is operating at the absolute minimum threshold for safe service. This indicates inadequate pressure resilience during peak demand, risking contamination (via backflow) and insufficient supply to consumers.

Flow rate indicates the volume of water moving through a pipe per minute (gallons per minute, GPM). An average of 25 GPM low flow typically emerges from small residential branches, nighttime demand. A100 GPM is high flow, typically from main transmission lines, and high demand. A range of between 25 GPM → 100 GPM locates pipes with stagnation (low flow) or overload (high flow) respectively. The high flows may explain recent pipe bursts that have occurred in the outskirts of Maseru.

Table 1: Network parameters of Ha Foso Network

Link ID	Length ft	Diameter in	Roughness
Pipe 1	1000	12	100
Pipe 2	2315.1	200	100
Pipe 3	5698.4	200	100
Pipe 4	9804.9	200	100
Pipe 5	3051.4	32	100
Pipe 6	4938.7	90	100
Pipe 7	4174.1	90	100
Pipe 8	7619.2	90	100
Pipe 9	4578.3	63	100
Pipe 10	1584.6	63	100
Pipe 11	7156.9	63	100
Pipe 12	2485.5	63	100
Pipe 13	4665.9	63	100
Pipe 14	8820.7	90	100
Pipe 15	5270.3	63	100
Pipe 16	8929.9	63	100
Pipe 28	2045.8	32	100
Pipe 29	9653	32	100
Pipe 30	3464.1	32	100
Pipe 31	2934.9	32	100
Pipe 32	9037.2	90	100
Pipe 33	9398.2	90	100
Pipe 34	1273.6	63	100
Pipe 35	8177.5	32	100
Pipe 36	3099	90	100
Pipe 37	1285.8	90	100
Pipe 38	4472.4	63	100
Pipe 39	2540.4	63	100
Pipe 40	6447.9	63	100
Pipe 41	8933.9	32	100
Pipe 42	4388.5	63	100

Table 1 above shows that flow enters through Pipe 1 (1000 ft, 12″ diameter), which acts as a severe bottleneck. Despite its short length, the small diameter causes disproportionately high head loss, triggering a sharp drop in pressure and flow immediately downstream.

After Pipe 1, the flow transitions into Pipes 2–4 (all 200″ diameter). These large-diameter pipes—especially Pipe 4 at 9,805 ft—minimize friction losses due to their hydraulic efficiency. Consequently, pressure and flow stabilize at moderately high levels across this segment, with only gradual declines.

The system encounters another major bottleneck at Pipe 5 (3,051 ft, 32″ diameter). Its moderate diameter and significant length drive substantial head loss, causing a second steep decline in pressure and flow. Downstream pipes (e.g., Pipes 6–8, 90″) partially recover efficiency but cannot fully offset losses. Pressure and flow progressively diminish through smaller, longer pipes (Pipes 9–16, 63–90″). At the downhill endpoint in Ha Foso, pressure and flow reach their lowest values, potentially nearing operational minima if elevation head is exhausted.

As far as flow distribution is concerned, smaller pipes (e.g., Pipe 1: 12") would dominate head loss, creating bottlenecks if demands are high. Example: A 12" pipe supplying a 200" main would act as a restrictive "valve," limiting flow. This is corroborated by Suribabu and Sivakumar (2022) in their study on the effect of water distribution network pipes size on flow rate of a house connection, and its hydraulic analysis, that the size of the main and distribution pipes determines the level of delivery to the customer. The study shows how the pipe sizes affect the flow rate at the service connection. Compared to the network made of bigger diameter pipes, the network composed of smaller pipe sizes may require a longer supply time to meet the volumetric demand (Suribabu, and Sivakumar, 2022). Industry Training Authority BC (2023), further asserts that when an undersized water pipe operates, it may cause an excessive pressure drop, which could cause an adjacent valve to abruptly run out of water. Similarly, a flush valve may not operate correctly if there is an extreme pressure drop brought on by flow (Industry Training Authority BC, 2023).

4.4 Examining the Frequency, Adequacy, and Reliability of Water Supply

Water supply access in this study pertains to how many times consumers are supplied with water in their households in a week, how many hours per day consumers have access to water (frequency), and whether or not there are interruptions/discontinuities in the water supply to the consumers (reliability). Figure 11 below purports that 49% of residents in Ha Foso are of the view that they are supplied with water several times in a week, while only 18% are of the perception that they are supplied with water daily.

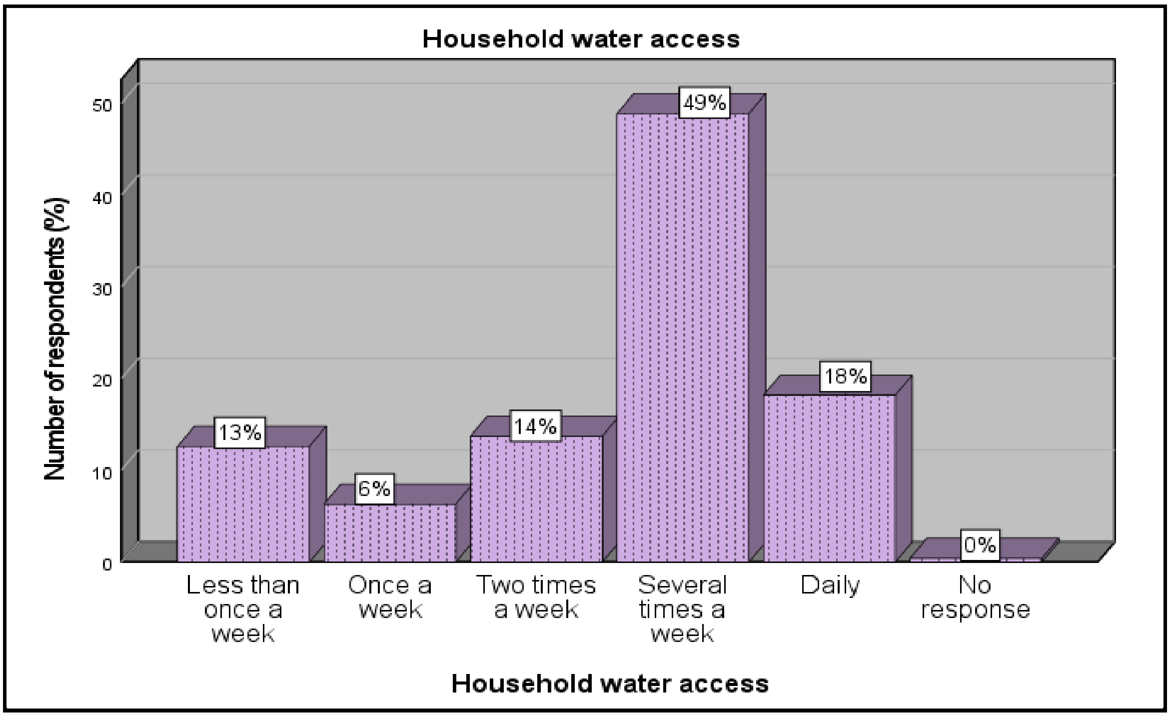

Figure 11: Weekly household water access

Their difference in the perception of the frequency of water supplied weekly may be attributable to several factors, including but not limited to peak demand times. Water pressure may decrease during times of heavy demand, which could impact supply in some places. The frequency of supply may be lower for households located farther from the source or at higher elevations. Various households may receive water on various schedules if the water supply is handled in zones. As a result, some residents might receive their supply every day, while others would receive it less frequently. Also, the perception of consumers in this area may be subjective. Depending on their usage habits, residents may have different opinions about how frequently the water delivery occurs.

A household with low water use, for instance, might believe they have enough water each day, but a larger household with higher water use would think the supply is insufficient or infrequent. Other than that, households without storage may encounter and report shortages more frequently than households with storage tanks or containers who may not notice supply disruptions as much and claim daily supplies. Cases of divergent views on the frequency of water supply can be likened to case of rural water supply in Maharashtra India, where 68.9% of homes reported receiving water daily, 12.5% reported receiving water every alternate day, and 18.6% reported receiving water once every three or more days (Sakthivel*, et al*, 2015).

4.4.1 Hours of Access to Water Per Day

Figure 12 below shows the average number of hours for which households have access to water on a day of water supply. Not less than 39% of consumers report that they can access water for more than 6 hours but less than 24 hours when it is available. Only 2% alluded that they only access it for less than one hour. Also, 30% of the consumers are of the view that they access water for 24 hours when it is supplied, which could mean that for them, water is of continuous supply, while for the rest of the consumers, it is intermittent. The difference in the hourly access of water by the residents of Ha Foso, could depend on their relative proximity to the reservoir. Residents close to the reservoir may get more hours of water supply than those further from it.

This observation is similar to one from the study at University of Toronto on intermittent water supply by Meyer (2022), who concludes that "If you live close to the reservoir, you might get more water than the person who lives at the top of hill, far away from the reservoir,". Also, Ha Foso emerged as an encroachment into agricultural land, which may mean lack of proper planning. Unplanned settlements often lack adequate water infrastructure, resulting in reliance on irregular or unreliable supply sources. This has been the case in the study by Aydamo *et al* (2023) in the Peri-Urban and informal settlements of Hosanna Town, Southern Ethiopia, where the majority of the studied households living in the selected peri-urban and informal settlements had access to unreliable drinking water sources.

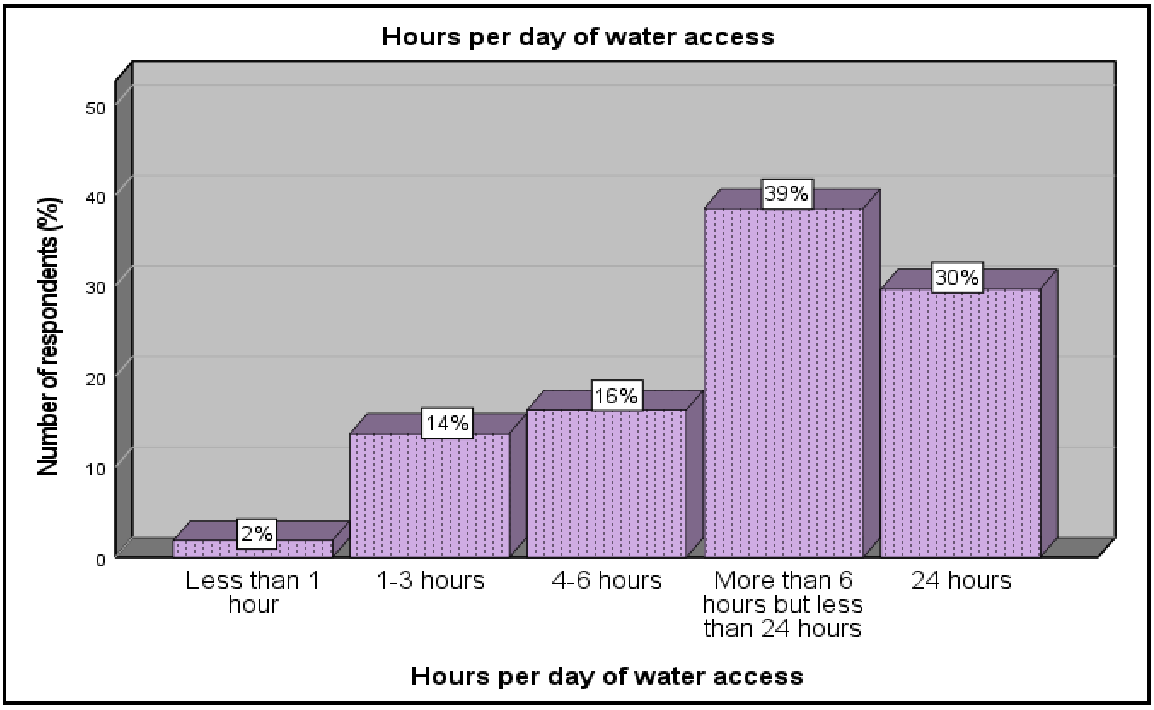

Figure 12: Hourly access to water per day

The implication for the intermittency calls for the need to have storage tanks. This is similar to the study by Edokpayi *et al* (2018), who concluded that despite having piped water connections to homes in certain areas, the storage of water in home tanks is necessary to curb the effects of intermittent supply. The situation in Ha Foso could be due to a necessary hourly water rationing because of the water scarcity problem the area is facing. The residents fall within the more than a billion people who get their daily water needs from water networks called intermittent water supplies (IWS). That means, rather than water constantly flowing, 21% of the world's water pipes turn on and off every day, according to Meyer (2022).

4.4.2 Water Supply Interruptions

In this study, water supply interruptions refer to a situation in which the regular delivery of drinkable water is interrupted or ceases. This indicates that water is not passing through the pipes as constantly as it ought to. Figure 13 below displays that irregular supply interruptions of Ha Foso have been experienced by 46% of the surveyed residents. This indicates that consistent, daily access to water is not the norm for a larger population in the area. The findings also suggest that disruptions are not perceived as frequent. A significant portion of respondents (49%) reported experiencing "No" interruptions in their water supply. This indicates that almost half of the surveyed population has a relatively consistent water service. One of the potential causes of the water supply's erratic behaviour for the rest of the population could be inadequate capacity, as the distribution system might not be built to accommodate the region's water demands. This result is in line with the graph ("Number of times of water interruption(s)"), which demonstrated that although most respondents did not record any interruptions, a sizable percentage did suffer interruptions at different frequencies. The substantial percentage of the community that copes with the instability of their water supply is highlighted in this graph, which offers a more binary viewpoint.

Nearly half of the respondents reported disruptions, indicating a serious problem that must be resolved to guarantee all Ha Foso inhabitants have steady and dependable access to water. These disruptions may be caused by anything from supply constraints and water rationing to maintenance issues and infrastructure failures. In the study of Water supply interruptions in the Umzinto water system in Ugu District, South Africa, the findings reveal that most of the current water and wastewater infrastructure was of varying ages and in varying conditions, while most were simply too old. Old age was one of the reasons for infrastructure breaking down more often, thus causing supply interruptions (Mwelase and Dzwairo, 2021).

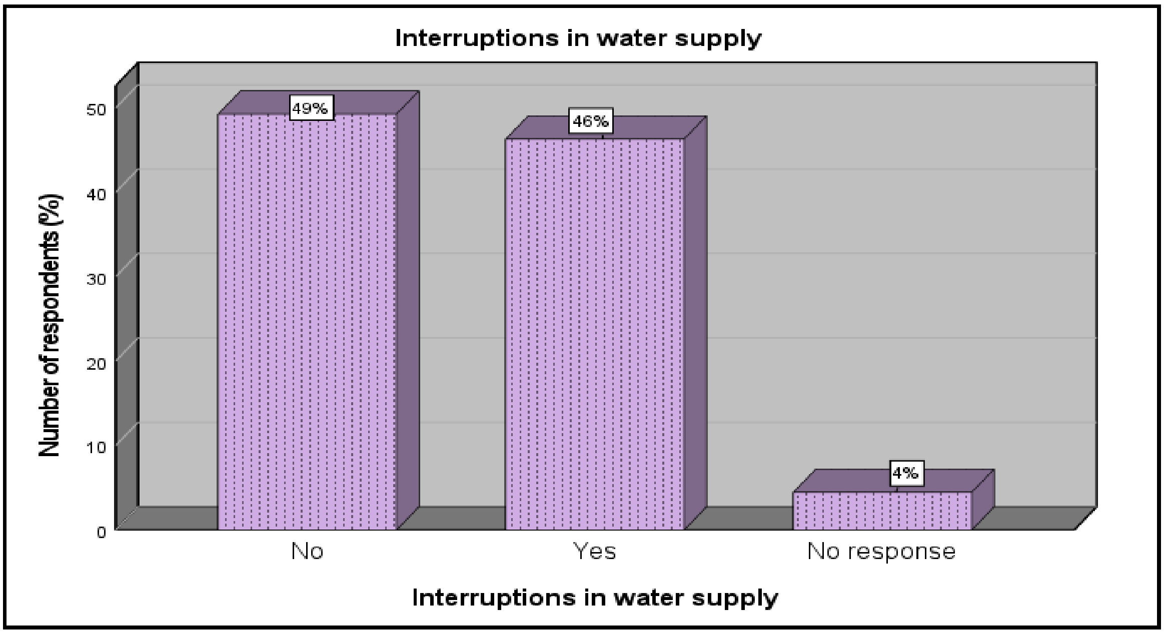

Figure 13: Experience with water supply interruptions

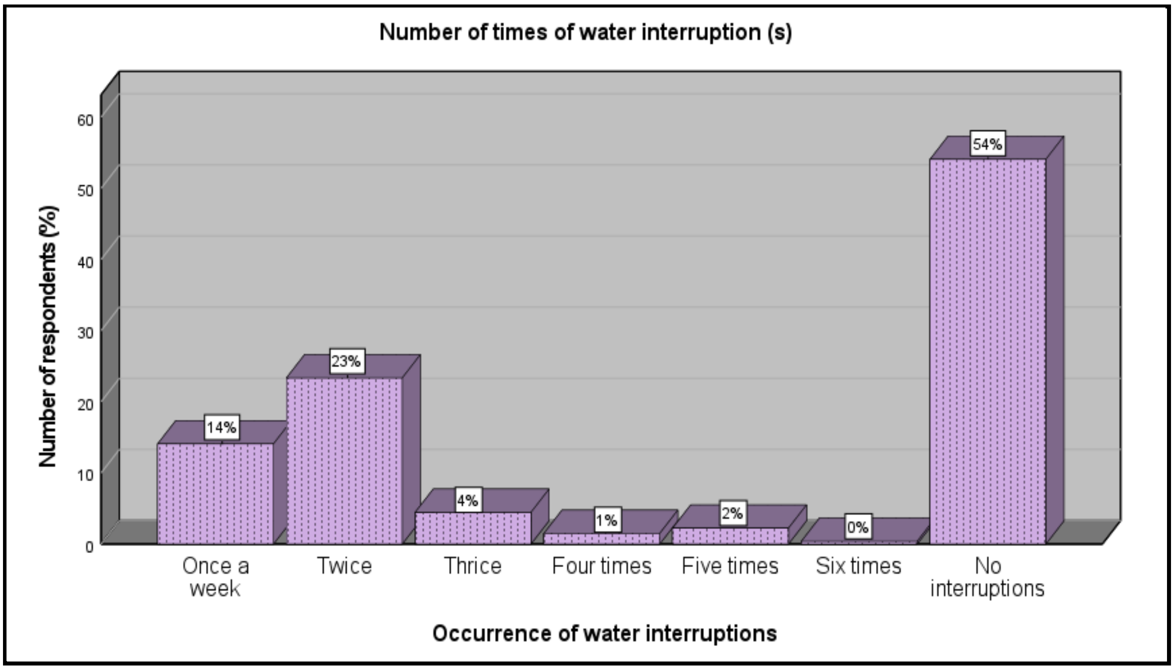

Figure 14: Occurrence of water supply interruptions

In Ha Foso, sporadic water delivery is common. When the water supply is not constant and is frequently or irregularly interrupted, it is referred to as an intermittent supply. Intermittent water supplies directly affect 46% of respondents who report one or more disruptions per week (14% + 23% + 4% + 1% + 2% + 0%). This indicates that nearly 50% of the population surveyed lacks consistent and dependable access to water via the piped system. These disruptions occur at widely disparate intervals. The fact that some people encounter it once a week while others do so several times suggests that the community's service reliability varies. A significant majority of respondents (54%) reported experiencing "No interruptions" in their water supply. This suggests that over half of the surveyed population has a relatively consistent and reliable water service. It should be noted, however, that those reporting "No interruptions" might still experience other issues associated with poor supply, such as low pressure (as indicated in a previous graph), even if the water does not completely cut off.

Intermittent flow can result from inadequate pressure, particularly in regions with higher elevations. The findings in Ha Foso are corroborated by findings from a study in South Africa. According to estimates from the South African case study, 39.3% of the country's population suffers from intermittency in some capacity, with 9.2 million of those affected living in the provinces of KwaZulu-Natal and Gauteng. Additionally, it was discovered that 29 of the 54 towns that practice IWS most likely do so permanently (Chimbanga, 2019). The findings from Ha Foso negate WASCO's Code of Practice: Water Supply Services, which states that the water utility's supply systems are continuously augmented to provide water for at least 18 hours per day. The code of practice further states that WASCO's pumps have a stand-by measure to ensure that there are the least disruptions to the supply and that the duration of disruptions is minimized (WASCO, 2023). This code of practice does not hold true for at least 46% of the respondents.

4.4.3 Water Supply Adequacy

Water supply adequacy suggests the sufficiency of water supply to meet demand/daily needs.

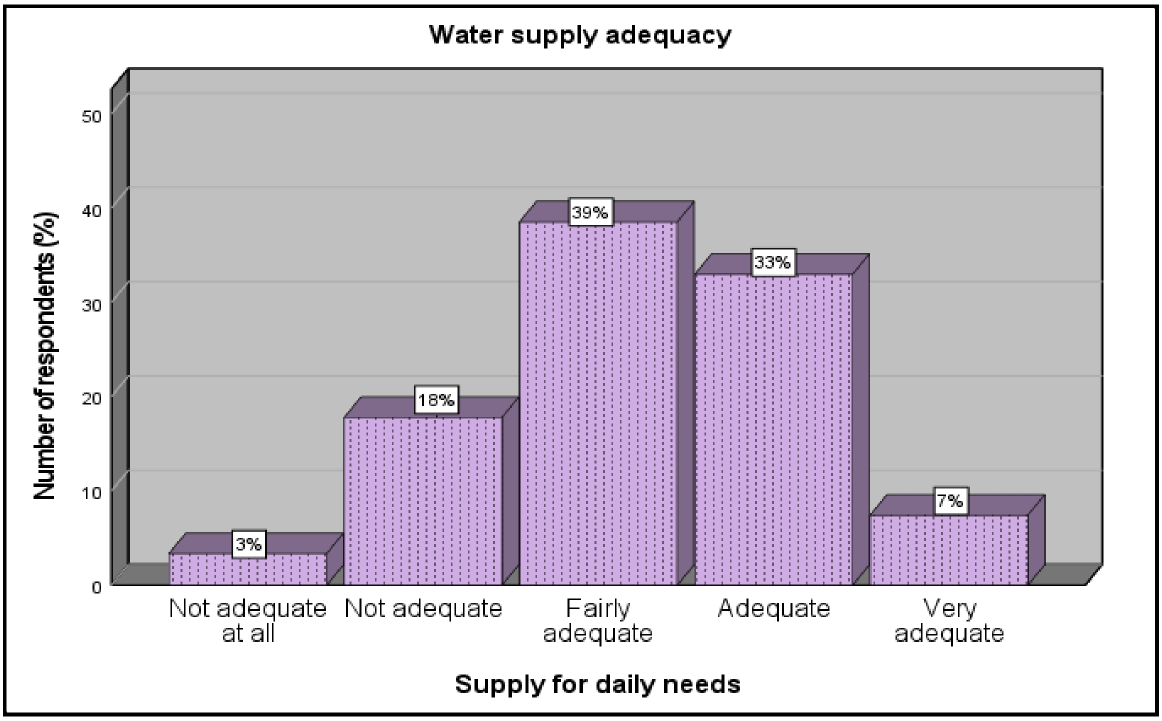

Figure 15: Water supply adequacy

Figure 15 shows that 3% of Ha Foso residents assert that the water supplied is not adequate at all for their daily needs. A further 18% report that indeed water supply is not enough to meet their daily demand, while 33% do believe that there is enough water supply to meet their daily needs. The combined proportions of 18% and 3% of people who consider water to be "not enough" and "not adequate at all" respectively, is 21%. This suggests that water scarcity affects more than 20% of the population. This represents a substantial portion of the population. The findings indicate a glaring problem with the supply of water for everyday requirements. However, there is a notable difference in perspective, as seen by the fact that 33% of respondents think the water supply is sufficient.

These differences in perception can be attributed to some factors, which are: 1. Geographic variation, in that there may be steadier supplies in Ha Foso in places with greater infrastructure or nearer to water sources. On the other hand, shortages might be worse in places with higher elevations or those that are farther from distribution points. 2. Socioeconomic disparities, where wealthier households may be able to mitigate the effects of shortages by having access to other sources or private water storage. Because they might only use the public supply, poorer households are more susceptible to disruptions.

4.4.4 Primary Uses of Water

The various uses of water by the residents of Ha Foso, as depicted by Figures 16, 17, and 18, are validated by the World Health Organization (WHO), which states that water is the essence of life; without water, human beings cannot live for more than a few days. It plays a vital role in nearly every function of the body, protecting the immune system (WHO, 2003). The organization further denotes that water is also essential for hygiene, growing food, keeping animals, rest, exercise, and relaxation, and for a variety of social and cultural reasons. The General Comment 15 on the water right also asserts that an adequate amount of safe water is necessary to prevent death from dehydration, reduce the risk of water-related disease, and provide for consumption, cooking, personal and domestic hygienic requirements (UN. Committee on Economic, Social and Cultural Rights 29th sess, 2002).

Figure 16: Uses of water for bathing and drinking

The amount of water a person needs for drinking and food preparation varies considerably, depending on their diet, climate, and the work they do. The minimum amount of water needed for drinking ranges from about 2 litres in temperate climates to about 4.5 litres per day for people in hot climates who have to carry out manual work (Howard and Bartram, 2003). Also, the high percentage of residents from Ha Foso who use water for drinking contributes to the MDG target of halving the proportion of the population without access to safe drinking water, which has been met as shown by the United Nations (WHO and UNICEF 2012a).

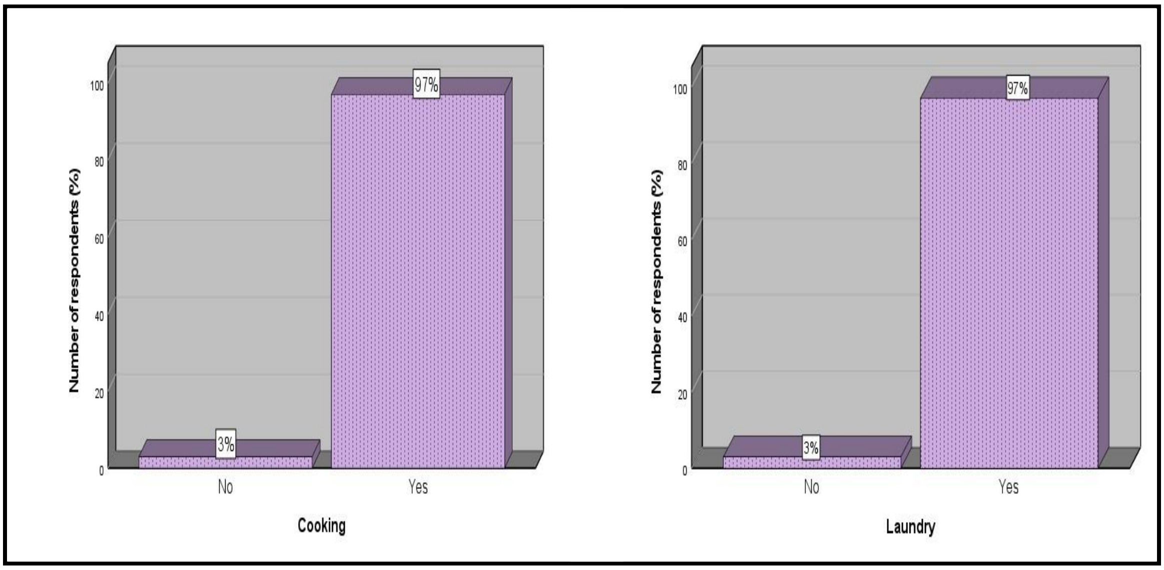

Figure 17: Uses of water for cooking and laundry

Just 3% of those surveyed said they do not utilize other sources of water for cooking. This implies that for this necessary domestic chore, the great majority rely on outside sources. Not less than 97% of those surveyed said they do utilize other sources of water for cooking. This demonstrates how heavily non-primary water sources are used for food preparation. The scope of the General Comment on the right to water concerning cooking is restricted to aspects of household use: water as an ingredient of foodstuffs (e.g. rice, pasta, bread), and water as a requirement for food hygiene – to ensure that food is safe to eat.

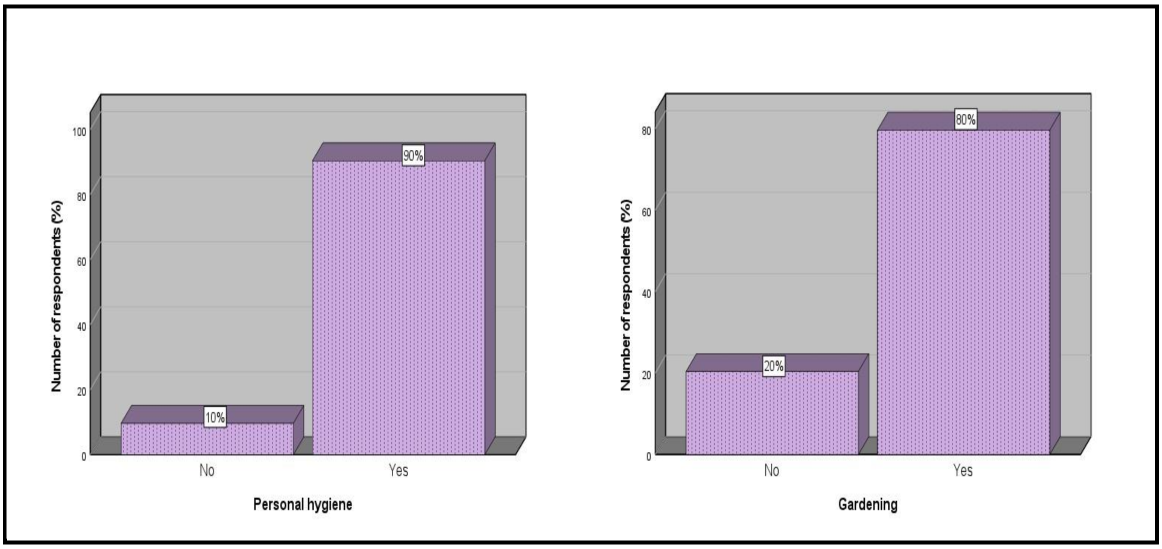

Figure 18: Uses of water for personal hygiene and gardening

4.4.5 Customer Satisfaction with Quality of Supply

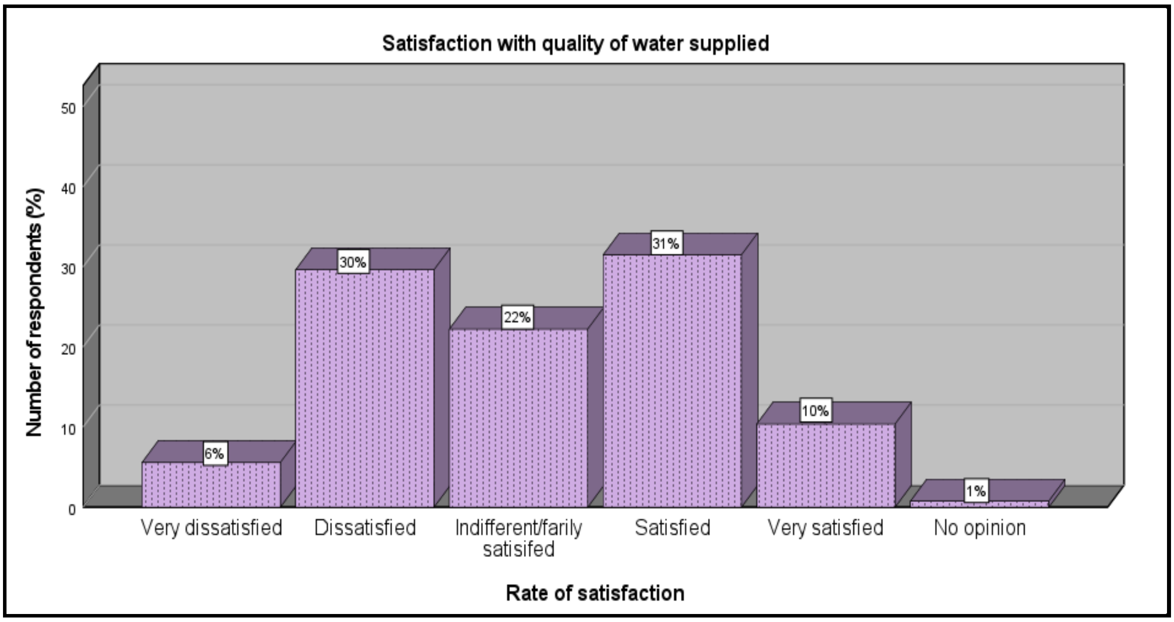

Figure 19: Customer satisfaction

Consumer satisfaction data was based on the lived experiences of water users regarding water supply. Satisfaction was also influenced by the consistency and reliability of the water supply, which includes consistent water pressure, freedom from frequent interruptions, and predictable supply schedules. The findings of these data are shown in Figure 19 above. The very satisfied (10%) group represents those who are highly pleased with the quality, frequency and reliability of their water supply. While not the largest group, it indicates that a portion of the population is experiencing a high level of satisfaction. The combined dissatisfaction (36%) group represents those who are unhappy with the quality of their water supply, ranging from general dissatisfaction to strong dissatisfaction. This is now the largest finding that highlights a significant problem with water quality.

These findings are similar to those of a study in Nigeria on residential customers' satisfaction with public water provision in Ojota, Nigeria, where responses to the first satisfaction of water quality indicated that over 80% of respondents are either fairly, poorly or not satisfied with the quality of water from the public utility; while only 19.74% were either very satisfied or satisfied (Ohwo and Agusomu, 2018). The findings on the satisfaction or lack thereof, is similar as well to the findings from a study in two provinces of Hubei and Shangdong in China, where a more significant proportion of the population was both concerned and dissatisfied with the quality of water supplied (Li, Cohen, Li, *et al*, 2020).

There are numerous indicators that consumers would have realized about the quality of water even though the laboratory water analysis was not conducted. These indicators may include the taste of the water that may be used by respondents to assess its quality. Unusual tastes or off flavors would create unfavourable impressions. Bad odors would be a sign of low quality. Appearance of the water, turbidity (cloudiness), discoloration (e.g., yellow, brown), or visible particles would be strong indicators of poor quality. These possible indicators of poor water quality are according to WHO (2022). Unappealing water will cause complaints, erode consumer confidence, and give the impression that the product is of low quality. The guidelines also specify that the consumer should be satisfied with the drinking water's appearance, taste, and odour (WHO, 2022).

Lasco and Hardon's (2024) study on sensing, knowing, and making water quality along the Marikina River in the Philippines supports consumers' sensory perception of poor water quality. They found that people used sensorial attributes—either directly through their senses and embodied experiences or indirectly through other things—to measure daily changes in water quality.

4.4.6 Water Supply Reliability

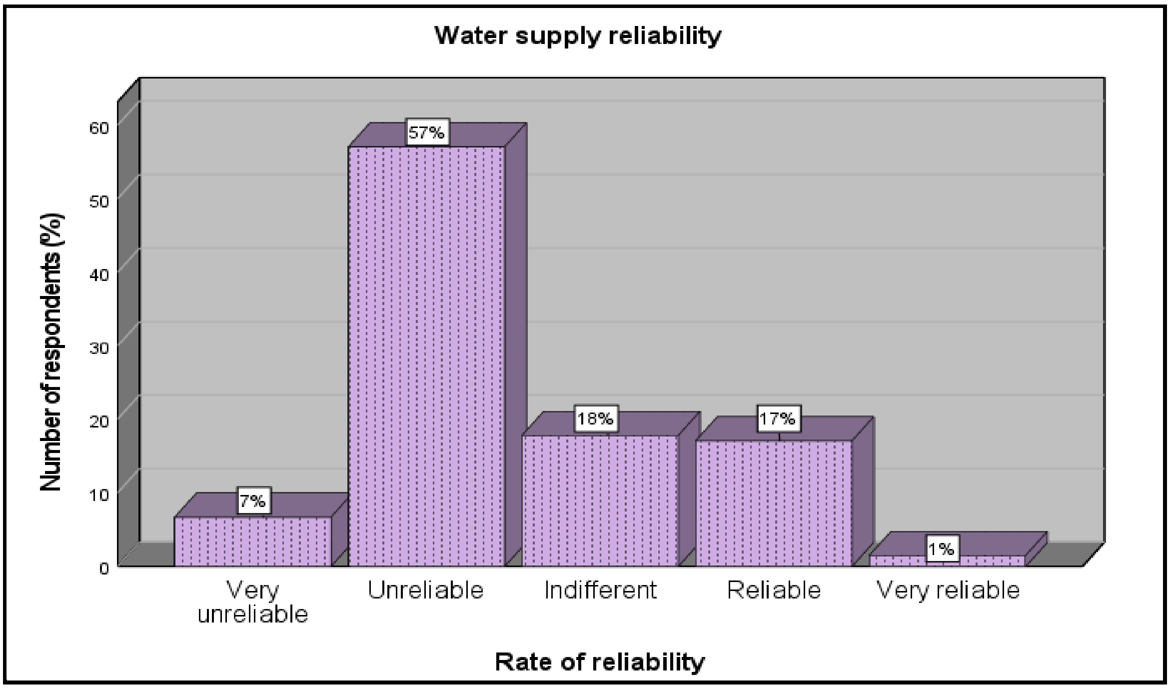

Figure 20: Water supply reliability

From the perspective of end-users in Ha Foso, water supply reliability is not just about having water, but it is about having consistent, predictable, and adequate access to it. It is also about sufficient pressure to meet household needs. Consumers want water to flow when they expect it to. In this area, a significant number of respondents (57%) are of the view that the water supply is unreliable. This group, combined with the 7% that views water supply as very unreliable, creates an undeniable view that water supply is indeed a problem in the area. Infrastructure deficiencies such as aging pipes and distribution networks, leaks, cracks, and blockages in aging infrastructure may have led to frequent disruptions, hence causing the perception of unreliability of water supply.

Very few respondents (17%) believe that the water supply is reliable. This is the group that likely experiences a more consistent water flow with minimal interruptions. They likely experience adequate water pressure. In their capacity, they may have access to water storage facilities, allowing them to mitigate the impact of occasional interruptions. The unreliable nature of the water supply is also similar to the Water crisis in South Africa's study, that currently, 19% of the population lacks access to a reliable water supply and over 26 % of all schools (urban or rural), and 45 percent of clinics, have no water access either (Igamba, 2022).

The results from Ha Foso are also corroborated by studies from South Africa, which have shown that the reliability of water services and infrastructure, as shown by frequent water supply interruptions, has been on a downward trend. On the other hand, the portion of households with reliable and safe water supply services, such as having clean water sources not too far from their household, decreased by 64% in 2018 from 67% in 1993 to an estimated 85% in 2015. The decrease in reliability is shown in the study by du Plessis (2022), where for every province in South Africa, water supply reliability is lower compared to the access to water infrastructure delivered.

4.5 Analysis of the Relationship Between Water Supply Infrastructure/Distribution Network and Its Performance on Water Supply

Table 2 below illustrates different parameters of the water distribution network infrastructure, such as pipe diameters, the material of pipes the utility uses, years of installation, and pipe lengths.

4.5.1 Pipe Material: HDPE

The pipeline of Ha Foso is made up of High-density polyethylene (HDPE) material. Ori-Plast Healthy Pipes (2023) asserts that HDPE, a robust and pliable plastic that is impervious to abrasion, corrosion, and chemical deterioration, is used to make polyethylene pipes. Water supply, gas transportation, and sewage systems are just a few of the many uses for them. Because polyethylene pipes do not corrode and do not release dangerous chemicals into the water, they are frequently utilized in drinking water delivery systems. They are a great option for isolated and difficult-to-reach locations because they are lightweight and simple to install.

According to InfrastructureNews (2024), the long-term solution to South Africa's water infrastructure problems has been the installation of premium HDPE pipelines. These pipelines, which have a potential lifespan of up to 100 years, provide sustainability, cost-effectiveness, and durability, aiding in the fight against the nation's continuous water losses brought on by ageing infrastructure. Williams (1984) in Vlase *et al,* (2020), denotes that some reasons can lead to damage to HDPE polyethylene underground pipelines, and these factors can be categorized as follows: internal circumstances (medium-transported temperature, high pressure, and changing pressure), installation-pipe laying (inadequate planning, mistakes in laying, mishandled materials).

4.5.2 Unplasticized Polyvinyl Chloride (uPVC)

The findings from Ha Foso show that the pipeline is made up of uPVC material. Despite being lightweight, flexible, corrosion-resistant, and simple to join, uPVC is vulnerable to impact damage, UV deterioration of exposed pipes, and locating leaks is challenging, and they are not appropriate for large diameters (Tsakiris and Tsakiris 2012). uPVC pipes, however, may contain lead due to the use of lead compounds as the stabilizer during the manufacturing process (Zhang and Lin, 2015). During the manufacturing of these pipes, stabilizers are frequently included with PVC powder to improve their thermal stability and prevent thermal deterioration. In one investigation, three locally acquired uPVC pipes (marked P1, P2, and P3) with an inner diameter of 25 mm were utilized for conveying drinking water. In all three pipes, lead was discovered on the pipe surfaces. The conclusion was that Lead compounds used as stabilizers in uPVC pipes have the potential to leak into drinking water and raise lead levels (Zhang and Lin, 2015). The same results of lead contamination were found in a study by Mehdar (2025) to who evaluated lead leaching from uPVC pipes into drinking water.

4.5.3 Pipe Length

The maximum length used by WASCO in the distribution network of Ha Foso is 5972.7 mm, and the minimum is 128.14 mm. One of the most crucial pieces of infrastructure for collecting, cleaning, storing, and distributing water from its source to its place of consumption is the drinking water distribution system (DWDS) (Agudelo-Vera *et al,* 2020). However, the water must frequently pass through kilometers of water pipes before it reaches the tap, which could alter its parameters (Gomes *et al*, 2014; Waller *et al*, 2018; Goraj *et al,* 2021). Microorganisms that can grow directly in the water column and in the form of biofilm on the inside surfaces of pipes are an intrinsic component of the WDS (Chan *et al*, 2019). The size of the DWDS also determines the time it takes for water to go through the system. The water used to characterize large and highly looped systems would therefore have a lower chlorine concentration, which may encourage the growth of microbes and the production of biofilm (USEPA, 2002). Because there are more leakage spots and pressure fluctuations in longer distribution networks, water losses are typically higher. NRW rises with network length, particularly in ageing networks with inadequate maintenance, according to a 2019 study by Liemberger and Wyatt (2019).

Taha *et al* (2020) believe that, in general, high-density networks, which consist of shorter pipes serving a greater number of connections, are more effective at managing pressure and delivering water. The authors have shown that minimizing needless extensions and optimizing pipe length can save on leakage and operating expenses.

4.5.4 Pipe Diameter

The findings from Ha Foso distribution network reveal that it uses pipes with a maximum diameter of 200 mm and a minimum of 12 mm (pipe 1), as seen in Table 2. The 32 mm (pipe 5) minimum diameter is characteristic of tertiary or service lines, which branch off the larger mains to supply individual properties like households in Ha Foso. While sufficient for localized demand, these smaller pipes inherently have higher frictional losses per unit length and are more susceptible to pressure drops, especially over longer distances or during periods of peak demand. 200″ diameter pipes (pipes 2-4) are larger than typical municipal water mains. Their excessive diameter minimizes friction loss but is physically implausible. Hydraulically, they waste potential energy by failing to convert elevation head into usable pressure/flow downstream.

Regarding leakage and pressure management, inadequate supply at endpoints could result from high pressure drops caused by smaller pipelines. Lambert (2001) demonstrated how greater diameters lower leakage rates by assisting in the maintenance of steady pressure. He examined how leakage rates in water distribution networks are affected by pipe diameter and system pressure. Based on the assertion by Lambert (2001), water supplied by 32 mm pipes (small pipes) in Ha Foso likely leads to an inadequate supply. Similarly, Gupta and Kulat's (2018) study on the Indian Urban Network indicates that 75 mm pipes caused persistently low pressure in the outskirts. These pipes, when replaced with 100–125 mm pipes, stabilized the supply and included pressure-reducing valves (PRVs).

Table 2: Attribute table of Network parameters of Ha Foso

Pipe_diame	Pipe_Mater	Year_Insta	Placement	PipeLength
200	uPVC	2016	Underground	5972.7
200	uPVC	2016	Underground	3437.2
90	uPVC	2017	Underground	2515.3
200	uPVC	2010	Underground	2297.4
90	uPVC	2018	Underground	1332.4
90	uPVC	2016	Underground	1260.6
90	uPVC	2018	Underground	982.34
63	HDPE	2018	Underground	946.34
90	uPVC	2018	Underground	936.63
90	uPVC	2018	Underground	918.54
90	uPVC	2017	Underground	775.47
63	HDPE	2018	Underground	766.11
63	HDPE	2018	Underground	706.23
110	uPVC	2010	Underground	699.55
90	uPVC	2017	Underground	609.15
90	uPVC	2018	Underground	581.22
63	HDPE	2018	Underground	573.43
90	uPVC	2018	Underground	501.6
90	uPVC	2017	Underground	500.85
63	HDPE	2018	Underground	483.51
63	HDPE	2018	Underground	465.46
63	HDPE	2018	Underground	454.76
32	HDPE	2010	Underground	447.3
63	HDPE	2018	Underground	435.02
63	HDPE	2018	Underground	430.9
110	uPVC	2010	Underground	430.53
90	uPVC	2016	Underground	409.33
32	HDPE	2010	Underground	378.13
90	uPVC	2018	Underground	330.38
32	HDPE	2010	Underground	306.14
32	HDPE	2010	Underground	298.98
63	HDPE	2017	Underground	295.54
63	HDPE	2018	Underground	292.2
32	HDPE	2010	Underground	279.42
32	HDPE	2010	Underground	270.3
63	HDPE	2018	Underground	270.25
63	HDPE	2018	Underground	262.24
90	uPVC	2017	Underground	199.47
32	HDPE	2018	Underground	198.32
63	HDPE	2018	Underground	191.08
32	HDPE	2018	Underground	155.61
63	HDPE	2018	Underground	154.6
32	HDPE	2010	Underground	151.4
32	HDPE	2018	Underground	148.32
63	HDPE	2018	Underground	128.14

4.5.5 Valves: Open, Closed

The distribution network of Ha Foso uses both closed and open valves. Several observations are made by Delgado and Lansey (2008) about closed valves:

1. A common issue with WDS is closed valves.

2. Not all valves that are closed during routine exercise or by contractors during system maintenance or construction are opened again,

3. The efficiency of operation is decreased when a valve is closed. A valve closure alters the flow rate of a pipe and frequently results in an instantaneous and brief change in pressure 4. A valve closure alters the flow rate of a pipe and frequently results in an instantaneous and brief change in pressure.

In a different study, Stephens *et al* (2002) make an observation that closed valves cause blockages. Their view is that when water supply lines are blocked, either during pumping to network storage facilities or during demand periods when water may have to use indirect and high-loss routes to meet consumptive demands, blockages reduce efficiency. The regular hydraulic condition is disturbed when valves are closed (Giustolisi, 2020). This literature may explain why the water supply at Ha Foso is inadequate – the network has closed valves.

4.5.5.1 Observed Changes in Water Pressure

Figure 21 below illustrates that 71% of respondents had experienced occasional low pressure. This implies that even if the water pressure may be sufficient most of the time, there may be times when it falls to an unacceptable level. Often, a smaller yet important group (6%) of respondents experienced low pressure, while a lesser but still significant portion had often experienced low pressure. This suggests that this group's insufficient water pressure is an ongoing problem. A sizable minority of respondents (21%) had experienced no changes in water pressure. This suggests that the distribution infrastructure is better in some places than in others, leading to a reasonably steady supply of water in those areas compared to others.

It is possible to link the observed variations in water pressure to the state and functionality of the water distribution network's open and closed valves. After repairs, maintenance, or operational changes, partially opened valves can impede flow and result in pressure decreases downstream. If such partial closures occur infrequently, this could account for the "occasionally low pressure" phenomenon. Significant head loss from partially blocked valves caused by corrosion, debris, or internal malfunctions can result in low pressure in the areas they supply. Both "often low pressure" and "occasionally low pressure" could result from this, depending on how severe and persistent the obstruction of supply is.

Certain parts of the network may have a well-maintained valve system, sufficient supply, and proper pressure regulation, which would result in stable pressure; they may also be nearer to the water source or pumping stations, which would result in more constant pressure; or they may use less water, which would make them less vulnerable to pressure variations, hence "No Changes" could be noticed.

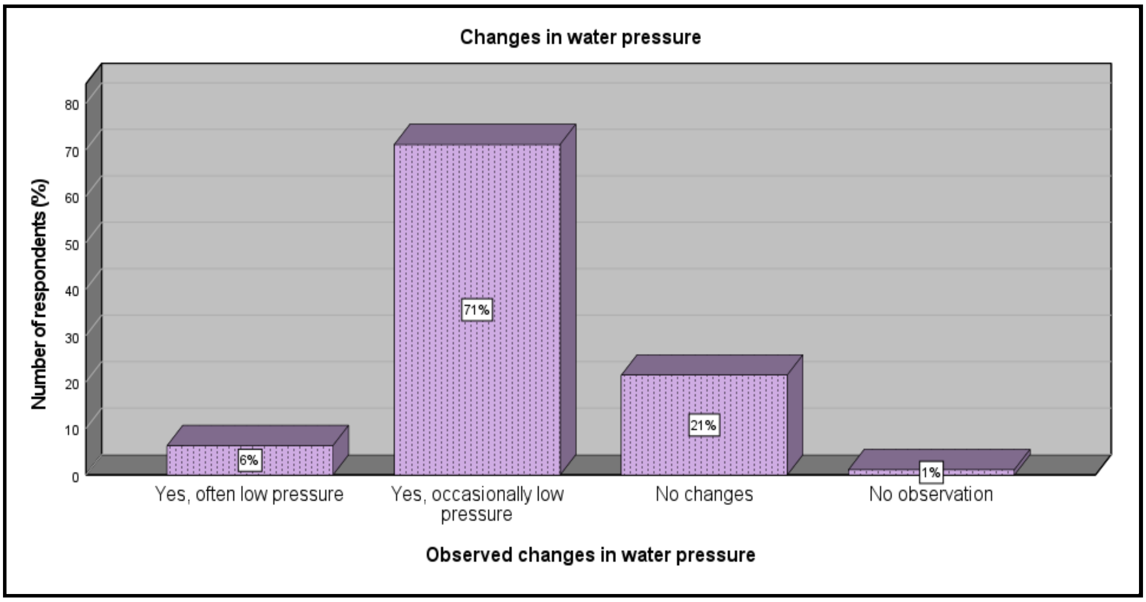

Figure 21: Observed changes in water pressure

4.6 Analysis of the Key Factors Responsible for, and Effects of Poor Water Supply

When residents of Ha Foso rated water supply on a scale of "Excellent" to "Very Poor," they essentially provided their perceived assessment of water services they receive. This rating encompasses several key aspects, and it's important to understand what factors influence these perceptions. Their views are given in Figure 22 below.

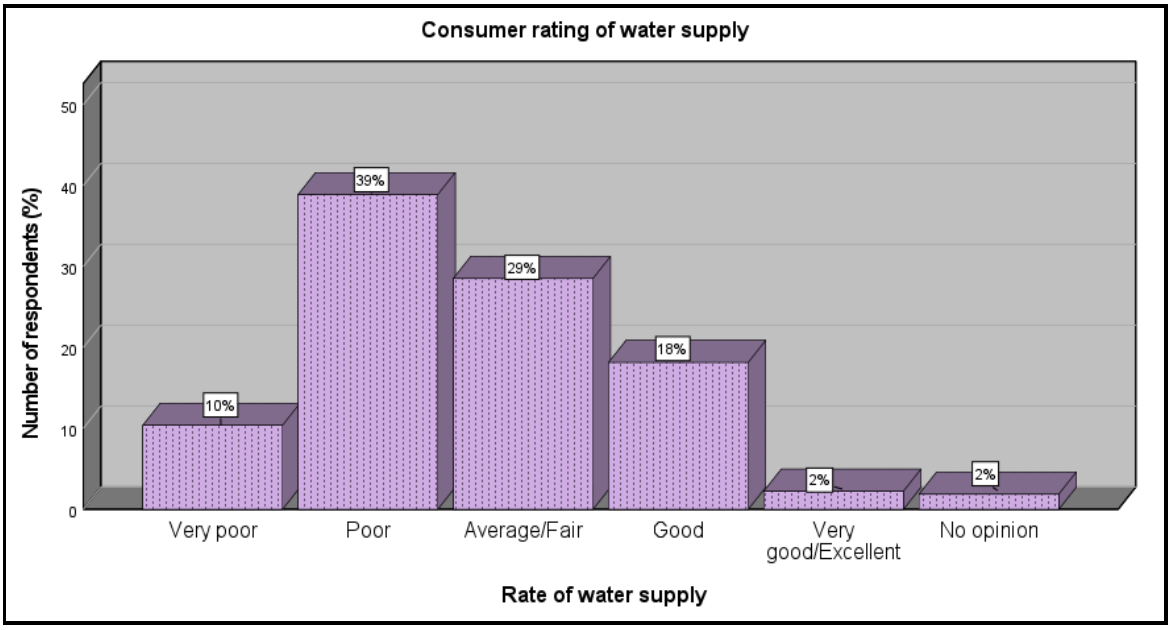

Figure 22: Overall rating of water supply

A large proportion of residents (39%) are of the view that water supply is generally poor, while for 29%, water supply is rated as average/fair. 10% of the respondents perceived the water supply as very poor. Different views may be attributable to factors of topography and elevation, leading to pressure variation. Gravity may play a role. Higher elevation areas often suffer from low pressure, especially at peak demand times. Residents in these areas may experience frequent disruptions and rate the service "very poor." This may be a different case with residents in the lower-lying areas who may have more consistent pressure, leading to "fair" ratings. This potential factor is supported by Gnann *et al* (2025), who state that topography affects the distribution of water on Earth. According to the PipeFlow Fluid Thinking Software (1997), as well, the pressure at a certain place in a pipe is also impacted by the fluid's elevation variations as it passes through a piping system, as pipes rise and fall, altering elevation. This explains the possible cause of the perceived supply by residents in the study area.

4.6.1 Perceived Causes/Reasons for Poor Supply

The most frequently cited reasons for poor water supply shown in Figure 23 below, are "Lack of infrastructure" (30%) and "Poor maintenance" (28%). This suggests that respondents believe deficiencies in the existing water network and inadequate upkeep is a major factor contributing to the problem. Notably, a sizable portion of respondents also mention "High water demand" (15%) and "Drought and climate change" (15%) for the inadequate supplies. This demonstrates an understanding of the strains on the ecosystem as well as the difficulties in providing for the population's water needs. The residents of Ha Foso believe that the poor water supply is primarily a consequence of insufficient and poorly maintained water infrastructure, compounded by high demand and the impacts of drought and climate change.

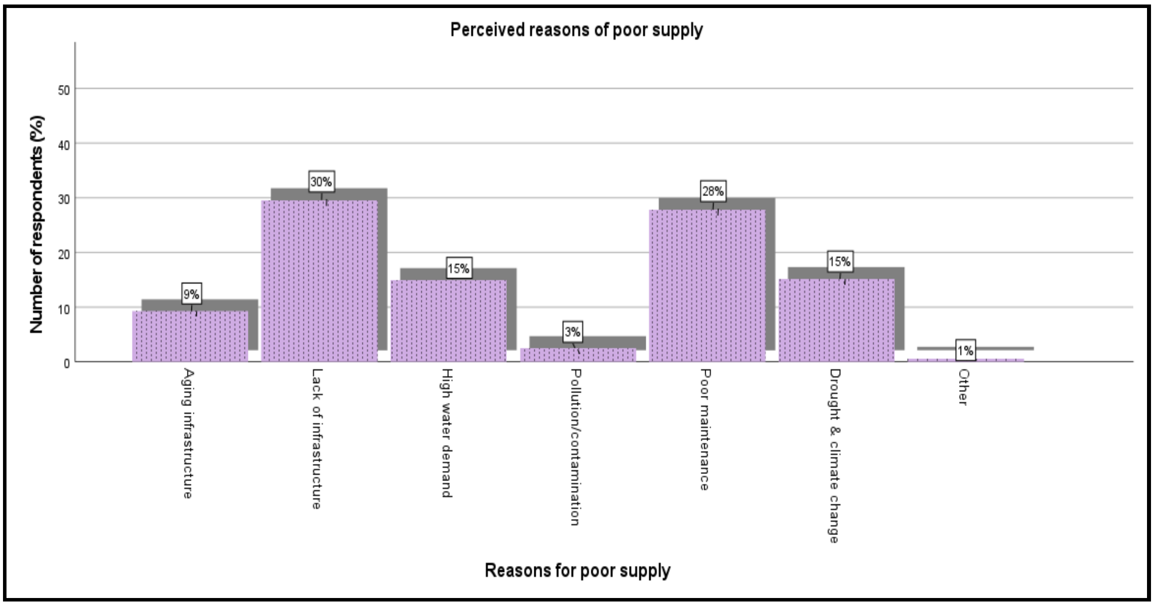

Figure 23: Reasons for poor supply

In her article in Global Society World News, Bahati (2024), quotes factors contributing to water loss in supply as aging infrastructure, where many water distribution systems, particularly in developed countries, are decades old and prone to frequent leaks. In many developing countries, Poor maintenance of water infrastructure is cited as not adequately maintained due to a lack of funding and technical know-how. This results in huge water waste and ongoing leakage.

Action Document for *Metsi a Lesotho* (Water of Lesotho) (2023) quotes that inadequate funding for periodic maintenance and operation of current water supply systems, and lack of the creation of new ones, is impeding WASH access in Lesotho. Lesotho Times (2023) substantiated poor supply as attributable to Lesotho's struggle to maintain a consistent water supply due to various factors, including aging infrastructure. The article elaborates that much of Lesotho's water infrastructure is old and deteriorating, leading to water losses, inefficiency, and interruptions in supply.

4.6.2 Family Experience of Health Issues

Figure 24 shows the distribution of health issues experienced by the respondents in the last year. Majority (84%), of the respondents had experienced different health problems in their family, while just 14% had never experienced any health problems in their family. A minor proportion of 2% were indifferent to the question. Over 80% of those surveyed (81%) said they had cholera. A smaller but significant portion (13%) had respiratory problems, while 6% of the respondents had skin infections. No responders mentioned polio, typhoid, hepatitis A, or dysentery. This could mean cholera is either highly prevalent in the area or the most well-known disease, leading to potential overreporting due to lack of awareness of other conditions.

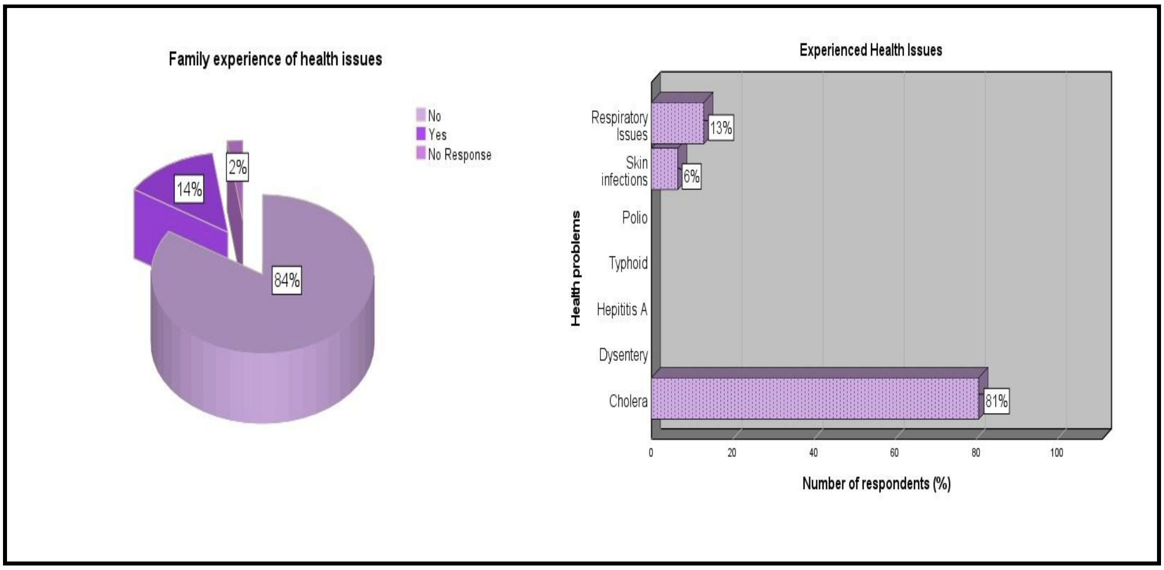

Figure 24: Family health issues

The pie chart establishes that a large majority of families in the surveyed population have experienced health issues. The bar chart then identifies Cholera as the dominant specific health issue experienced by these families. This reinforces the earlier finding (from the graph titled "Experienced health issues that cholera is a significant health concern linked to the local context. Experiencing health issues due to poor supply contributes to a first flush (FF) effect. FF is the discharge at the initial stage of a runoff event that contains high concentrations of pollutants (Gao *et al*, 2023). In a distribution network system, the first flush is the discharge at the first stage of water supply, and has high amounts of pollutants after there has been an interruption. The issues associated with poor water supply may be ascribed to stagnation. This is proven true by Guzder (2020), who is of the view that when a water supply is interrupted, especially for extended periods, several things can happen, including stagnation - allowing bacteria to multiply. The observed results are supported by the National Research Council (2007), which asserts that service lines have longer residence time, more stagnation, and consequently can have a profound effect on the quality of water reaching the consumer.

4.6.3 Impact of Poor Supply on Family Health

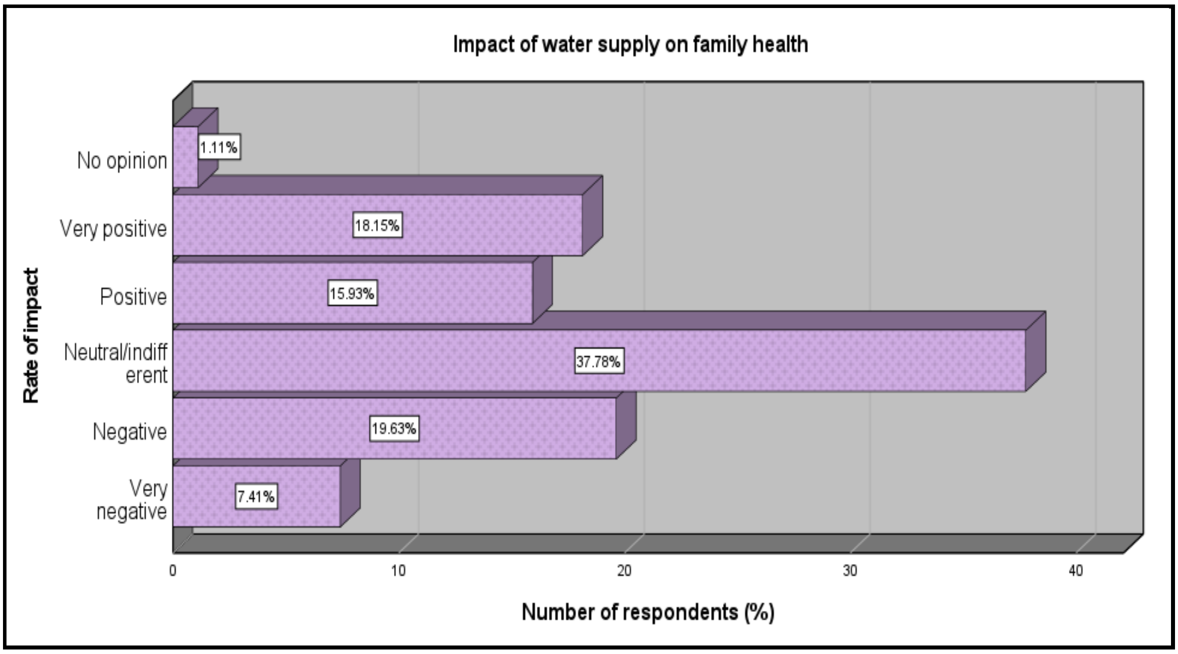

Figure 25: Supply impact on poor supply

The bar graph (Figure 25) illustrates the percentage distribution of respondents' opinions on the impact of water supply on their family health. The vertical axis represents the "Rate of impact" categorized as "Very negative," "Negative," "Neutral/indifferent," "Positive," "Very positive," and "No opinion." The majority of respondents (37.78%) stated that the water supply had a "Neutral/indifferent" effect on the health of their family. This may indicate that a sizable section of the population does not believe that the existing water supply has a substantial beneficial or negative impact on their health, or that they are unsure of the relationship or lack a clear opinion. Negative effects were reported by a sizable fraction of respondents: 19.63% said they had a "Negative" impact, while 7.41% said they had a "Very negative" impact. All told, 27.04% of respondents believe that their family's health is negatively impacted by the water supply.

A significant portion of respondents indicated positive impacts, however, not as high as those who gave neutral or negative answers: 15.93% said the impact was "Positive," and 18.15% said it was "Very positive." All told, 34.08% of respondents think their family's health is improved by the water supply. The graph shows differing opinions about how the water supply affects family health. A sizable portion perceives negative repercussions, somewhat outnumbering those who perceive favorable impacts, while a sizable portion is neutral or disinterested. Significantly poor perceptions point to possible problems with the water supply, such as accessibility, reliability, or quality, that may be affecting a sizable portion of the population.

4.6.4 Health Issues Attributed to Poor Water Supply

Figure 26 illustrates the percentage of respondents reporting specific health issues that may be attributed to poor water supply. The graph lists various diseases and health problems: cholera (81%), dysentery (0%), hepatitis A (0%), typhoid (0%), polio (3%), skin infections (3%), and respiratory issues (13%). The most common health problem mentioned is cholera, which the vast majority of respondents (81%) said was caused by a poor water supply. This indicates that among this population in Ha Foso, Lesotho, cholera is a serious issue and a substantial health consequence linked to poor water quality.

The second most reported, according to 13% of respondents, are respiratory problems linked to a poor water supply, making them the second most reported health condition after cholera. Although the relationship between respiratory problems and inadequate water supplies may not be as clear-cut as that between waterborne illnesses, it may still be connected to things like inadequate hygiene owing to a shortage of clean water. The outbreaks may be associated with distribution network failure. According to Moreira and Bondelind (2017), the main causes of contamination in the water distribution network are cross-connections, pipe breaks, and wastewater intrusion into the network (Moreira and Bondelind, 2017). A study on water supply interruptions and suspected cholera incidence in Uvira Democratic Republic of Congo (DRC), also revealed that in an area where cholera was endemic, the unreliability of the tap water supply was linked to a nearly 4-fold rise in areas with higher tap water consumption and a more than 2-fold increase in suspected cholera incidence at the city level. The findings also indicated that erratic tap water supplies may have contributed to 23% of the cases admitted to the Cholera Treatment Centre (CTC) in Uvira between 2009 and spring 2014 (Jeandron *et al*, 2015).

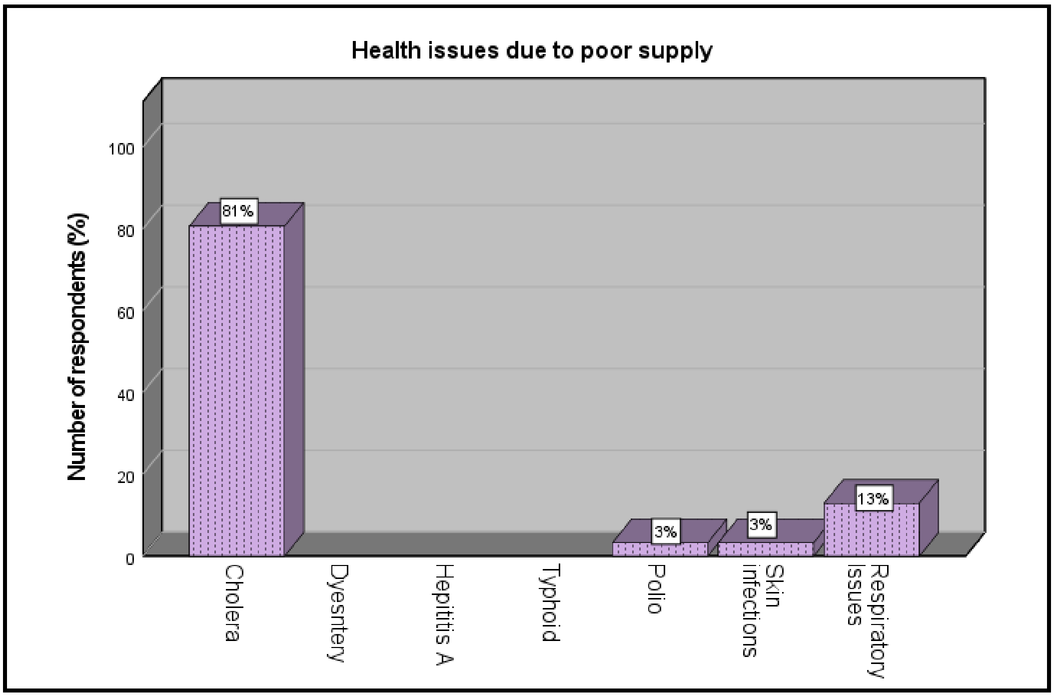

Figure 26: Health problems experienced

Cholera incidence seemed higher in the period 2014 to 2023 in the study that explored the burden of cholera in the WHO African region: patterns and trends from 2000 to 2023 cholera outbreak data. The analysis revealed that slow progress in the development of good water, sanitation, and hygiene (WASH) infrastructure and the associated challenges remained the key factors for cholera outbreaks in the African region (Koua *et al*, 2025). The high incidence of cholera as a health issue linked to poor water supply in Ha Foso aligns with the WHO's understanding of cholera as a major waterborne disease prevalent in regions with inadequate water and sanitation. The reported skin and respiratory issues also have plausible links to poor water supply and hygiene, as recognized by WHO.

4.6.5 Alternative Sources of Water

In the case of inadequate water supply and related health problems, residents of Ha Foso have alternative sources, as illustrated in Figure 27. About 26% of respondents reported using rainwater harvesting as an alternative source, indicating a notable adoption of this method, likely influenced by rainfall patterns and the desire for a more independent water supply. Not less than 20% of respondents reported using bottled water from stores as an alternative, likely reflecting concerns about the quality or reliability of the primary source for drinking and cooking, while 34% used water tankers or deliveries as an alternative water source, suggesting a significant reliance on this method to supplement or replace the primary water supply. This observation clarifies the small number of consumers who spent at least M1000.00 on alternative sources. Other options when water is unavailable include rainwater harvesting, purchasing bottled water from stores, and extracting water from boreholes.

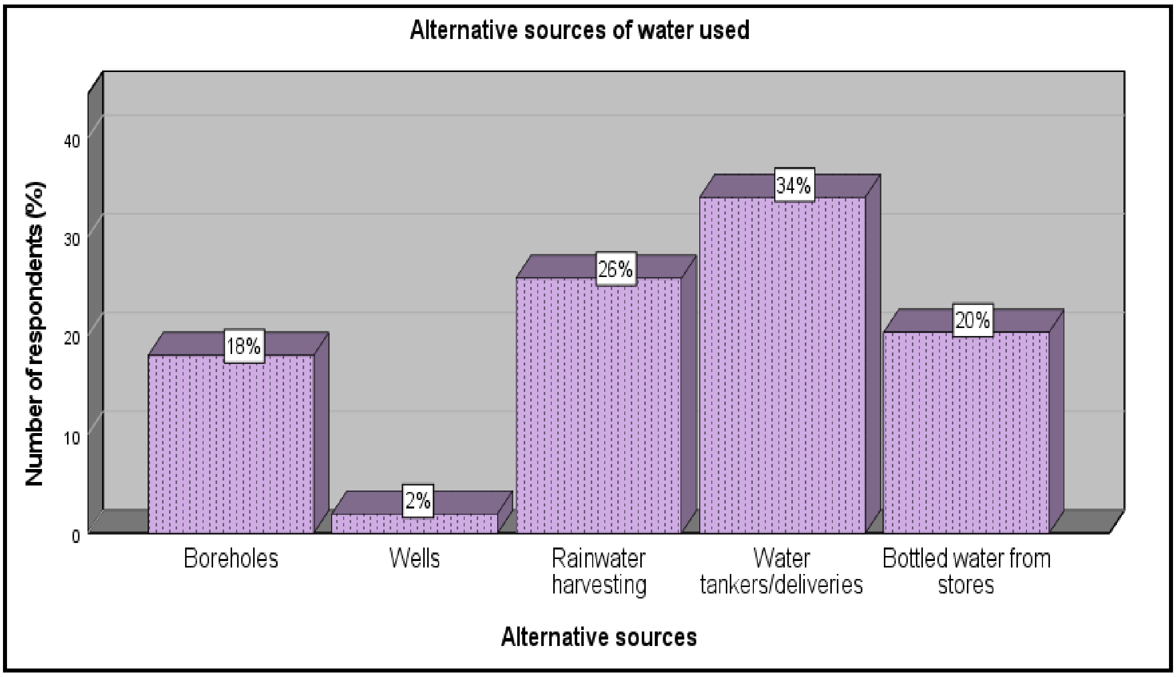

Figure 27: Alternative sources of water

In a study on water scarcity and alternative water sources in South Africa by Prins *et al* (2023), results (49.7%) showed that storm and rainwater harvesting was the most preferred alternative water source. In Mexico, purchasing water delivery from private individuals to supplement the municipal water supply was a common practice. When residents did not receive water from the public supply, the decision did not come without cost, just like it did not with consumers from Ha Foso. The majority of residents purchased bottles, 20-liter jugs of drinking water, which they reported buying either name-brand from local convenience stores for about 40 pesos ($2.08 2019 USD), or from local water purifiers for about 15–30 pesos (about $0.78 or $1.56 in 2019 USD) (Huberts *et al*, 2023).

4.6.6 Distance Traveled to Alternative Sources

Figure 28 illustrates the percentage distribution of respondents based on the time they travel to access alternative water sources. The horizontal axis represents the time travelled in different categories: "Less than 30 minutes," "30 minutes - 1 hour," "1-3 hours," "More than 5 hours," and "No travelling." The vertical axis represents the number of respondents in percentage.

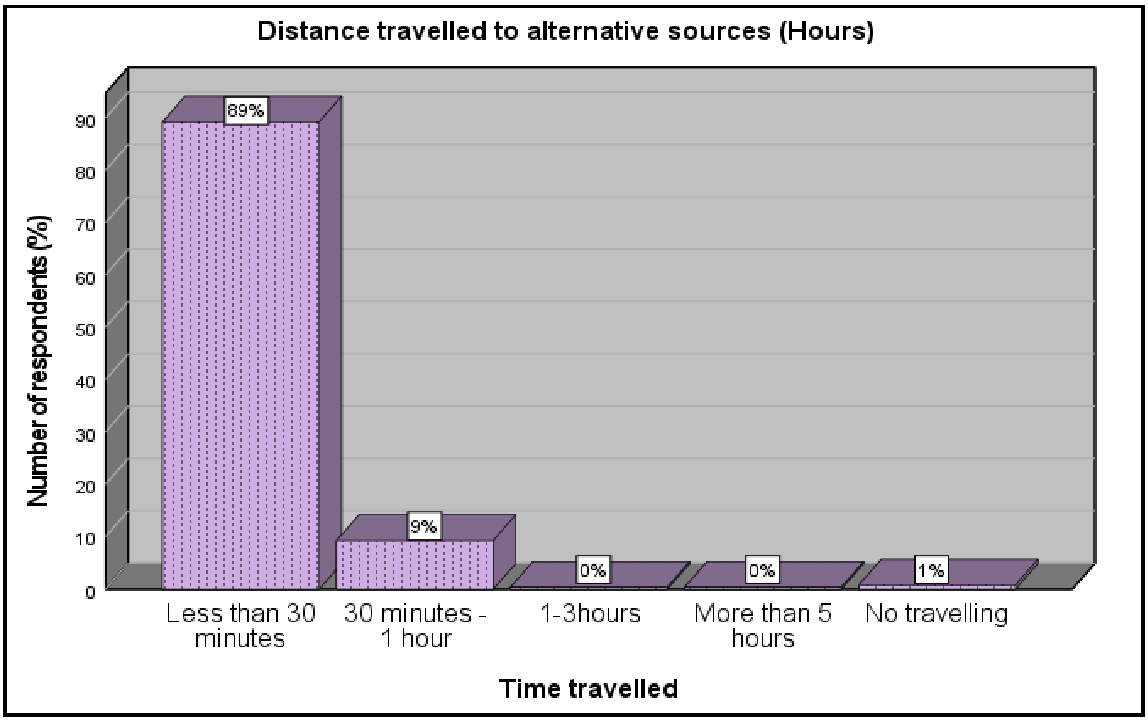

Figure 28: Time-traveled to water sources

A significant majority of the respondents (89%) reported travelling "Less than 30 minutes" to reach their alternative water sources. This suggests that for a large portion of the surveyed population, alternative water sources are relatively accessible in terms of travel time. A notable minority (9%) indicated travelling "30 minutes - 1 hour" to access alternative water. While not as large as the first group, this still represents a considerable time investment for these individuals. A small fraction of respondents (1%) reported "No travelling" to alternative sources. This could suggest the presence of alternative sources within their immediate vicinity.

The average travel time to reach an improved water source remains high in most countries studied. (Cassivi et *al*, 2018)'s study indicates that large numbers of people live in households where the collection burden is over 30 minutes. Proportions of the population fetching water from an improved source at a distance of over 30 minutes range from 2% of the population in Madagascar to 38% in Uganda. Thus, it can be seen that by simply taking into account this threshold, a non-negligible proportion of the population should be considered as not having good access to water. Fetching water is a demanding task, particularly in Sub-Saharan Africa, where it is common for people to spend over 30 minutes for a single water fetching trip (The World Bank Group, 2024).

For Ha Foso, the findings suggest that while the vast majority of the surveyed population can access alternative water sources within a relatively short travel time (less than 30 minutes), a non-negligible portion still faces a time burden of up to an hour. Extremely long journeys to alternative water sources appear to be rare in this specific context. The small percentage with no travel indicates localized access for a few.

4.6.7 Money Spent on Alternative Sources

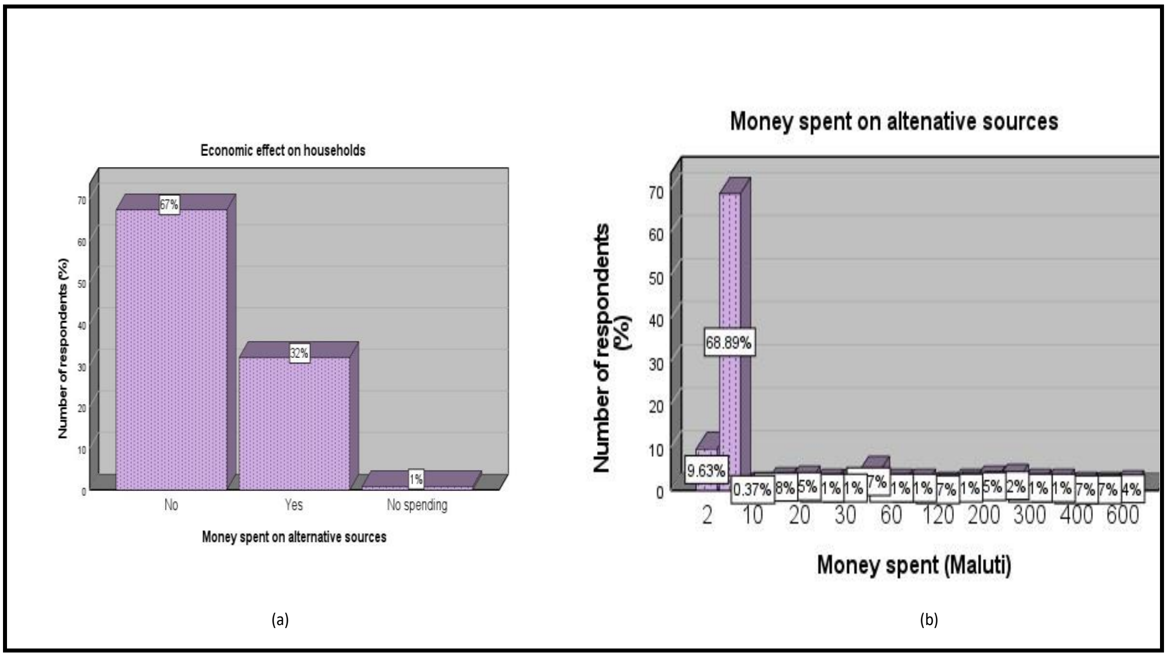

Figure 29: Economic burden of alternative sources

The percentage of respondents who indicated whether or not spending money on alternative water sources has an impact on their households' finances is displayed in Figure 29. The vast majority of respondents (67.41%) said that their households do not see any financial impact from the money they spend on alternate water sources. Any expenditure would normally have some economic impact; thus, this appears contradictory. This reaction may suggest that these households have normalized this expense or that the amount spent is insignificant in comparison to their total income.

A sizable minority (31.85%) stated that their households' finances are impacted when they spend money on alternate water sources. This implies that this expense is a significant financial strain for many households. Just 0.74% of respondents said they do not spend any money on alternate water sources. This may be the result of reliance on free alternative sources (such as collected rainwater when accessible without infrastructure expenditures), regular access to a primary water source, or other specific circumstances.

"No spending" on alternate water sources was the most common choice, accounting for 68.9% of all responses. This represents a sizeable percentage of the respondents.

The next most common spending level is M2. Following "No spending," M2 is the most often reported amount spent (9.6%). This implies a minor, perhaps sporadic, expense for a portion of the population. Spending is dominated by low levels, where a significant percentage of spending is concentrated at lower levels. Findings are that 78.5% of the respondents belong to either the category of no spending or that of limited expenditure when the results for "No spending" (68.9%) and those spending M2 (9.6%) are combined. In general, the proportion of respondents involved declines as spending rises. Overall, the trend indicates that fewer individuals are paying more money for alternative water. Smaller proportions at greater spending levels indicate that only a small fraction of respondents (e.g., M 100, M 200, M 300, and M 600) reported spending considerable amounts.

A study in Nsukka and Enugu urban towns in Enugu State, Nigeria, indicated that households spend money on alternative sources. More than a third (35.23%) of the respondents in this study purchase water from vendors selling in tankers. Spending on alternative sources seems to be a common practice. UNICEF is of the view that economic water scarcity occurs when access to water is restricted because of a lack of infrastructure, among other reasons, even when there is water in the environment. It is distinguished by a lack of investment in infrastructure intended to provide and distribute water equitably. Poor households find it challenging to get a domestic water supply, making them susceptible to seasonal variations in supply and high retail water prices. In the Horn of Africa, the majority of people depend on vendors delivering water on donkey carts or trucks. Water prices have risen by as much as 400% in regions most affected by water scarcity (UNICEF, 2022).

4.7 Perceived Strategies for Improving the Frequency, Adequacy, and Reliability of Water Supply

The bar graph below (Figure 30) illustrates the percentage distribution of respondents' opinions on the appropriateness of "Rainwater harvesting systems (RWH)" as an improvement strategy for their water situation in Ha Foso Maseru, Lesotho. Rainwater collecting systems are viewed by a sizable majority of respondents (50%) as an "Extremely appropriate" approach to bettering their water status. This suggests that the surveyed population has a very favorable opinion of this option. Additionally, "Very appropriate" provides strong support, as a further 19% of those surveyed think rainwater collection technologies are "Very appropriate." This indicates that a total of 69% (50% + 19%) of the participants believe that rainwater collection is an excellent improvement method. This suggests that the community is likely aware of the potential benefits of rainwater harvesting in addressing their water challenges.

The findings from this study are validated by Alim *et al* (2020), who are of the view that the adoption of the RWH system contributes to the economic benefit in one of two different ways, which is to reduce water demand. According to these authors, the RWH system can be a viable option to provide clean water to people who do not have a centralized water supply. This was observed in Mexico City, where it was reported that 100% of water demand was met by harvesting rainwater (López Zavala *et al*, 2016). Domènech and Saurí (2011) also surveyed on people's perceptions about adopting a RWH system. The findings were that the general public have a positive attitude towards RWH system for its long-term benefit to society.

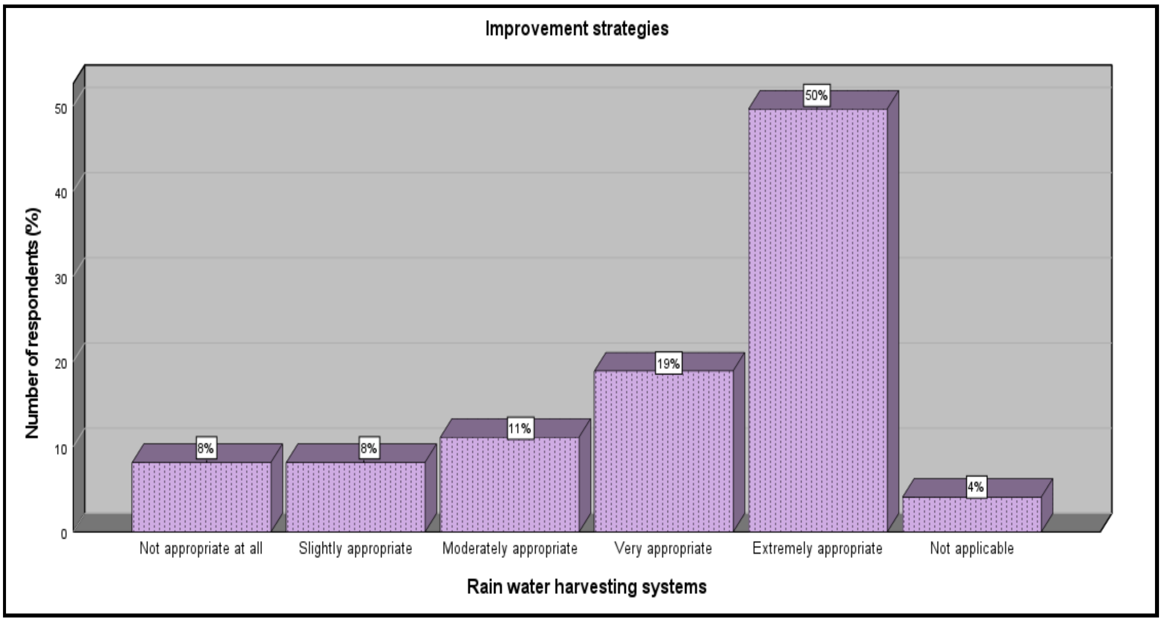

Figure 30: Appropriateness of rainwater harvesting systems

Community water education programs in this study are centered on empowering individuals and communities with essential knowledge on water conservation and sustainable practices. The percentage distribution of respondents' opinions on the appropriateness of "Community water education programs" as an improvement strategy for their water situation in Ha Foso is presented in Figure 31 below.

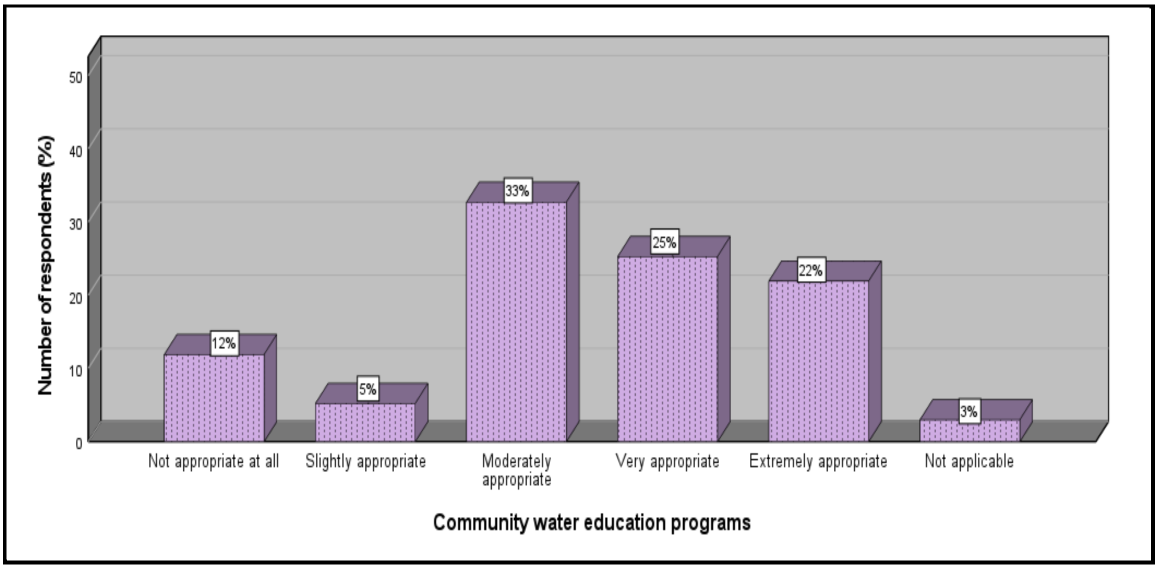

Figure 31: Appropriateness of Community Water Education Programs

The largest percentage of respondents (33%) believe that community water education programs are "Moderately appropriate" as an improvement strategy. This suggests a generally positive view, recognizing the potential benefits but perhaps with some reservations about the extent of their impact. Additionally, a sizable percentage of respondents think these initiatives are highly acceptable: 22% think they are "Extremely appropriate," and 25% think they are "Very appropriate." Collectively, 47% of those surveyed believe that community water education is very beneficial. The substantial support for "Very appropriate" and "Extremely appropriate" highlights that many believe education can play a crucial role in fostering better water management practices at the community and household levels, potentially leading to more sustainable water use and improved health outcomes. A significant percentage thinks they are "Not appropriate at all": According to 12% of respondents, community water education programs are "Not appropriate at all" in terms of addressing their water-related problems. This implies a certain amount of skepticism or the conviction that other initiatives are more important. This group might believe that the problems are more infrastructural or systemic and require direct public interventions like improving the water network, providing alternative sources, or policy changes, rather than just education.

Community education programs are a practice in Lesotho. This is evident by Natural Resources as a lead institution in strengthening local institutions to protect water resources through sensitization of Village Water Committees and training for local institutions. Department of Soil and Water Conservation also leads in capacitating the community members on the utilization of resources (ReNoka, 2023). This is also a practice by the Ministry of Natural Resources through the Department of Rural Water Supply, whose goal, amongst others, is to build capacity and empower communities in the operation and maintenance of water supply systems through its community liaison program. Community water education programs are important as deemed by the community of Ha Foso because with such programs, long-term advantages include lowering expenses, lessening the impact on the environment, and guaranteeing water availability for future generations. All things considered, educating people and increasing awareness about water conservation are crucial first steps in achieving sustainable water management (AquaWiki, 2023).

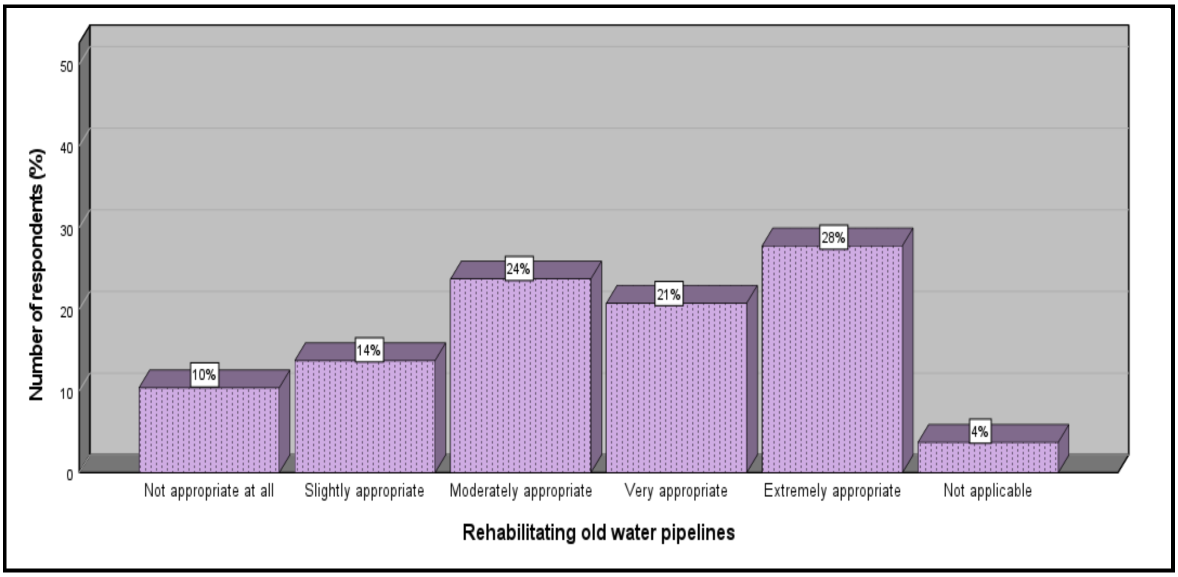

Figure 32: Appropriateness of Rehabilitating Old Water Pipelines

Figure 32 above indicates that repairing outdated water pipelines is an important strategy, as the majority (28%) of the residents rated it as an "Extremely appropriate," way to improve their water condition. This suggests that fixing the current water infrastructure is highly supported. There is considerable evidence in favor of "Very appropriate" and "Moderately appropriate". Additionally, a sizable percentage of respondents have positive opinions of this strategy, with 24% thinking it is "Moderately appropriate" and 21% thinking it is "Very appropriate." In total, 45% believe that pipeline rehabilitation is highly beneficial. This could stem from the knowledge that old and broken pipes can waste a lot of water, making the problem of water scarcity worse, or the belief that households' capacity to obtain water may be impacted by low water pressure caused by corrosion and clogs in outdated pipes.

A small minority of (4%) stated that rehabilitating old water pipelines is "Not applicable" to their situation. This could be due to various reasons, such as not being connected to the piped network or believing the issues lie elsewhere. According to Evangelista, Brentan, and Lima (2023), rehabilitating pipes can be as easy as washing their wall to restore or at least increasing their hydraulic capacity by making the wall less abrasive. Another option is to swap out a portion or the complete pipe. Key findings from a study conducted in the Johannesburg suburb of Westbury show that the pressure at which demand is satisfied increases with the smoothness of the internal pipe walls. Additionally, as internal pipes become smoother, more power is transferred to customers, and as pipes become rougher, more power is wasted across the network. Rehabilitating the network's most crucial nodes, which had low pressure, had a 10.32% increase in pressure from 24.99 m to 27.57m (Nyende-Byakika, 2017). The strong support for rehabilitating old water pipelines in Ha Foso Maseru aligns with the understanding that aging infrastructure is a major impediment to reliable and safe water supply in many urban areas of developing countries.

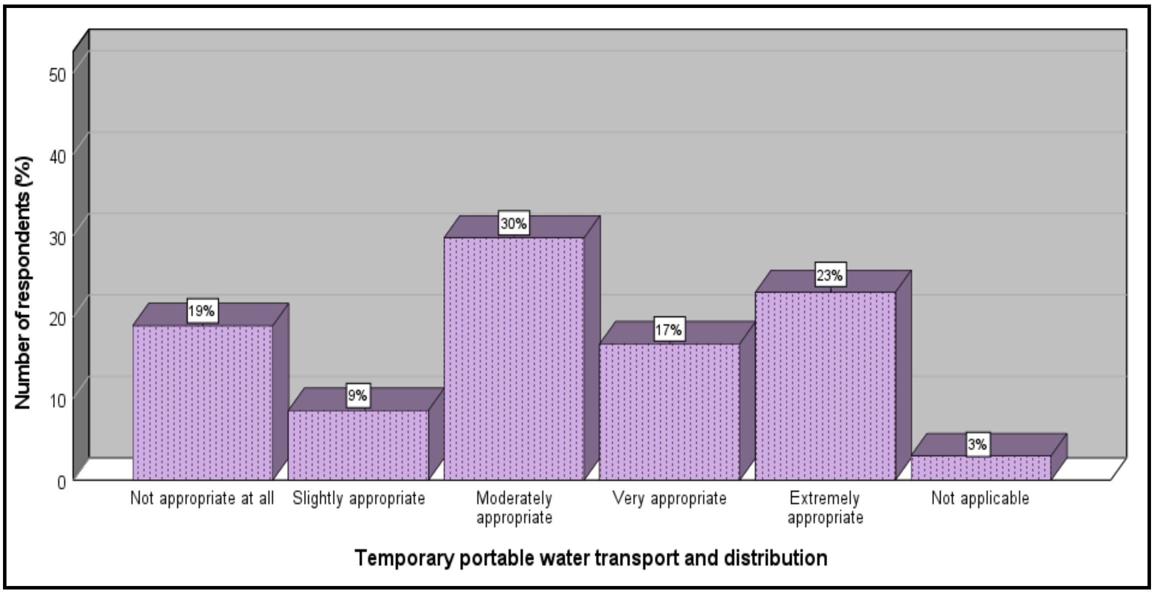

Figure 33: Appropriateness of temporary water transport and distribution

Figure 33 shows that temporary portable water distribution and transportation are perceived as a water improvement approach in Maseru in a mixed but generally positive way. A significant 19% categorically reject it, despite the majority (30% + 17% + 23% = 70%) finding it at least somewhat appropriate. The popularity of "Moderately appropriate" indicates that many people believe this could be a quick solution or a means of easing severe water shortages. Water can be swiftly delivered to places with disruptions or inadequate infrastructure using portable water conveyance, such as water trucks or bladders. The high share of the category of "Not appropriate at all", however, probably indicates worries about the cost-effectiveness, sustainability, and possible quality problems of short-term fixes. The significant support for "Extremely appropriate" indicates that a large segment of the population likely experiences severe and frequent water shortages, making any immediate solution, even if temporary, highly valued.

Water delivery is a common service, often utilizing privately owned and WASCO-contracted water tanker trucks for both potable water and sewage removal. Private companies like Maitin Transport and Nkomo Transport, as well as WASCO, offer water trucking and sewage removal services. Amthor International (2024) is of the view that potable water tankers are specially designed for transporting potable water and follow strict regulations to ensure the quality and safety of the water during transport. This practice ensures an uninterrupted water supply during emergencies or temporary water shortages and promotes community resilience.

In some locations, such as Ijara District and Greater Samburu District in Kenya, portable water trucking is an everyday reality. For instance, in the Greater Garissa District, there are over 200,000 people who require water trucking. There are three water bowsers in the district; two of them can hold 16,000 litres, and one can hold 7,000 litres (Wekesa and Karani, 2009). A sizable majority considers temporary portable water distribution and transportation to be a somewhat to highly suitable short-term option. The strong opposition, however, emphasizes the need for longer-term and more sustainable upgrades to Ha Foso's water supply and infrastructure. This strategy is likely seen as a necessary Band-Aid but not a long-term answer.

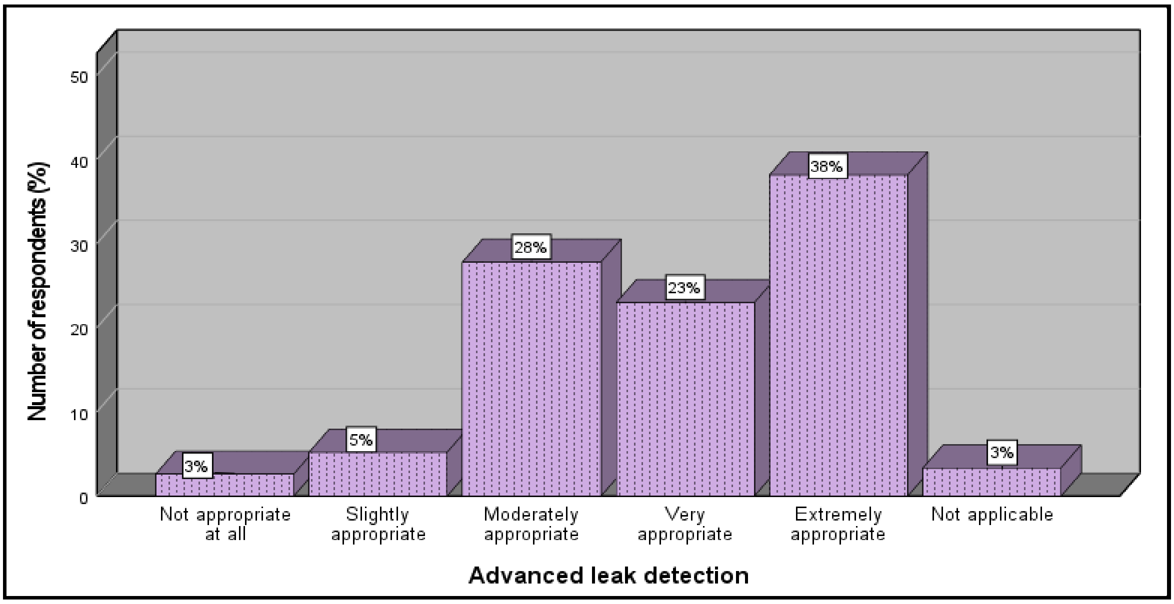

Figure 34: Appropriateness of Advanced Leak Detection

Advanced leak detection is considered an "Extremely appropriate" technique by a significant majority of respondents (38%) to improve their water status. This suggests that there is a lot of support for this strategy. Additionally, a sizable percentage of respondents have positive opinions of this approach: 28% think it is "Moderately appropriate," and 23% think it is "Very appropriate." On the other hand, 51% of respondents believe that enhanced leak detection is very valuable. This resounding support most likely results from an awareness that water loss is a serious issue. The community is probably aware that leaks greatly contribute to water scarcity and an unstable supply, as seen by the prior strong support for repairing outdated water pipelines. When it comes to detecting and resolving water losses, respondents appear to believe that contemporary leak detection techniques can be more successful and efficient than conventional ones. Advanced leak detection is considered "Not appropriate at all," by only 3% of respondents, while 5% think it is "Slightly appropriate." This implies that there is virtually little outright opposition to this tactic. One Small Minority is "Not applicable": Only 3% of respondents said enhanced leak detection was "Not applicable" in their case.

Leaks detection triggered a "*Hlasela metsi a Qhalanang*" campaign by WASCO in Lesotho. For example, WASCO reported that 390 million litres of water were lost during the third reporting quarter at the Maseru Centre due to a non-revenue water (NRW) rate of 52%, of which 15% was caused by service connection leakage. High pipeline system pressures and the merging of new and old distribution networks are the main causes of these serious leaks. The NRW manager stated that WASCO intends to tackle these problems by launching a comprehensive repair program that will concentrate on locating and fixing leakage hotspots and putting in place a strong awareness campaign to encourage leak reporting and detection (Phakoana, 2025).

A case study from recent field verification and inspections of Rand Water's bulk water pipelines is presented by South Africa. More than 11 million people in Africa receive bulk potable water from Rand Water, the continent's largest supplier. Its pipeline network consists of more than 3000 km of large diameter pipelines that supply mines, big companies, and local governments with an average of 3,550 million litres of water each day. To find leaks around pipelines, Rand Water employs a cutting-edge Dynamic Probe Super Heavy (DPSH) soil penetration test (Webb *et al,* 2009). Farah and Shahrour (2024) speak of acoustic sensors (Noise Loggers) as tools for advanced leak detection in a pipe network. The authors explain that these sensors are placed in clusters of six or more at nearby pipes, with metallic networks spaced 200–500 meters apart and plastic pipes as close as 80 meters. They are made to turn on automatically at night in order to track the acoustic vibrations caused by water system leaks and to give useful information about where the leaks occur. The effectiveness of leak detection in water distribution networks has been greatly increased by the use of permanent acoustic noise loggers with wireless data transfer. Detecting leakages may be one of the critical matters to be managed to enhance the effectiveness and efficiency of a WDS and to ensure that there is a continuous supply of water at Ha Foso.

Figure 35 shows that there is a very high level of common ground among Ha Foso residents who were polled about how important routine maintenance is to enhancing their water condition. Most people think it is at least moderately appropriate (52% + 19% + 19% = 90%), while more than half think it's "Extremely appropriate." This strong support most likely results from an acute awareness of how ignoring maintenance can cause the exact issues they are facing, like larger and more frequent leaks caused by pipelines and infrastructure that are not regularly inspected and repaired. Service interruptions: When pumps, valves, and treatment facilities are not maintained, they break down and the water supply is interrupted. Decreased efficiency: Equipment left unattended to perform less effectively, raising expenses and perhaps affecting water pressure.

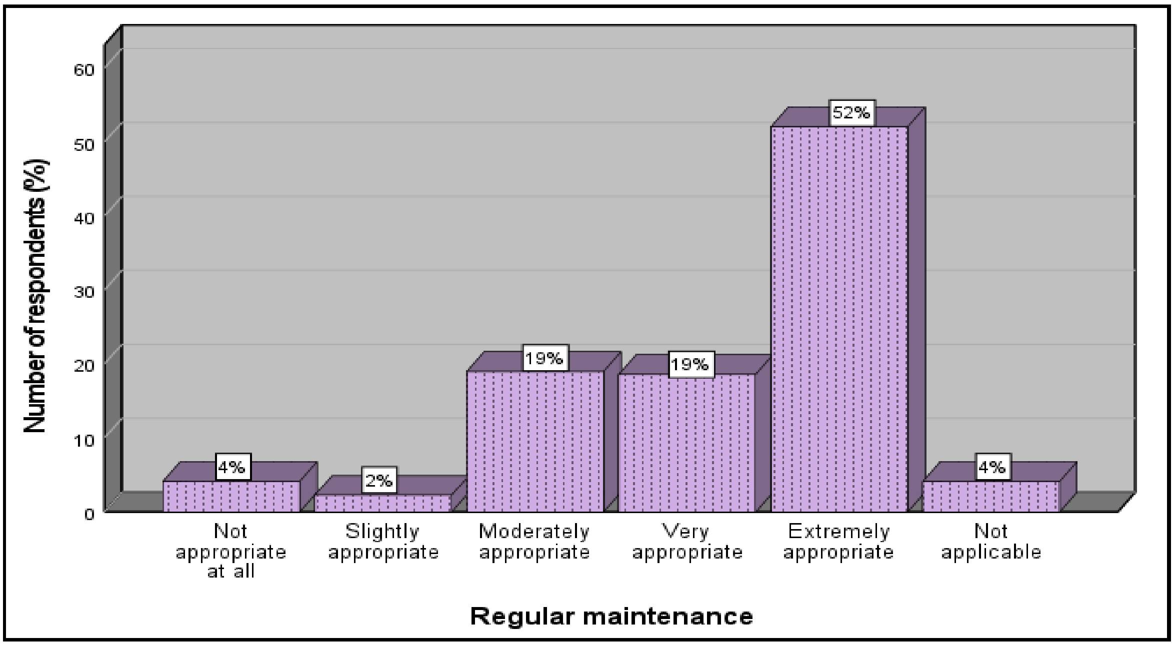

Figure 35: Appropriateness of regular maintenance

From WASCO's Maintenance Statement, available at https://www.wasco.co.ls/wp-content/uploads/2017/07/maintanance-plan.pdf, WASCO operates on three-tier maintenance measures. 1-The preventive measures, which include steps to guarantee that scheduled maintenance is completed by identifying potential issues through testing and inspections, 2- predictive maintenance approaches, which are used to decrease equipment failure and maintenance workload. 3- Emergency or reactive maintenance is work that needs to be completed right away. It includes actions taken to stop significant equipment damage or worker injuries. van Zyl (2014) is of the view that to guarantee that collected sediments are eliminated from pipes, a variety of maintenance procedures, such as flushing or cleaning, should be carried out methodically. Also, to guarantee that repairs are completed correctly and do not lead to new issues, quality control procedures are essential (van Zyl, 2014).

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The conclusions and recommendations section synthesizes findings from the EPANET-based appraisal of Ha Foso's water distribution network, which revealed systemic inefficiencies in supply frequency, adequacy, and reliability. It examines critical issues such as limited daily access hours, frequent interruptions, and the cascading effects of aging infrastructure, including pressure deficits, contamination risks, and community reliance on unsustainable alternatives like rainwater and tankers. By analyzing the interplay between network design, maintenance gaps, and performance outcomes, this section identifies root causes of poor supply, such as leak-prone pipes, valve mismanagement, and undersized segments. Building on resident-endorsed strategies and hydraulic insights, it proposes targeted interventions—infrastructure upgrades, advanced leak detection, and community-centric maintenance—to transform the network into a resilient, equitable and more functional system. These recommendations aim to bridge technical solutions with local priorities, ensuring reliable water access and safeguarding public health.

5.1 CONCLUSION

Based on the findings from this study, the following conclusion could be drawn:

i) Low-pressure zones of 25 psi pose a risk of contamination ingress (due to negative pressure) and inadequate supply during peak demand. Optimal pressure of 50–75 psi at least denotes that pipes in this range are functioning well, ensuring reliable service. High-pressure zones of 100 psi, however, risk pipe bursts, joint failures, or accelerated wear on valves. Possible causes may be over-pumping, lack of pressure-reducing valves (PRVs), or steep elevation drops, bringing the impact on Ha Foso of frequent infrastructure repairs and water loss (non-revenue water).

ii) Low flow of 25 GPM in Ha Foso indicates closed valves and an inefficient network layout. High Flow (100 GPM), on the other hand, poses an overload risk: Main transmission lines facing excessive velocities, thereby causing transient pressure surges (water hammer).

iii) Ha Foso's network shows moderate performance with clear opportunities for improvement. The distribution network utilizing uPVC and HDPE pipes demonstrates both strengths and vulnerabilities in its design and operation, directly influencing water supply performance. The range of pipe diameters (12mm–200mm) suggests a system tailored to varying demand levels, with smaller pipes (12mm–50mm) likely servicing localized connections and larger diameters (100 mm–200 mm) functioning as primary transmission lines.

iv) The prevalence of low-pressure experiences reported by 77% of respondents (71% occasionally, 6% frequently) points to systemic inefficiencies. The extremely short pipe segments (128.14 mm–5972.7 mm) imply excessive joints and fittings, which increase frictional losses and leakage risks, particularly in rigid uPVC pipes.

v) The 21% of users reporting stable pressure likely reside in zones with optimized pipe sizing, fewer joints, or better valve management, highlighting the network's uneven performance. The relationship between infrastructure design and water supply performance is evident here: the combination of small-diameter pipes, short pipe lengths, and suboptimal valve operation creates hydraulic inefficiencies.

vi) The reliance on alternative sources, such as rainwater harvesting (26%) and water tankers (34%), reflects community adaptation to systemic gaps but introduces risks, as untreated rainwater or inconsistently regulated tanker water may contribute to waterborne diseases.

vii) The short travel time (<30 minutes) to alternative sources suggests localized availability but does not mitigate the health or financial burdens for vulnerable groups. Cholera prevalence underscores the urgency of addressing both water quality and access.

In general, the water distribution network in Ha Foso performs poorly due to aging infrastructure, insufficient maintenance, and design flaws, resulting in inconsistent supply, low pressure, and health risks like cholera. Residents' reliance on alternative sources and strong support for solutions—pipe repairs, leak detection, rainwater harvesting, and routine maintenance—highlight systemic neglect and a demand for urgent action. Addressing these issues requires modernizing infrastructure, enforcing proactive maintenance, and integrating community priorities to transform the network into a reliable, equitable system. Without such measures, the cycle of inefficiency, health hazards, and public distrust will persist, undermining both water security and community well-being.

5.2 RECOMMENDATIONS

In accordance with the findings in this study, to improve water supply in Ho Foso and other locations with similar water supply conditions, the following recommendations are made:

i) The recommendations to WASCO as the water utility regarding pressure management would be to install PRVs in high-pressure zones to protect infrastructure, and add booster pumps or elevate storage tanks in households that receive low pressure of 25 psi within the network in Ha Foso.

ii) To optimize flow, the utility company may loop dead-end pipes to reduce stagnation and improve water quality. In a water system, looping a dead-end pipe means making a closed loop by rejoining the pipe's end to the main line.

iii) To guarantee enough water pressure and flow, particularly in larger communities like

Ha Foso, this is frequently carried out in grid or looped systems. Multiple water flow channels provided by looped systems increase reliability and lower the possibility of water stagnation in dead-end areas like in Ha Foso.

iv) To ensure adequacy, it would be advantageous to WASCO to exercise Demand-Supply Balancing by conducting a hydraulic audit to identify undersized pipes or overburdened sources, (e.g., boreholes, treated wastewater reuse) to augment supply and partner with residents to map "water deserts" (e.g., areas with <6 hours/day access) for targeted interventions.

v) The water utility company can transition to longer HDPE pipe segments (where feasible) to decrease joint density, leveraging its flexibility for coiled installations, thereby lowering leakage risks and pressure drops. The valve management protocol can also be put in place by implementing standardized valve operation procedures, ensuring valves are fully open unless required for maintenance, and by introducing pressure sensors near valves to monitor real-time impacts of valve adjustments.

vi) WASCO, as the regulating body, could launch public health campaigns on water treatment practices and cholera prevention, coupled with real-time water quality monitoring in distribution networks and alternative sources. By aligning infrastructure resilience with community-level adaptations, the system can reduce health risks, enhance equity, and restore trust in public water supply, breaking the cycle of infrastructural neglect and public health crises. It may also consider formalizing alternative sources by promoting treated rainwater systems (e.g., subsidizing filters) and regulating tanker water quality to reduce health risks.

5.3 CONTRIBUTION TO KNOWLEDGE

The study has evaluated the water distribution network using EPANET in Ha Foso, a peri-urban area in Lesotho. It has made significant contributions to knowledge in several key areas. Firstly, it has provided a detailed understanding of the current state of water distribution systems in peri-urban regions of Lesotho, which are often characterized by rapid urbanization, inadequate infrastructure, and resource constraints. By utilizing EPANET, a widely recognized hydraulic modeling tool, the study offers precise insights into the network's performance, including pressure variations, flow rates, and potential inefficiencies such as leakages or inequitable water distribution. This shall fill an existing gap in the literature, as peri-urban areas are frequently underrepresented in water distribution studies despite their unique challenges.

Secondly, the study contributed methodologically by demonstrating the applicability and effectiveness of EPANET in resource-limited settings. It highlights how such tools can be adapted to address the specific needs of peri-urban areas, where data availability and infrastructure complexity may differ significantly from urban or rural contexts. This methodological contribution is expected to be valuable for researchers and practitioners aiming to replicate similar studies in other developing regions.

Furthermore, the findings of this study provide practical implications for policymakers and water utility managers in Lesotho and beyond. By identifying critical areas for improvement, such as network upgrades, leakage reduction, or demand management strategies, the study has provided evidence-based recommendations to enhance the resilience and sustainability of water distribution systems. This is particularly important in the context of population growth, which is likely to exacerbate water scarcity and infrastructure challenges in peri-urban areas.

Lastly, the study has contributed to the broader discourse on equitable water access and sustainable development. By focusing on a peri-urban area, it sheds light on the socio-technical dynamics of water distribution, including how infrastructure limitations impact vulnerable populations. This knowledge is expected to inform more inclusive and targeted interventions, ensuring that water services are accessible to all, regardless of geographic or socio-economic status. Overall, the study has advanced both academic understanding and practical solutions for improving water distribution networks in peri-urban contexts, with potential applications for similar regions globally.

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APPENDIX

THE NATIONAL UNIVERSITY OF LESOTHO

WATER INSTITUTE

Evaluation of Water Distribution System and its impact in Ha Foso, Berea, Lesotho.

Questionnaire for consumers

Dear Respondent

A study is being conducted on the subject above, and requires relevant information from water consumers. Please, kindly complete the questionnaire below for necessary information to improve water supply system in this area. All supplied information shall be treated with absolute confidentiality.

Thank you

Ts'epang Mofolo (M.Sc. Student and Researcher)

Demographic Information

What is your age?

i) Under 18
ii) 18-30
iii) 31-45
iv) 46-60
v) Over 60

What is your gender?

i) Male
ii) Female

What is your occupation?

i) Student/Apprentice
ii) Employed/self-employed
iii) Unemployed
iv) Retired

How long have you lived in this area?

i) Less than 1 year
ii) 1-5 years
iii) 6-10 years
iv) More than 10 years

Water Supply Frequency

How often do you receive water supply in your household?

i) Less than once a week

ii) Once a week

iii) Two times a week

iv) Several times in a week

v) Daily

On average, how many hours per day do you have access to water on a day that you receive water?

i) Less than 1 hour

ii) 1-3 hours

iii) 4-6 hours

iv) More than 6 hours, but less than 24 hours

v) 24 hours

Have you experienced any interruptions in water supply in the past week?

Yes……………….

No…………………

7b. If yes, how many times did the interruption (s) occur? ………………………………………………..

Water supply adequacy

How adequate is the water supplied for your daily needs?

i) Not adequate at all

ii) Not adequate

iii) Fairly adequate

iv) Adequate

v) Very adequate

What is the primary use of water in your household? (Select as many as applicable)

Water Use	Yes	No
Drinking		
Bathing		

Laundry		
Cooking		
Gardening		
Personal hygiene		
Other (specify)		

How satisfied are you with the quality of water supplied?

i) Very dissatisfied

ii) Dissatisfied

iii) Indifferent/fairly satisfied

iv) Satisfied

v) Very satisfied

Water supply reliability

How reliable do you find the water supply in your area?

i) Very unreliable

ii) Unreliable

iii) Indifferent

iv) Reliable

v) Very reliable

Have you noticed any change(s) in water pressure during supply?

i) Yes, often low pressure

ii) Yes, occasionally low pressure

iii) No changes

iv)

Water supply issues

How would you rate the overall water supply in your community?

i) Very poor

ii) Poor

iii) Average/fair

iv) Good

v) Very good/Excellent

What do you think are the primary reasons for poor water supply? (Select all that apply)

Reasons for poor supply	No = 0	Yes = 1
Aging infrastructure		
Lack of Infrastructure		
High water demand		
Pollution/contamination		
Poor maintenance		
Drought and climate change		
Other (specify)		

Have you or any family member(s) experienced any health issue(s) related to poor water supply in the last one month?

Yes………….

No……………

If yes to question number 15, what type of health issues have been experienced in your household in the last one year? (Select all that apply)

Health impacts	No = 0	Yes = 1
Cholera		
Dysentery		
Hepatitis A		
Typhoid fever		
Polio		
Skin infections/irritations		
Respiratory issues		
Other (specify)		

How would you rate the impact of water supply on your family's health?

i) Very negative
ii) Negative
iii) Neutral/indifferent
iv) Positive
v) Very positive

Alternative sources

What alternative sources of water do you use? (Select all that apply)

Alternative sources of water	No = 0	Yes = 1
Boreholes		
Wells		
Rainwater harvesting		
Water tankers or deliveries		
Bottled water from stores		

On average, how far do you travel to access alternative water sources? (Distance in hours)

i) Less than 30 minutes

ii) 30 minutes – 1 hour

iii) 1-3 hours

iv) 3-5 hours

v) More than 5 hours

Do you spend money on alternative sources of water (e.g., bottled water, tanker delivery)?

i) Yes………

ii) No……….

If yes, how much do you spend on average per month for alternative water sources? M.................

Can you rate the appropriateness of each of the water supply improvement strategies below (on a scale of 1-5) as adjudged by your experience

Improvement strategies	Rating				
	1	2	3	4	5
Rainwater harvesting systems					
Rehabilitating old water pipelines					
Community water education programs					

Temporary potable water transport and distribution					
Advanced leak detection					
Regular maintenance					

1= Not appropriate at all, 2 = Slightly appropriate, 3 = Moderately appropriate, 4 = Very appropriate, 5 = Extremely appropriate.

Thank you for your contribution.

Interview guide

Interview Guide for Water Agency Officers/Officials

a) What types of water infrastructure does your utility manage?

....

....

b) What is the age of the majority of your water infrastructure?

………………………………………………………………………………………………..

c) How would you rate the current condition of your water infrastructure?

……………………………………………………………………………………………….

d) How frequently does your utility impose water interruptions/supply?

………………………………………………………………………………………………..

e) What are the primary causes of water interruptions identified by your utility?

…………………………………………………………………………………………………

f) On average, how long do water shortages last when they occur?

…………………………………………………………………………………………

g) How do water shortages impact your operations?

…………………………………………………

h) How often do you do maintenance work on your distribution network?

………………………………………………………………………………………

i) What measures has your utility implemented recently to mitigate water shortages?

…………………………………………………………………………………………….

Thank you for your contribution.