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Water Distribution Network Analysis using Web GIS-Based: The Case of Lemi Kura Branch, Addis Ababa

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Water Distribution Network Analysis using Web GIS-Based: The Case of Lemi Kura Branch, Addis Ababa

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This is to certify that the thesis prepared by Yonas Nikola entitled: "Water Distribution Network Analysis using Web GIS-Based: The Case of Lemi Kura Branch, Addis Ababa" and submitted in the fulfillment of the requirement for the Degree of Master of Arts in Geographic Information System, Remote Sensing and Digital Cartography complies with the regulation of the University and meets the accepted standards with respect to originality and quality.

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Abbreviation and Acronyms

AAWSA	Addis Ababa Water and Sewerage Authority
CAD	Computer-Aided Design
CSA	Central Statistical Authority
CSS	Cascading Style Sheets
CSW	Catalog Service for the Web
FOSS	Free Open-Source Software
GCP	Ground Control Point
GDP	Gross Domestic Product
GIS	Geographic Information System
GTP	Growth and Transformation Plan
HTTP	Hyper Text Transfer Protocol
HTML	HyperText Markup Language
MCE	Metaferia Consulting Engineers
MDGs	Millennium Development Goals
NGOs	Non-Governmental Organizations
NRW	Non-Revenue Water
OGC	Open Geospatial Consortium
SDGs	Sustainable Development Goal
UN	United Nation
WFS	Web Feature Service
WHO	World Health Organization
WMS	Web Map Service
WMTS	Web Map Tile Service
WSS	Water Supply System

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Abstract

Water distribution management methods are extremely complicated and multifunctional, requiring the modification of conventional approaches. One of the current concerns with the increase of urban areas in Addis Ababa due to population growth, economic development, inadequate and inefficient infrastructure, high water leakage, conventional network analysis and management, and potential shortages of water due to climate change is efficient water management of the urban water system. To meet the rising demand for water, it is critical to develop modern water management systems that provide real-time monitoring and decision support in order to properly manage the water supply network. In order to solve such issues, this study provides a Web-GIS based water analysis and management system, which enables opportunities to obtain the correct facts at the right time to make the right judgments. This paper describes and implements web-based architecture using open-source tools. The research relied on both primary and secondary data sources. GPS location tracking and key informant interviews were used to acquire the primary data. Secondary data were acquired from existing water network CAD map files. This information was gathered from the AAWSA. Other secondary data obtained from different institute and examined in narrative form using the descriptive analysis approach. According to the findings of this study, there is an imbalance between supply and demand. Only 72% of the total area is covered by a water supply. To collect data on the water supply system, the authority has limited resources and skills. In general, there is a lack of a comprehensive utility infrastructure governing framework, standards, and organizational coordination, as well as difficulties in utilizing GIS data. This study modified and integrated an open-source Web-GIS solution using GeoServer as a GIS web server, PostgreSQL/PostGIS as a relational database for storage, and a GIS application for producing spatial database of a water distribution network. An attractive and interactive geographic user interface was created with the help of MapStore. The developed system includes all water utility layers such as distribution pipelines, valves, and so on in a web map, the capability of querying the layer's information, sharing and printing maps, and some spatial operations such as distance and area measurement, as well as a mechanism for system administrators to add or remove the utility layer at a specific location. In conclusion, Water Distribution Network Analysis using WebGIS-Based systems offers significant advantages, improving efficiency, decision-making, and stakeholder engagement in water distribution networks.

Key words: Addis Ababa, GIS, Open-source Application, Water Distribution, Web

Chapter One

1. Introduction

1.1. Background of the Study

Water is one of the fundamental elements needed to sustain life for all living things on Earth. (Mokhena et al., 2016). An acceptable supply of water in urban area is necessary for a society's well-being and overall health and is thus critical to a nation's advancements. The inefficient management of scarce water resources, urbanization, the growing living standards and population growth, deteriorating infrastructure, and the long-term viability of traditional water management is a major issue that towns and cities in developing countries are currently dealing with (Zeraebruk et al., 2014).

The Water Distribution System (WDS) is made up of three major components: a water supply, a treatment system, and a distribution network. Reservoirs, rivers, and groundwater wells can all be used as water sources. Water treatment plants disinfect the water to meet drinking water quality standards before delivering it to customers. The distribution network, which mostly consists of pipes, pumps, junctions (nodes), valves, fittings, and storage tanks, is responsible for distributing water from the source or treatment facilities to its customers at serviceable pressures. WDS is mandated to supply water to home, commercial, and industrial organizations at or above a certain pressure, with consumer demands varying during the day, week, season, and year. (Bhatt and Paneria, 2017). Several spatial aspects are included to the complicated water supply system. A sufficient water supply, functional pushing infrastructure, and an interconnected distribution network are requirements for an effective water distribution system (Zeraebruk et al., 2014). A water distribution network that was not properly installed and that was not effectively operated and maintained would inevitably fail.

In order to increase the effectiveness with which their systems are operated and maintained; infrastructure utilities are under increasing pressure to develop sophisticated utility management plans. When organizing and executing design and construction projects, pinpointing the precise location of utilities is essential. GIS is essential tools for the geographical and statistical evaluation of water resources in order to manage them in a more effective and efficient manner (Jaiswal et al., 2021). The complexity of the water distribution network can be optimized using GIS technology, and maintenance costs can be somewhat decreased. Resource managers may benefit from using Web GIS and GIS technologies to deliver better services (Ajwaliya et al., 2017). Using GIS in the service industry has many benefits; globally more than 80% of the data in water companies use a geographic reference (Shamsi, 2005). The water distribution system's geographically distributed facilities can be located using GIS and spatial analysis.

A fundamental part of all the data at a water company that is frequently shared is the spatial location. Since judgments about the immediate surroundings and impacted assets can be made quickly (Chauhan et al., 2020). This water network data can be better analyzed, tracked, displayed, and managed with the help of GIS. We get a comprehensive, integrated sight of the system in connection toward the adjacent infrastructure because of the visualization and mapping features. The ability to make wise judgments in relation to the immediate environment and affected assets depends on location information, which is crucial for efficient management. They also need to know where their workers are working, where customers utilize water, as well as which facilities require maintenance (Chauhan et al., 2020).

The World Wide Web (WWW), in particular, is quickly becoming a vital component of our everyday lives and a required means for achieving fundamental needs (Mamai et al., 2017). The internet and World Wide Web enable it to store and share information nowadays. Web mapping apps have developed as a result of the internet's rapid expansion and a rise in users' interest in online geospatial information. A distributed information system known as Web GIS at a minimum includes a user side and a server side. A web-based platform provides all-around access to software data and utilities without the requirement for a specific application and may conduct the operations requested by a large number of users at the same time. Therefore, users are a web application, personal computer or smartphone software, and GIS server used as a server. GIS that connects a server and a client server using web technologies is known as a Web GIS (Chauhan et al., 2020).

In Addis Ababa, there is a high need for water services. As an outcome of this, the city has no extra capacity or reserve water supply, which would provide the system redundancy. 60% of the groundwater and 40% of the surface water used to supply water are already stressed sources, and the failure of either one would cause a crisis. The water authority has detailed data on the place of the main water infrastructure, on the other hand nothing is known about how well it is now maintained or if it could continue to function in the occasion of a crisis. Additionally, there is no preventative repair strategy in place, and most progress is made immediately after a reported line break (Doyle et al., 2020). In large cities, dependent on water supply lines for water delivery with high leakage loss accounts for a substantial share of water demand, and so leakage management is an important technique for minimizing water loss (Kitessa et al., 2021).

Considering the above factors of demand and management of water supply and utilizing of GIS in water distribution management in Addis Ababa, this study was demonstrated to a GIS-based water distribution network management structure and evaluates the condition of the current water delivery systems of Lemi Kura branch of Addis Ababa. The study develop a web GIS prototype model based on free open-source software and libraries. A relational database, an intermediary layer for managing geospatial data, two layers of web interface for customizing services, and other software components will serve as the foundation for this web application. Web services for organizing, displaying, and storing geographic data will make up this application.

1.2. Statement of the Problem

Among the essential municipal services that have a substantial influence on both the wellbeing of residents and the economic development of cities is a reliable and safe water supply. Economic and social advancement are correlated with the accessibility of water assets, indicating that the accessibility and management of water resources have a significant impact on development (Lawrence and Meigh, 2003).

Addis Ababa has only a limited surface and groundwater resources, which are both vital for meeting domestic demands but whose failure would cause a crisis (Admasie, 2016). The issues facing Addis Ababa city's water supply system include low production capability, insufficient networks, high volume of water linkage, increased water demand, a high population and urbanization (Kassa, 2017). The stress of rapid population growth and increasing living standards has raised the per capita water consumption as well as the demand for water. A fast-growing economy and an unheard-of construction boom are driving up water demand from the industrial, commercial and construction industries. The accessibility and quantity of water are declining as a consequence of intense subsurface water exploitation, resource depletion, and Changes in the climate, despite an increase in demand for water across all significant sectors (Feyissa et al., 2019). To make certain that more drinkable water is made accessible for the population, the percentage of city water demand met is not larger than 60% (Worku, 2017), as well as anticipated that the system's predicted 36.5% water supply leakage (Feyissa et al., 2019).

At the moment, Addis Ababa still has serious water shortages and is not yet completely covered by the water supply. AAWSA currently provides water on a shift-by-shift basis to several areas of the city and Lemi Kura branch. The piped system supplies water to a number of pocket communities two or three days per week. Less than 60% of Addis Ababa’s residents have access to safely managed water through AAWSA's piped network. 36.5% is a high estimate for the rate of water leakage. Given the fact that water, insufficiency is currently a problem for the municipal and is predicted to get worse owing to changes in the climate and rising demand, physical leakage accounts for 20% of total produced water loss, while 17% is economically unaccounted for AAWSA. These include insufficient water supply to the distribution system, water loss from leaks, and an ineffective supply system, such as, there are only a few reservoirs serving the entire city and branch served area, it was designed to accommodate small populations. There were rusted and broken pipes even in the places the network served, which resulted in water loss from leaks and contaminated water from particles getting into the damaged tubes. Inadequate operations and maintenance increased the problem. Additionally, there are no comprehensive databases that can assist managers in estimating the number of customers and water consumption in their service branch.

At the city level, various departments offer public infrastructure services. There is not a single organization that will oversee all of these utilities at once, including water supply, wastewater, electricity, roads, and telecom. Infrastructure utilities are constrained by data type, storage, maintenance, and accessibility. There is a greater repetition of work as a result of poor coordination and strategic planning, which wastes time, money, and labor. All of these circumstances are seriously affecting people's lives, negatively affecting their quality of life, reducing their life expectancy, and raising their cost of living of the study area population.

Various writers have written about the importance of GIS in planning water resources management, water supply and distribution modeling. However, the ideal water delivery system, that takes into account together the database and the physical utility asset, is given less focus according to the studied. A study conducted by Seifemicheal, (2018) emphasized the significance of linking recording of the city water network data for water demand allocation and pressure required for decision making. Similarly, Dureti, (2015) to make a good plan for the water supply network, the AAWSA took into account the location and elevation of various water authority facilities, such as storage tanks, stations for pumping, and water supply pipelines of Addis Ababa city.

This research tried to understand the current water distribution network analysis and try to address possible remedies for the problem with the help of the Web-GIS system using the available data for the city's sustainable development.

1.3. Research Objectives

1.3.1. Main Objective

The aim of this study was to assess the management system of Lemi Kura branch water distribution and management, and model a web-based prototype in order to enhance the water distribution system.

1.3.2. Specific Objectives

The following specific objectives are intended to be met, based on the above-mentioned core objective:

1. Examine the current water distribution network and geospatial database of water distribution utility network in the study area.
2. To identify the cause of water distribution network problems in relation to data management in the study area.
3. Develop a Web-GIS system for water distribution system management.

1.4. Research Questions

1. What is the current state of the distribution system network and geospatial database of water distribution utility network in the study area?
2. What are the major challenges utilizing spatial data management in water distribution management in the study area?
3. What are the challenges in developing web-based applications for spatial data processing and analysis?

1.5. Significance of the Study

Water is necessary for the existence of all living things, in both sufficient both in terms of quantity as well as quality. Because water is essential to the development and basis of ecosystem health, its use has significant effects on the social, political, and environmental areas. In this study, the optimal water distribution systems will be established using contemporary methods. The outcomes of the study will be the base for effective water distribution analysis in Ethiopia. A thorough database to direct workers in water distribution is necessary for best productivity. This study will assist researchers in figuring out the most effective water distribution system because the majority, most developing countries' water distribution systems, if they have any, lack operable, current databases for assisting employees. This study will offer insightful data on the strong correlation between water distribution system performance and the use of GIS in building and managing water distribution systems. Additionally, this study will give insight on the necessity for additional local studies and research toward assess the performance of the water delivery systems in Addis Ababa city. It will offer water planners and policy makers in Addis Ababa a path forward for enhancing the water supply system. It also offers NGOs, community-based organizations, and other stakeholder’s insight into the issues surrounding urban water supply.

1.6. Scope of the Study

The study's purpose is to create a geographic database and a web system for the water utility network up to the main transmission and secondary distribution line, but it will not consider connections to home water supplies. The availability of data is also limited by asset mapping. With the aid of GIS software, data were gathered, entered, preserved, changed, and assessed in order to construct a model for efficient water distribution system in Lemi Kura branch.

1.7. Limitation of the study

The study's limitations include a lack of time for in-depth field data collection, respondent unwillingness during the interview, lack of adequate documents, reports, secondary data (Shapefiles), and out-of-date data. Even though the above factors constrain the study, the researcher digitizing the incomplete data, replacing investing much time on filed data collection to gather real and updated data.

1.8. Organization of Thesis

This thesis was structured into five chapters: an introduction, a literature review, methods and materials, data analysis and discussion, and finally a conclusion and recommendation. The background of the study, the problem statement, the study's objectives and questions, the scope, and its significance were covered in the introduction chapter.

The second chapter described the literature review and attempted to show some works by other writers that address related research questions as this research study. The third chapter provided information on the materials and methods, elaborated on the methods and tools the thesis utilized to accomplish its objectives, and explained the procedures used to create a database of the current drinking water distribution system in Addis Ababa.

The data result and discussion chapter presented the analysis of the data obtained during the course of this research; in this chapter, the methodologies used in the analysis of the data analysis software were also examined.

The thesis was concluded in Chapter 5 by a summary of the points made in the introduction and literature review, a brief analysis of the research methods and design employed a discussion of the implications of the study findings, and an outline of the research's scope. This chapter also makes recommendations according to the evaluation and informs the reader on what to do in response to the study's findings.

Chapter Two

2. Literature Review

2.1. Introduction

Moreover, a majority of the world's surface has been covered by water, most of which is salty and useless for drinking. Only 2.7% of the globe's water source is drinking water, while only 1% of this supply is easily available through rivers, lakes, and underground. Due to their location in glaciers and deep aquifers, that are hidden parts of the hydrologic cycle, the vast majority of available freshwater resources are unreachable. This means that just three percent of the world's drinking water resources are safe to drink. Desalination is a method for obtaining freshwater from seawater. Some countries lack access to enough freshwater (physical scarcity). Although there is a portion of freshwater available in some nations, it has a high cost of use (economic scarcity) (Megersa, 2002).

Ethiopia will see an average annual rainfall of 1500 mm in 2021 (Berhan and Meda, 2021), and the World Bank has categorized it as a country with abundant water resources. Ethiopia, the second-most populated nation within Africa, is frequently called the "water tower of East Africa" because of its numerous water resources, which include nine main river basins. Despite this wealth, the nation has a persistent water problem. The problems of diminishing water quality brought on by pollution and decreased water supply because of population increase are factors in the worldwide water scarcity crisis.

A need is that there must be a sufficient, reliable, and adequate drinking water supply for all users (Bos, 2016). A universally accepted definition of "safe drinking water" is currently not established. However, water that presents no significant health risks throughout a person's lifetime is generally regarded as safe for human consumption (Fogden and Wood, 2009). The Joint Monitoring Programme oversees monitoring organizations that define "safe drinking water" as water sourced from an "improved water source." This category includes various sources such as household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater collections.

Safe drinking (potable) water refers to water that is not only accessible to users but is also considered safe for a range of activities including drinking, food preparation, personal hygiene, and washing (Bos, 2016). It meets the necessary standards and requirements to ensure it is free from harmful contaminants or substances that could pose health risks to individuals who consume or use it (DeZuane, 1997). The standards established for the various quality parameters are likewise different, and as such, the meaning of "safe drinking water" depends on the laws and regulations of a particular country. The Ethiopian norm and the WHO standard are marginally different. Depending on a person's particular level of resistance, what is meant by the word "safe" changes.

The United Nations' Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) highlight the global significance of ensuring safe drinking water as a priority (MDG 7 and SDG 6). Despite efforts made under the MDGs, a significant number of people still lack access to basic water supplies, including safe drinking water. Over 1 billion individuals worldwide do not have access to clean drinking water. While the world's population continues to grow, the availability of freshwater resources remains largely unchanged. As a result, more people are experiencing a lack of access to clean drinking water. This situation is primarily attributed to the rapid population growth in developing nations and the insufficient provision of water supply infrastructure by governments in these regions (UN-Water, 2015).

2.2. The principles of providing drinking water

There are fundamental requirements, rules, criteria, and indicates for safe drinking water. Safe drinking water is governed by numerous laws, procedures, and initiatives. These phrases are clearly explained by Bos, et al 2016. The term "Norm" links to the general social group's accepted norm of development. The term "criterion" describes the accepted norm or standard applied during the decision-making process. An indication is the determined value for each specific water quality parameter. The approved objective/threshold value defined as an established goal that is determined by an authority is referred to as a standard. Different criteria and standards for water quality exist around the world (Megersa , 2002).

2.3. Water supply system challenges

Water supply systems (WSS) face a variety of challenges, including old infrastructure, long-term planning, challenges particular to a catchment change in the climate, hydrological uncertainties, precise demand forecasting, modifications to land use, efficient operation, recovering costs, water pollution, limited availability, leaks, low pressure, overuse, drought response, increasing population, urbanization, migration, demographic shifts, growth in the economy, consumer habits, system efficiency, alternative water sources, and alternative water sources. To overcome these issues, adaptability indicators, inclusive policies, and holistic programs are required to ensure secure and reliable water services for current and future generations. (Sedlak and Schnoor, 2013).

As stated by Alexander Danilenko et al., (2014), WSS has had numerous international difficulties in the twenty-first century. Population expansion, global climate change, socio-environmental problems, lack of water supplies, financial crises, and a continuous aging process are the main obstacles. Water loss due to low pressure and deteriorating in quality of water are just a few of the issues brought on by ongoing aging (Alegre et al., 2016). The main obstacles to providing clean Hygiene and water supply around the world. According to (Pusch et al., 2005): (1) pollution of water in distribution networks; (2) growing insufficiency and deficiencies of water; (3) putting in place creative and inexpensive hygiene schemes; (4) offering megacities Sanitation and sustainability water supply systems; (5) reducing inequalities in terms of drinking water and hygiene; and (6) creating Services for drinking water and hygiene that are financially viable.

2.4. Ethiopia's urban water supply challenges

Ethiopia has an abundance of water resources; yet, their distribution across the country is uneven, and their availability varies with the seasons and years. Maintaining a supply that is sufficient to meet people's requirements throughout the year is a difficulty in any circumstance. Selecting the appropriate water source is a crucial consideration, considering both current and future water demands and associated costs. The proximity of reliable water sources to communities significantly affects the affordability of water services. Many towns face challenges in locating nearby water sources. Planning for current and upcoming demand must take population increase into account. Cities and towns are experiencing population growth as people migrate from rural areas in search of better opportunities and improved living standards. The amount of water needed for home consumption varies on the population size, as well as on their habits, culture, and access to water. In Ethiopian cities, the average daily water consumption per person for basic needs is typically around 15 liters (MoH, 2011; Mushir & Abraham, 2020).

2.5. Water Supply Services in Addis Ababa

Local autonomy and administrative boundaries are unique to each Kebele. By combining the majority of Kebeles and granting them additional authority, recently the number of Kebeles has decreased. Addis Ketema, Kirkos, Yeka, Bole, Arada, Lideta, Akaki Kaliti, Nefas Silk, Kolfe Keraniyo, Gulele, and Lemi Kura are the sub-cities.

Numerous densely populated urban areas lack the necessary infrastructure to access formal water supplies (Khatri & Vairavamoorthy, 2008). The increased demand for water services in Addis Ababa's urban areas remains a serious problem. Addis Ababa is defined by unplanned land use and shanty or informal settlements on the periphery. The city's requirement is not met to the satisfaction of 50%. The Authority must launch water supply projects creating more pipes and revise its management techniques to solve the severe mismatch between water demand and supply. Particularly in the public water tap services, the poor quality of service delivery is evident. Due to the lack of clear regulations governing the public water tap system, there are significant price differences between domestic connections and public tap users (Sharma & Bereket, 2008).

Despite tremendous progress made in recent decades, the city continues to face severe difficulties in providing residents with reliable and safely managed water supplies. Less than 60% of Addis Ababa's residents have access to safely managed water through AAWSA's piped network. 670,000 people use AAWSA, which also delivers water to 2,249 public fountains (public outlets). Prior to the Millennium Development Goals (MDG), however, there were inaccurate reports and overstated estimates on coverage, such as 92% in 2011, which indicates issues and loopholes in the system of monitoring and underestimating of the problems with access to water (Worku, 2017). In general, there is a shortage of water due to an exceptional rise in demand, even if the supply has increased over the past ten years. 20 percent of the total amount of water produced is lost through leaks, and 17 percent is not financially accounted for. Additionally, a higher percentage, 51%, of water is produced from surface water sources (Ewunetu, 2019; Worku, 2017).

2.6. Water supply system

The water distribution system is designed to ensure the delivery of water that meets quality standards, in sufficient quantity, and at appropriate pressure levels to individual customers. It is designed to handle the maximum expected flow rate while maintaining acceptable pressure throughout the network.

2.6.1. Methods of Water Supply Systems

1. Continuous supply system

Water runs constantly across the distribution network without interruption in continuous supply systems, allowing consumers to receive water at any time without relying on individual storage. This type of system necessitates the availability of sufficient water. The fundamental advantage of continuous supply is that water stays fresh, and pipe rusting is minimized. Water losses, on the other hand, are more likely in the event of leakage (Walski et al., 2003).

2. Intermittent supply system

The water supply system in many developing countries is characterized by intermittent rather than continuous availability. Intermittent supply entails delivering water to a complete village or town for a set number of hours or separating the supply into zones and supplying water to each zone for a set number of hours or on specific days. When water availability is restricted, this strategy is used, but it can lead to water waste because societies tend to save more water than is necessary. Intermittent supply can hasten pipeline rusting owing to soaking and drying cycles, however maintenance can be done during off-hours. However, irregular supply leads to inequitable water distribution, especially for users who live distant from supply sites or at higher altitudes un the area (Totsuka et al., 2004).

2.7. Types of water distribution systems

Transmission and distribution systems are classified as looped or branched. Multiple channels are available for water to flow from the source to a specific customer in looping systems. In contrast, there is just one feasible channel for water to move from the source to a consumer in branched systems, also known as tree or dendritic systems (Beckwith, 2007).

According to Beckwith, (2007), the water distribution networks can be classified as explained below;

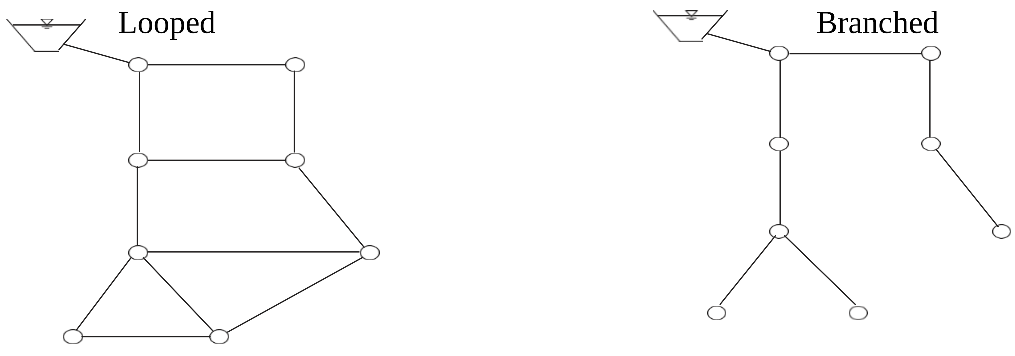

Figure 2.1: Looped and branched distribution system

1. **Looped system (grid systems)**

As the name suggests, it offers several paths water can travel through looping systems to get from the source to the client. Because they can add an extra level of reliability when combined with enough valve’s, looped systems are generally preferable to branched systems. Because there are multiple water paths in this system, the network's performance has increased, and the distribution system's hydraulics has been upgraded. This kind of distribution network has no dead ends. This type of architecture is especially desirable since water may be supplied to any one spot on the grid from several ways, which means that maintaining the operation did not affect the entire area as it would have in a branching system (Beckwith, 2007).

When valves are placed properly, this leads to in substantially lower head losses than would normally occur, as well as the least amount of interruption when repairs or maintenance operations are needed. The area is completely covered in the mains that make up the grid system (Beckwith, 2007). The majority of water delivery systems are complex networks of loops and branches, with loops typically being more reliable (redundant) than branches due to their lower infrastructure costs (Beckwith, 2007).Consider, for instance, a major failure in each of the systems shown in Figure 2.2 below that occurs close to the reservoir. The looping approach allows for the isolation and repair of that break with minimal impact on users outside of the immediate area. The impact of a water service disruption, however, is greater for branched systems.

2. **Branched systems**

A tree system is another name for this network. There is only one route that water can take from source to a customer (Beckwith, 2007). As a result, they are suited to small-capacity water sources, which are widespread in the majority of developing nations. These systems have the advantage of being the most inexpensive due to their low cost, but they also have significant drawbacks, which are low reliability, especially for users downstream of a system failure, has an impact on all users. As a result, until the repairs are complete, their water services have been interrupted. Water demand fluctuations cause the system's pressure to vary significantly. When necessary, new branches will emerge with network development, and new dead ends will be constructed. It also poses a risk of contamination during the network's absence of water. Additionally, there is a risk of pollution while the network is waterless.

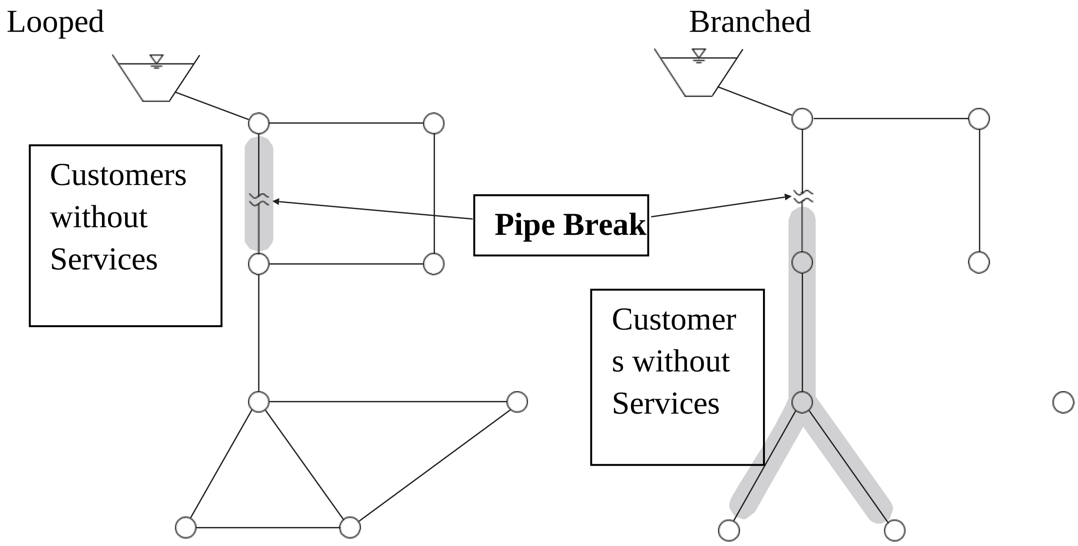

Figure 2.2: Looped and branched networks after network failure (source: Haestad Methods)

2.8. Methods of Water Distribution

Distribution of Water must go through the piping system at the proper pressure and flow rate in order for the distribution to be effective. There are three primary distribution system types that municipalities might use:

A. **Gravity Distribution:** This is achievable if the source of the city's water supply is elevated above it, allowing for the transmission of enough pressure in the mains for domestic and emergency services. The benefit of this distribution strategy is that it reduces the amount of power required for pumping (Beckwith, 2007).
B. **Distribution by Pumping without Storage:** Water is pumped into the mains in this distribution system, and the only output is the water that is actually used. The rate of pumping ought to be adequate in order to meet demand. The power outage results in a full suspension of the water supply, making this distribution system the least desirable. A benefit of direct pumping is the possibility to use a large fire service pump to raise the pressure to any necessary level, which is made feasible by the design of the mains. (Beckwith, 2007).
C. **Distribution by means of pumps with storage:** Pump-assisted distribution with storage involves using raised tanks or reservoirs to store excess water pumped during low-demand periods. The stored water can then be utilized during high-demand periods, ensuring a consistent pumping rate and cost-effectiveness. (Beckwith, 2007).

2.9. Water Demand

Users' water demand is the amount of water needed to suit their needs. Although the two terms are essentially different and don't have the same meaning, they are occasionally used interchangeably when referring to water usage (Wallingford, 2003). Theoretical water demand typically exceeds actual water usage in underdeveloped nations (Abera, 2018). Water demand is calculated by adding the algebraic total of the water that is physically available to the user and the amount of water that is utilized by the customer (leakage). It is frequently expressed in terms of demand per person. Water usage per person can vary significantly due to factors such as climatic conditions, lifestyle choices, population growth, types of commercial and industrial activities, and water pricing. Over time, water usage tends to increase, primarily driven by population growth. To be able to achieve the present and future water demand, new water resources must be created (Uthman and Abdo, 2009).

2.9.1 Types of urban water demand

According to the characteristics of the users, water demand is frequently divided into different categories. The most common forms are unaccounted water demand, domestic, commercial, industrial, and firefighting.

1. **Domestic water demand**

Domestic demand encompasses the water consumption for essential household activities such as drinking, cooking, bathing, flushing toilets, and doing laundry. Domestic consumption varies depending on the consumers' living conditions, the business conditions of the community, the weather, the service type provided, and the cost and accessibility of that service. In Ethiopia, daily water use per person is often relatively minimal. DWD is prohibited in almost all communities across the nation due to a scarcity of supply. Actual demand would be higher than present consumption if more products were available to the society (Ministry of water and Energy, 2011).

2. **Non-domestic Demand**

Non-domestic demand encompasses various factors such as industrial, commercial, and institutional water requirements, firefighting needs, and unaccounted water demand (UWD). It represents the total water demand outside of residential usage.

Industrial water demand: reflects the volume of water that companies and industry in cities need. Although companies typically consume 50 liters of water per person per day, new technology that allows for the reuse of wastewater has lowered this requirement.

Commercial and institutional water demand (CIWD): Cities' water requirements include not only those of residential users, but also those of commercial and institutional customers such public schools, clinics, hospitals, workplaces, stores, bars, restaurants, and hotels. CIWD and population density are frequently related. The CIWD estimate for a medium town is based on 10% of DWD (Ministry of water and Energy, 2011).

2.10. Drinking water quality

The most essential factor in forming the land and regulating the climate is water. It is one of the most significant resources that have a significant impact on life. The most fundamental governing factor for health and the prevalence of diseases in both people and animals is water quality. About 80% of all human diseases, according to a WHO report (WHO, 2014), are brought on by water. Water quality analysis considers a range of biological, physical, and chemical variables that are relevant to the specific purpose of the water. The selection of these variables depends on the intended use of the water and the specific goals of the water quality assessment. Drinking water is generally expected to be free of poisonous chemicals and harmful bacteria (Bos, 2016).

Since there are numerous elements that might affect water quality, the concept and theory are very wide. The potential uses of water for multiple uses determine the water's quality since they have varied requirements that must be met. All of the acceptable and unacceptable values for each quality variable in an analysis of water quality must be specified. If the quality parameters satisfy the prerequisite requirements for a particular usage, it is regarded as safe for that use.

2.11. Operation and Maintenance of Water Supply Systems

Water management involves the comprehensive management of water resources, encompassing planning, development, and maintenance of water quantity and quality for various purposes. It encompasses the establishment of institutions, infrastructure, incentives, and information systems that facilitate effective water management practices. The distribution system, treatment facility, service reservoirs, and water source are all parts of the urban water supply. Water utilities are in responsible for operating and maintaining water treatment facilities and supply systems, which is essential for ensuring supply reliability and quality.

All the tasks required to keep a water supply system running continuously in order to deliver the required service are referred to as operation and maintenance. The shorthand "O&M" is frequently used to refer to the two words when they are used together. To ensure a system that is effective, efficient, and sustainable is the overarching goal of operation and maintenance (Castro et al., 2009). **Efficiency** is the ability to complete a task with a small amount of time, effort, and resources wasted; **effectiveness** is the ability to produce the desired outcome; and **sustainability** is the ability to maintain the greatest level throughout time, in this instance, the supply of water.

An asset register is a detailed record of a company's physical assets, such as equipment and buildings. It includes critical information such as item description, technical drawings, acquisition date, service life, location, cost, manufacturer data, serial number, warranty and insurance information, operating instructions, and maintenance requirements. Documenting failures and their causes can also provide useful information for formulating operational and maintenance guidelines based on equipment experience (OpenWASH, 2016).

2.12. GIS Applications for Water Distribution Systems

More than 80% of the data a water service providers uses has a geographic reference (Shamsi, 2005). In other words, the information's position in relation to additional geographic features and objects is a crucial component of the information used by utilities. GIS technology is the best option for efficient management of the infrastructure used by the water sector because it combines the power of geography and information technologies. Although GIS applications for water distribution systems are still in their infancy, it can be difficult to move beyond the most fundamental mapping and inventorying tasks (Zhang, 2006). A water system GIS is nothing more than a nice map unless it is used effectively. This is why the focus of GIS is currently turning away from computerized mapping and toward crucial enterprise applications. GIS applications simplify the performance of ordinary business operations, increasing productivity and lowering costs (Shamsi, 2004). GIS applications could improve water system administration and prepare them for the operational challenges of the 21th century.

In the late 1980s, GIS uses in water sector first emerged. In the early 1990s, the water industry began using GIS for mapping, modeling, facility administration, and work-order control to establish capital improvement programs and operations and maintenance plans

(Morgan, T.R. and Polcari, 1991). Drinking water research began to use GIS widely in the middle of the 1990s. At the time, potential applications included (Schock, M. R., and Clement, 1995):

- GIS can serve as the foundation for researching the presence of regulated substances to calculate the cost of compliance or assess the effects on human health.
- A water utility can utilize mapping to study process changes or to evaluate the efficacy of some current treatment's plants.
- Weighing the viability and effects of system development can be helped by GIS.
- Plans for protecting wellheads can be created with the aid of GIS.

GIS has grown in popularity as a management tool since the late twentieth century. Over the previous ten years, the number of GIS users has grown dramatically. GIS technology has streamlined time-consuming processes. The argument of information among GIS, CAD, supervisory control and data acquisition (SCADA), and hydrologic and hydraulic models is turning into considerably easier. For instance, stream network delineation has become simpler, and the challenges associated with managing geographical data and parameterizing models have decreased (Miller et al., 2004).

GIS uses for water distribution systems include the development of hydraulic models, the generation of thematic maps displaying the model's results, network simplification for hydraulic modeling, estimation of node demands and elevations, valve identification for water main isolation during maintenance or replacements, and pressure zone separation. GIS is widely used in the study and management of water distribution systems, providing significant tools for representing and analyzing water-related phenomena. A manager of a water distribution system may efficiently construct complete capital improvement projects and operations and maintenance plans using geographic data derived through mapping, modeling, facility administration, as well as work order management (Sargaonkar and Islam, 2009). GIS is now utilized in conjunction with programs for customer service, capital planning, and maintenance management. Many of us use GIS applications on wireless devices and the Internet without even being aware that we are doing so. Because of these advancements, GIS is a fantastic tool for organizing information on water utilities and for enhancing their performance (Shamsi, 2005).

2.12.1 Advantages of GIS Applications for Water distribution and management

Applications for GIS come with several benefits for water distribution and management system. The following subsections provide an overview of typical GIS application benefits.

GIS technology reduces costs and saves time of maintenance of water system: GIS applications make life easier, which raises people's quality of life. GIS allows us to do routine jobs more rapidly, such as recording maintenance work or feedback from clients. GIS tools have improved in usability and simplicity (Shamsi, 2005).

GIS can be used to organize information on customers and water assets such as pipes, fire hydrants, the pumps, and water treatment apparatus. To more effectively plan, manage, operate, and maintain its infrastructure, a utility can use GIS technologies to analyze geographical data about its customers and assets.

The time and expense involved with traditional analysis and evaluation procedures can be greatly reduced by using GIS tools* (*EPA, 2000)

GIS Systems Provide Integration Power: GIS unifies various types of data and programs with a geographic module into a single, controllable system. The ability of GIS to combine information is its true strength. The potential of GIS applications is practically limitless because to this integration power. Whatever we want it to be; a GIS can be. A municipality or utility's geospatial data can be arranged using GIS into a single, streamlined environment. A complete picture of a scenario can be created by bringing together (integrating) different data sets thanks to GIS's special integration capability. When many data sets are combined, GIS technology shows links, linkages, and patterns that are sometimes not immediately visible when looking at individual data sets. GIS technology's integration capacity enables firms to make better decisions based on all available information (ESRI, 2003). GIS provides integrated solutions for planning and the field of engineering, operation and maintenance, and even administration and finance.

GIS Applications Provide a Framework for Decision Support: GIS assists decision-makers by assembling important informational fragments into a "whole" and displaying the "large" picture. In this sense, GIS can be a tool for reaching agreements and making decisions. GIS enables the combining and analysis of data from a wide range of diverse sources by using geography as the common denominator. As a result, a key advantage of GIS applications is their built-in capacity to combine and analyze all spatial data to aid in decision- making. GIS offers consistency in data usage as well as the freedom to test and assess various scenarios. The disparities in display, assessment, and decision-making based on the usage of various forms and types of data are eliminated by the use of a shared database (Shamsi, 2005).

GIS Programs Offer Powerful Communicating Tools: GIS encourages improved communication and teamwork between many participants of a building or development project in the water business. Many people learn more well from maps than from words or figures. GIS can be used to convey information to various audiences by presenting the same data in visually appealing ways. For instance, presentations at town meetings can employ 3D plans sights of a water system renovation plan to visually represent the improvements that are required. GIS is a visual language, making it a fantastic communication instrument for those who learn best visually. Only one picture can express many words. A map can be worth a million figures. A GIS, however, is superior to a thousand tables.

For bottom-up decision making to thrive, GIS technology in various forms must be accessible to all stakeholders (Miller et al., 2004)**.**

2.12.2 GIS Database

The spatial database and the corresponding attribute database are two separate branches that make up GIS databases. Numerous GIS software programs uphold this difference. The spatial data's attributes are stated to include a "vector" architecture composed of lines, points, and polygons. Other spatial data in GIS is stored as images, and "raster," with simple row-and-column formats. In relational database software, the strength of the relational model is utilized to attribute data, usually comprises records and fields. Such attribute data are "tagged" in the spatial database to facilitate tabular data retrieval (Shamsi, 2005).

GEODATABASES

Computer programs called database management systems (DBMS) are used to store and manage massive volumes of data. A DBMS must perform the following functions: (a) reliability with minimal or there is no redundancy; (b) maintenance of the accuracy of data, include upgrading; (c) metadata-driven self-explanatory; (d) a query response database language and generating reports; (e) security, including access control; and (f) user sharing capability. The majority of DBMS are built to manage attribute data. The joining of spatial and attribute data for water resources system features is a unique feature of geodatabase.

There are four fundamental ways to arrange data, which correspond to the logical models used to represent elements of the real world. Hierarchical, network, relational, object-oriented, and first among them (Shamsi, 2005).

2.13. Web GIS

Online mapping applications are changing how people use and manage geographic data for their water systems. A rising number of people are turning to the Internet for their mapping needs. In fact, one of the most popular search terms on the Internet is "global map" (ESRI, 2003).

The most effective and rapidly expanding skill for making Geographical Information available to the general public is the Internet. The World Wide Web and the Internet have made it easier to build and maintain maps. Sharing GIS data among many institutions is made easier by the Internet. GIS data can now be easily shared across employees of the same company thanks to intranets. Employing it has become known as internet GIS equipment, dynamic GIS Web pages first allowed the public to interact with and query GIS datasets in the late 1990s (Shamsi, 2005). Web browsers now offer a standard, powerful, affordable, and user-friendly interface for accessing a GIS for both experts and beginners. Now that the general public is able to use GISs via web pages, GIS professionals in the water operations can devote more time to extending the database and improving customer service (Shamsi, 2005). The Internet and GIS are increasingly being used by several large utilities to enhance the management and operation of their water and sewage systems. To do this, they are employing software for work order administration and customer service that is Internet- and GIS-based (ESRI, 2003).

2.13.1 The Web Services Framework

Web services represent a modern framework of technology and standards for computing, offering a means to connect distributed computing nodes in a loosely coupled manner. These nodes encompass a variety of devices, including servers, workstations, desktop clients, and lightweight devices like phones and PDAs. Web services standards aim to establish a foundation for seamless interaction among computers and devices, enabling a comprehensive computing network accessible from any device within the network. It's worth noting that Web services are not limited to the Internet but represent the evolution of distributed computing, providing a pathway for enhanced connectivity and integration (ESRI, 2003).

Through a registry, the Web services architecture enables the integration of information and functionality across a distributed network. This architecture is especially useful for organizations like as local governments, where numerous groups or departments separately collect and maintain spatial data pertaining to diverse features such as roads, pipes, surveys, property records, and administrative boundaries. Many government operations, however, necessitate the integration of various databases. This demand for integration can be efficiently addressed by combining Web services as a connecting technology and GIS as an integrating technology. As a result, data custodians can keep their unique datasets within a distributed computing environment while being able to dynamically query and integrate multiple layers of information (ESRI, 2003).

2.13.2. Looking Forward with Web Services

The GIS community has been pursuing open interoperability for many years, and the solutions to achieving this goal have changed with the development of new technologies. Web services allow GIS users to publish spatial data and functionality to integrate GIS with systems external to the GIS. Web services help avoid many issues and complications that interoperability at the database and application levels can cause. GIS users can manage their data using the best methods and tools of their commercial GIS in whatever database environment they choose, yet publish selected capabilities using an open Web services framework that enables disparate applications to communicate. A web service is a collaborative computing model that enables existing computing nodes and software to work in peer-to-peer relationships. Web services allow server-to-server as well as client-to-server interoperability of data and functionality (ESRI, 2003).

GIS providers, like Esri, enhance the performance capabilities of their applications by using relational DBMSs with specific schemas and procedures, as well as specialized file formats. Web services enable each GIS the supplier to build and distribute its own GIS products using the best available technology and methods, while also allowing the technology to interoperate with a wide range of external systems without compromising the core technology's design and implementation. The end result for the GIS user is a distributed GIS computing platform that enhances efficiency and functionality internally while also ensuring external interoperability.

2.14. Architecture of Web GIS

Applications for Web GIS employ a web browser as a client to send and receive data and queries, and a web server to respond. Non-spatial online applications normally simply have a web server, whereas web GIS has an additional server for spatial data called a map server (Agrawal and Gupta, 2017). This server handles geospatial data, provides WMS and WFS geospatial data services, and performs GIS activities like editing, navigation, and object tracking. A Web GIS has two components. The client-side interface, the first component runs in a web browser and sends the user's queries to a server. A Web GIS server, also known as an Internet mapping server (IMS), supports mapping and spatial analysis services, as well as Web GIS software and databases (Figure 2.3) (Pispidikis and Dimopoulou, 2015). Thin client, thick client, and hybrid architectures are the three essential designs for constructing web-based GIS apps (Agrawal and Gupta, 2017).

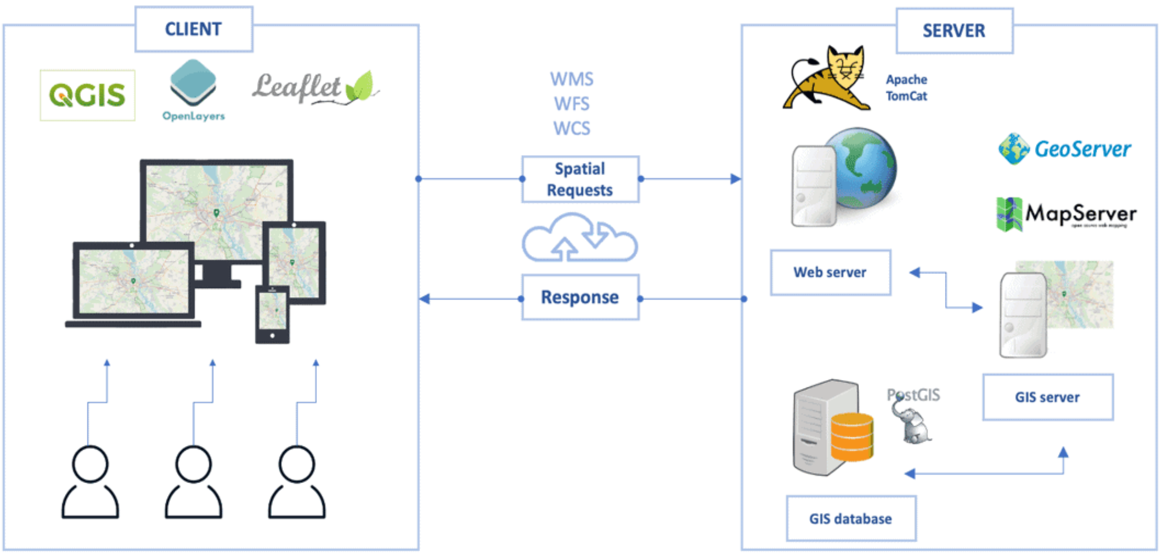

Figure 2.3: How a typical Web GIS model works

2.14.1 Web Server and Application Server

The Web server is the software that replies to HTTP requests from clients. It's designed to handle a great number of client requests and mail static files quickly. The request has been sent to the Web server via HTTP, which searches the server's hard drive for the requested file (Pispidikis and Dimopoulou, 2015). The most extensively Web servers were utilized nowadays is the Internet services and the Apache server. It's free software that's distributed under the Apache software license. It is maintained by the Apache application and is backed up by an open-source community (Pispidikis and Dimopoulou, 2015).

The incapacity of the web server to handle and return static pages protects the application server. Using the supporting script engine, it controls both dynamic and static web page content and concurrent requests from users. As a result, the website server anticipates receiving the dynamic contented result from the application server, and the application server anticipates receiving the final static file derived from Web server. The database and other servers, such as the GeoServer, can be communicated with by the application server (Pispidikis and Dimopoulou, 2015).

2.14.2. Web Mapping Servers

A Web Map Server (WMS) is a software application that generates maps from geographic information by processing spatially referenced data. It serves as an interface for web-based mapping applications, allowing users to request specific layers and zoom levels. The server responds to these requests by providing maps in standard picture formats like GIF or PNG, or in vector formats such as KML or GML. The WMS enables dynamic map creation and retrieval, facilitating interactive and customizable mapping experiences on the web (de Blois, 2016). GeoServer and MapServer are two popular web mapping servers that support web map services. Both are open-source server software that allows geographic data to be published and online maps to be created. ArcGIS Server, on the other hand, is a proprietary server program that also supports web map services. Esri created it, and it provides extensive capabilities and functionalities for producing and serving web maps. These three servers are important in the transmission of spatial data via web mapping applications, with GeoServer and MapServer being open-source possibilities and ArcGIS Server being a proprietary solution (de Blois, 2016).

Chapter Three

3. Materials and Methods

3.1. Study Area Description

3.1.1. Location

The study area is found in Lemi Kura Sub city, East part of Addis Ababa, the branch which spans an about 62.74 km2 area is located Latitude 8° 56' 30" N 9° 1' 30"N and Longitude 38° 49' 15" E 38° 54' 15" E (Feyissa et al., 2019).

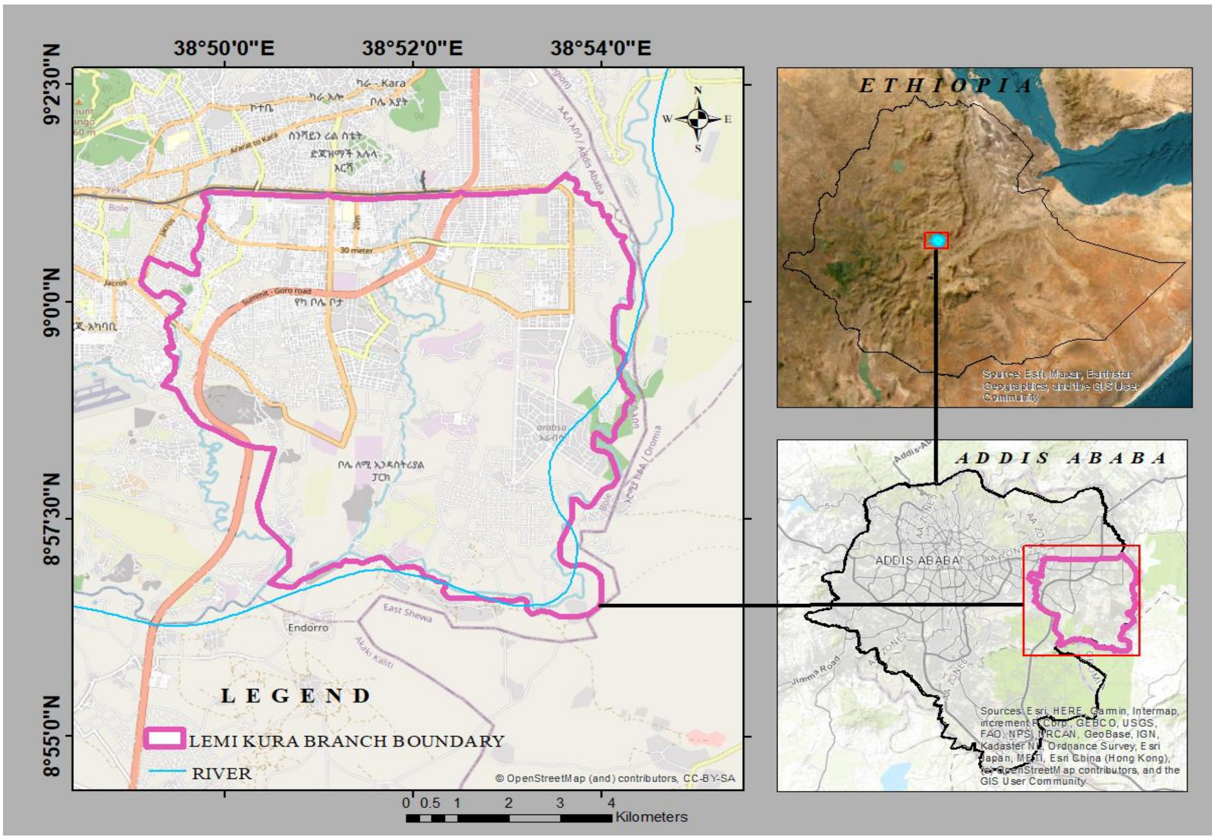

Figure 3.1: Study area map

3.1.2. Climate and Topography

The weather is warm and temperate in Addis Ababa. June to September is the rainiest month of the year, not the winter. By Köppen and Geiger, the capital's geographic position is categorized as having a "Cwb" (Oceanic Subtropical Highland Climate). The typical maximum and lowest temperatures range from 22.9°C to 10.2°C, while the average temperature is 16°C (Feyissa et al., 2019). The city's average annual rainfall is 97 mm, while the average humidity is 57.67% (Feyissa et al., 2019). The amount of the rains from July to

September is what causes this comparatively large amount of rainfall. Addis Ababa lies at an elevation of 2,355 meters. The city lies at the foot of Mount Entoto and forms part of the watershed for the Awash. From its lowest point at 2,326 meters above sea level in the southern periphery, Addis Ababa rises to over 3,000 meters in the Entoto Mountains to the north.

Temperature and Rainfall Chart of the Climate of Addis Ababa City

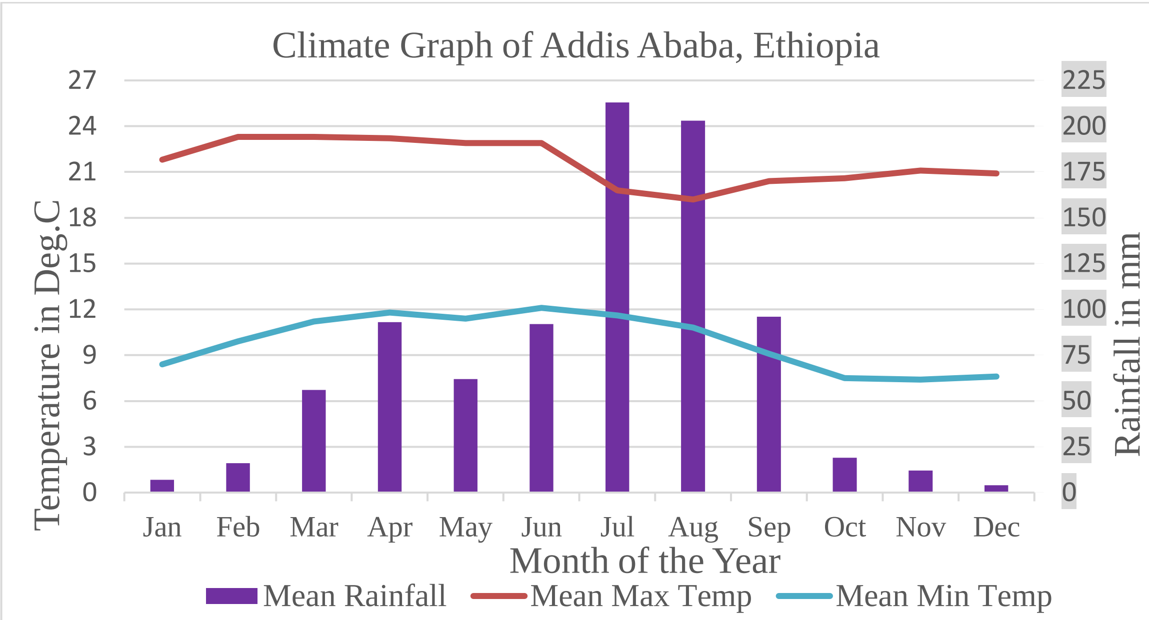

Figure 3.2: Temperature and Rainfall Chart (Source: NMI, 2022/23)

3.1.3. Demography

The city's current population is based on estimations because Ethiopia last conducted a census in 2007. According to projections from the national central statistical service, which conducts national censuses, The population Addis Ababa's is 3,859,638 (CSA, 2013). According to this figure, Addis Ababa's population represents 3.6% of the Ethiopian total population and 18% of urban population Ethiopia's. Its population has grown at a rate of 2.1% each year. When it comes to population, Addis Ababa is Ethiopia's most primitive metropolis. Its population is ten times greater than that of Adama, the second-most populous town. The assessment also indicates that there are somewhat more female residents than male residents. Since a few years ago, the city's proportion of young people has decreased, indicating low fertility that is below replacement level. Thus, the large migration to the city in searching of work and better education is to blame for the high population growth rate seen in recent years. Contrarily, the population of working age is fairly large; in Addis Ababa, 72%

of the population is between the ages of 15 and 65. 4.2 people make up the average family, according to a 2013 assessment (CSA, 2013).

3.1.4. Economic activity

The heart of Ethiopia's quickly growing economy is Addis Ababa. Despite having just over three percent of the country's citizens, the city generates 68% of all urban jobs and 30% of the nation's urban GDP. The city is experiencing a development boom, with several new condos, skyscrapers, and highways giving the impression that it is a construction site. Compared to other African cities, it is developing quickly in terms of modernity, and the skyline now boasts more half-finished skyscraper structures more than ever in addition to new emerging hotels that are becoming constructed at a rapid progress (Doyle et al., 2020). The government expects that the development boom in Addis Ababa, which is being supported by both public and private funds, would attract more capital and aid in the industrialization of the economy, allowing Ethiopia to reach a middle-income level by 2025.

As the seat of both the African Union and the United Nations Economic Commission for Africa, the city is home to numerous diplomats and international agencies. The service industry, which includes hotels, catering, and banking, is the city's main source of job creation and employment. Additionally, the city's economy dominates the wholesale and retail trade in the nation. One of the city's main job areas, construction is in a boom (World Bank, 2018).The city's spending largely mirrors the priorities set forth in the municipal strategic plan by the city council. Road building, housing construction, and drinking water supply are the three most critical areas of capital investment (World Bank Group, 2010).

3.1.5. Description of the Current Water Supply System

According to AAWSA, piped water began operation in 1901 as part of the historical progression of the conventional water supply system. Contemporary water service began in 1924, with a water administration established inside the municipality of Addis Ababa in the 1940s and the Gefersa dam and central distribution network completed in 1944 (Ewunetu, 2019). Since the city's water demand has grown, construction of an additional water supply dam at Legedadi, including a treatment facility, began in the 1970s. AAWSA (Addis Ababa Water Supply and Sewerage Authority) was founded in 1971. As a result, the city's water supply system evolved over time, from isolated springs primarily at the foot of Entoto Mountain and manually dug wells in various locations to a more complex, centralized "modern" water delivery system.

The capital of Ethiopia presently derives its water from three surface water sources (the Gefersa, Legedadi, and Dire dams in Oromia regional state) and a groundwater supply (Akaki well fields and numerous boreholes spread throughout the city). This shows that the city is heavily reliant on water sources outside of its control. The entire water supply is currently 580,000m^3/day, whereas municipal demand has increased into 1.1 millionm^3/day(WATER, 2008). Surface and groundwater are used to produce 450,000 m^3 of water per day, and it is estimated that 36.5 percent of this water is lost owing to leakage and other infrastructure deficiencies. The estimated per capita distribution is around 40 liters/day, which is much lower than the city's aim of 110 liters/day (WATER, 2008).

3.2. Research Design

The research design explains just how the study was carried out, including the data gathering technique and the information gathered. A descriptive cross-sectional design is used in this research. Furthermore, the study takes a mixed research approach, incorporating both qualitative and quantitative data. As a result, the mixed methodologies used in this research integrate inquiry strategies that involve the simultaneous collection of qualitative and quantitative data in order to fully appreciate the research subject under study. The study was guided by the principles of employing many sources and subsequent material cross-checking, as well as the use of various types of data gathering methods and analytic techniques-both quantitative and qualitative.

3.3. Data Sources and Types

3.3.1. Data Source

To examine Lemi Kura branch water distribution system, all the information required for this research, data was gathered from primary as well as secondary sources. The primary data that comprises GCP, spatial utilization and management and challenges of spatial data management were collected from field and key informant interviews. In order to conduct this research, interviews with 15 water managers and engineers were conducted. The primary sources of data were key informants from AAWSA main office and Lemi Kura Branch office different department unit leaders, engineers, and employees. In addition to primary data, secondary data like CAD files, statistical reports, bulletins, to supplement the primary data, published and unpublished literature sources were used. The data is both spatial and non-spatial.

3.3.1.1. Primary data

The primary data consists of fieldwork and surveys were conducted for collecting GCP and comprised of conversations with employees of the water corporation to gather more pertinent data about the topic. The data collected from these multiple primary sources was integrated with data from secondary sources to develop a prototype water distribution management model for the pilot study area. Major water facilities were surveyed and identified on the ground to acquire primary source data.

3.3.1.1.1. Data Gathering Instruments

1. **Filed Survey and Observation**

Field observation was used to collect information about water infrastructure data, including the type of water source, the geographic coverage of water supply lines, storage tanks, and the reasons for certain variations, such as position. Along with field observations of the research area, operations and maintenance, and restoration or upgrading activities were observed.

The primary data were gathered using a handheld GPS (Garmin 64S). With the aid of a handheld GPS, visits were made to locate water infrastructure including pumping stations and wells on the ground. The GPS point data showed the exact position of each water resource in the study area. After that, the collected data was imported into the GIS software. Building a geodatabase and encoding their attributes to its spatial and non-spatial data. The main office of the Addis Ababa Water and Sewerage Authority (AAWSA) provided the existing distribution map in CAD File of the Lemi Kura branch, which was utilized as secondary data to compare the old system with the new one. AAWSA only had distribution mains data and no maps of water connections at the household level.

2. **Key informant interviews**

Water service officers were the subjects of key informant interviews. A total of 15 (6 from Main AAWSA, 9 from Lemi Kura Branch) key informants were purposively selected. Key informants (distribution manager, budget and plan, and senior technician) were chosen from Lemi Kura branches and main office in the case of key informants. The main informants had a range of roles, backgrounds, and qualifications. The city's water coverage, current status, water supply, and the main obstacles facing service delivery in terms of spatial data management issues and other were all covered in interview questions. The key informants were purposefully chosen with the assumption that they possess in-depth knowledge of the issues from their official roles and ongoing involvement in them. (See Appendix 1, the details of Key informants of the interview questionnaire). The interview was administered by the researcher and semi-structured interview method was applied to gather the necessary data.

3.3.1.2. Secondary data

Secondary data sources include institutional reports that have been published and unpublished, books, journals, online data (from sources on the internet), and digitally developed platforms and portals. Secondary data were gathered from the AAWSA. It also includes population, water production data and customer water consumption and water distribution system map.

Even though some of the data were incomplete, historical billing data for water consumption were also received from the Lemi Kura AAWSA branch billing office. The case teams for surface water production team and groundwater production team provided past records of water production. Based on the availability of the data, surface water production data from the Gefersa and Legedadi surface water production teams were collected. The number of costumers and connections, well inventory, and reservoir parameters are among the other data gathered by AAWSA. AAWSA provides computer-aided design (CAD) maps of the pipe network and administrative boundaries.

In addition to academic and non-academic publications, yearly and asset inventory reports, and past research, facts as well as data important to this study were obtained from those sources. In addition, project-related information on the development and status of Addis Ababa's water system was assessed.

Data on the population at the city and sub-city levels were provided by the Central Statistical Service. The National Meteorological Institute provided data on temperature and rainfall. To handle and process queries quickly, the data gathered from primary sources were cleaned up, sorted, and stored in a database. Table 3.1 below shows the information gathered from various sources.

Table 3.1: Summary of the data gathered

Data	Data Type	Data Source	Data Form
Municipal boundary Map and Cadastral Map	Spatial/map and Attribute	Municipal land Development and Management Agency	Spatial/ Shapefiles
Existing Water Network Map	Spatial and Attribute	AAWSA	CAD, Analog
Water Production, Demand and consumption	Non-Spatial	AAWSA	Text
Ground Control Point data (GCP)	Spatial	Field survey using handheld GPS/own Survey	Text
Climate	Non-Spatial	NMI	Text

3.3.2. Web GIS development Methodologies

According to Mir (2006), there are several components of developing a GIS-based project that are distinct from or do not resemble typical software development processes, including data organization, data creation, and application development. Figure 3.3 shows the six major steps that make up the Web-GIS development method; this begins with a supply analysis and concludes with the installation of a web GIS system.

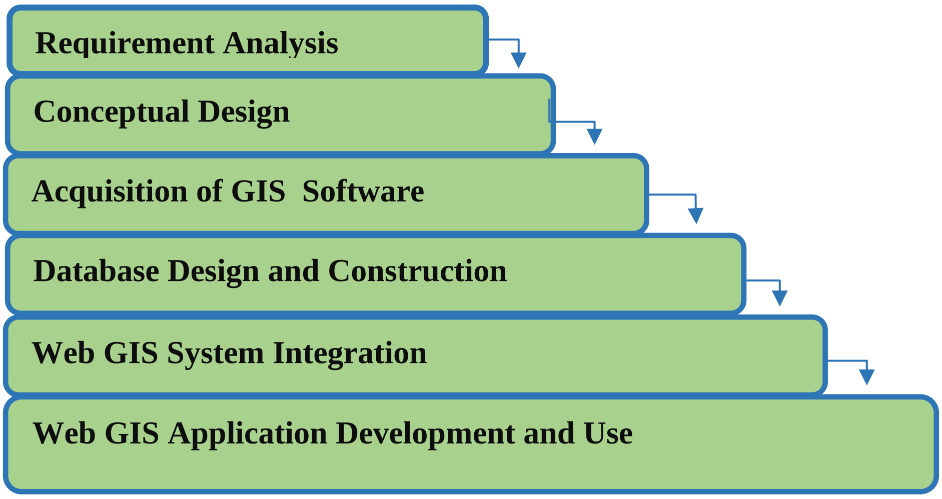

Figure 3.3: Web GIS Development Methodology(adapted from Alesheikh et al. 2002)

3.3.2.1. Requirement Analysis

In order to construct the Web GIS and achieve the water distribution network management goals, Researcher concentrated on the following general and preliminary system requirements:

- The technological prerequisites for obtaining and sharing water distribution network asset information via interactive and dynamic web maps are a server that hosts web pages and internet access.
- A list of the functions those are required. Basic visualization functions like Pan and Zoom, as well as more advanced functions like examine the current water pipe layout; specify length, diameter size, age of material and pipes material are necessary. Water networks operators and water users can utilize these features to get information about a specific asset location.

3.3.2.2. Conceptual Design

Regarding the implementation of the Web-GIS system application, the model uses an open-source system architecture. Client and server are required components in Web-GIS systems. As a result, a client contains the web browser on the user's end. A client is used by the user to submit request and access maps along with additional associated information. The server is made up of four components: a database server, a web server, an application server, and a mapping server. It is typically used to link users to mapping servers and give different mapping programs tailored features. Figure 3.4 displays a comprehensive System Architecture Design (SAD) utilized to develop a Web-based GIS database for water distribution management in Addis Ababa City. The theoretical architecture is constructed as a three-tiered software framework in order to fully execute the main architecture concepts.

A web application, a web server, and a spatial database make up its three components. There are numerous web interfaces for management and a website that uses JavaScript/OpenLayers coding to display information with some basic GIS functions. In the web service, there is a web server that uses Apache Tomcat as a web server. The spatial data is stored in the database using PostgreSQL/PostGIS.

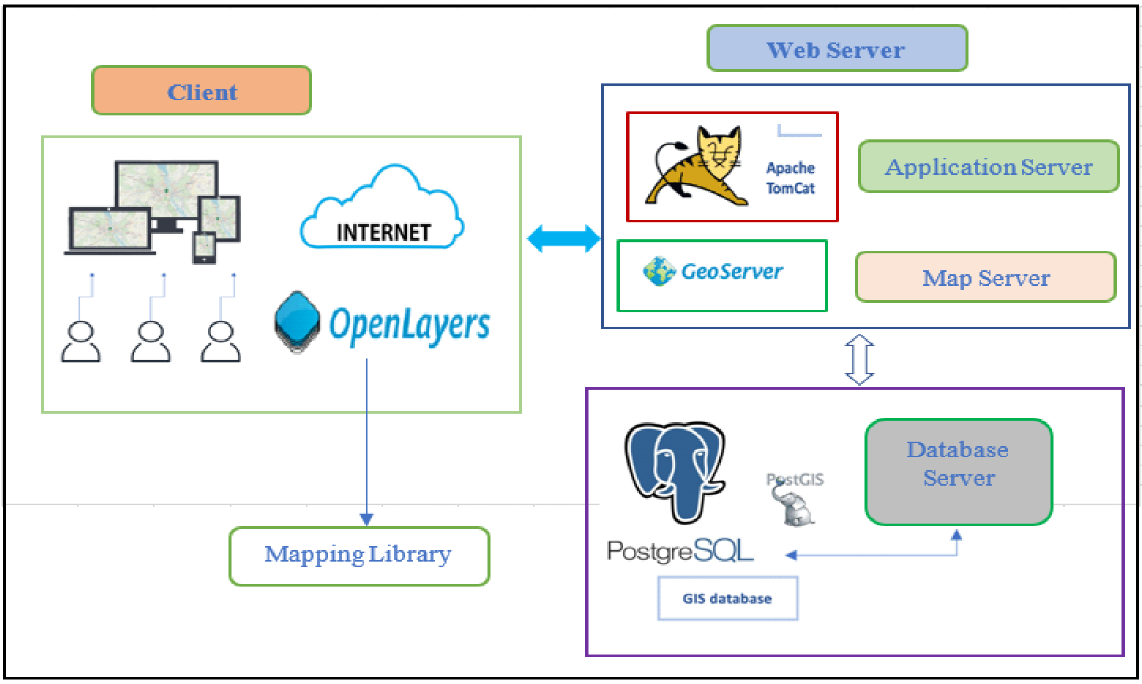

Figure 3.4: Conceptual System Architecture

Server Side: Backend or server-side development encompasses all of the operations that occur behind what is going on in a website. The key components of the backend include database administration, servers, and conceptual elements.

Client-Side: This layer, often known as the frontend, is primarily responsible for the visual presentation and design of the web page. Frontend developers integrate CSS, HTML, and JavaScript to create a single user interface through responsive web pages.

3.3.2.3. Acquisition of GIS software

Currently, Web GIS alternatives based on Free Open-Source Software For Geospatial (FOSS4G) that are consistent with Open Geospatial Consortium and Open Standards are plentiful. Adopting standards allows for a more flexible evolution of the application, allowing for the integration of new features and services. The most important FOSS Web GIS projects have all more than one standard compliancy (Calbet, 2011).

The present study used MapStore from among the several Free Open-Source Software (FOSS) programs because it possesses a solid and design adaptability which allows us to consistently manage and disseminate GIS data. Therefore, this study employed PostgreSQL/PostGIS, GeoServer, and OpenLayers and Apache Tomcat.

Figure 3.5: Prototype Software Components

GeoServer: It's a Java-based open-source software server for sharing, viewing, and editing geographical data. It uses Open Geospatial Consortium (OGC) It is designed for interoperability and uses protocols to publish data from any significant spatial data source(GeoServer, 2022). Unlike MapServer, GeoServer more than just providing spatial data, offers a wide range of GIS functions (Zhelu, 2009). GeoServer can read data from a various kind of spatial data bases, including PostgreSQL/PostGIS, and output it in a variety of forms.

PostgreSQL and PostGIS: It provides a free, open-source object-relational database system that may be used to create, manage, and utilize spatial and attribute databases. PostGIS is a PostgreSQL extension that provides geographic-related capabilities to the database. Because it can alter data using simple SQL queries, it has an advantage over many commercial options that simply act as registered tools (acquire and alter their geocoded data) (Mitchell, 2005).

Apache Tomcat: This serves as a free and open-source web and application server. The web server component of the program is Apache, or Apache HTTP Server. It can also be deployed individually on a database server such as PostgreSQL. By hosting and exchanging web content the format of HTML documents, Apache can power websites and web services.

PgAdmin: It is an open-source PostgreSQL administration and development environment that works with Mac OS X, Windows, and Linux. The software's user interface makes managing a PostgreSQL database and creating tables, for example, a breeze. Using tools like pgAdmin's SQL Editor, the user can run SQL queries against the database. The PostgreSQL License applies to both pgAdmin and PostgreSQL.

OpenLayers: It is a JavaScript-based toolkit or API for producing interactive map elements in the HTML environment that's open source. OpenLayers can display and mix geographical content from several sources, such as a WMS created by GeoServer as a vector layer on top of an OSM or Bing Maps base layer. It supports a wide range of types of data and web services, including Keyhole Markup Language (KML), Geography Markup Language (GML), WMS/WFS Services, Web Map/Feature Services, Representational State Transfer requests (REST), Geographic JavaScript Object (GeoJSON), GeoRSS, TileCache web accessible caches, and many other commercial and free web map services, such as Google Maps and Yahoo! Maps. JavaScript could be utilized for showing feature data on the map using OpenLayers. This type of data may be retrieved direct via a user interface or a GeoJSON feed, and it also may be retrieved from a GML or KML source of data (Ganesan, 2009).

MapStore: A highly modular Open-Source Web GIS framework was created by GeoSolutions. It is used to build, manage, and distribute maps, dashboards, and stories that combine geospatial contents from servers that adhere to OGC standards like WFS, CSW, WMS, and WMTS with content from sources like Bing and OpenStreetMap.

ArcGIS: Is a Desktop GIS tool that allows you to create, edit, and visualize geospatial data.

3.3.2.4. Database Design and Construction

According to Guan et al., (2011) a file was designed for GIS purposes as a single set of information that is simply kept, as well as a file that is structured in a specific way by a Database Management System (DBMS) and retrieved through it. The design of a geospatial database includes the production and arrangement of diverse geographical data such as point, polyline, and polygon objects, as well as associated attribute tables.

Using the user-friendly PgAdmin4 interface, a new database was established in PostgreSQL, and it was equipped with the PostGIS extension to store spatial data in the database. A new created shapefile was imported into the established database after it had been generated. All shapefiles were translated to the appropriate database table. There is a geometry column and a corresponding geographic description in each PostgreSQL database table. The tables then take on the form of spatial tables. For the purpose of the study, each vector layer that was produced underwent this procedure once again. Once the PostgreSQL database had been set up and created. Topology refers to the relationships between the points, lines, and polygons that make up the features of a geographical area. In order to validate the topology errors, ArcGIS software was utilized with the following topology rules defined for polylines:

☑ End Points Must be covered by
☑ Must Not Have Dangles
☑ Must Not Have Invalid Geometries
☑ Must Not Have multi-part Geometries
☑ Must Not Have Pseudo Nodes
☑ Must Not overlap

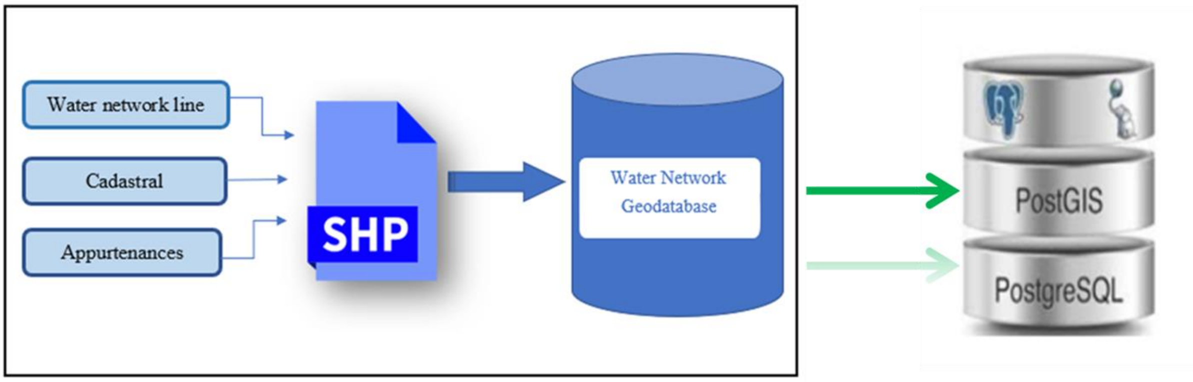

Figure 3.6: Design of the GIS database for Water Network

In this study, the database was designed using water network data (assets used by operators and users such as supply/distribution line, valves, meters, water tanks, and reservoirs). Figure 3.6 depicts a comprehensive geodatabase design that utilizes online base maps. The data collected were organized and processed into a GIS database for map visualization. As a result, were blend vector and attribute data into feature classes as pop-ups on online maps by pre-defining data types like 'text' for textual information.

3.3.2.5. Web GIS System Integration

The objective of this part was then to incorporate various Components of software as well as hardware, test each to make sure they worked correctly, and commence the operations required to use the GIS (Alesheikh et al., 2002).

The basic software for this research, Apache Tomcat, PostgreSQL/PostGIS, ArcGIS, GeoServer, OpenLayers, and MapStore must all be integrated at this phase. The steps that used for installing the software are

- Installing Java and Apache Tomcat
- For simple configuration and management tasks, Apache Tomcat includes a web interface. It is used to install GeoServer. Then, launch a new browser and navigate to

http://localhost:8080/. Explore the manager application. Scroll down to the **Deploy** section.

- Unzip the archive file (GeoServer) Then, in the WAR file to deploy, click the Browse button and navigate to the geoserver.war file. Deploy the system by pressing the Deploy button. After a little while, you should receive an OK response from the manager. GeoServer is now shown as one of the web applications running in Tomcat. Click the /GeoServer link in the column that appears on the left edge of the list that appears. http://localhost:8080/geoserver/web
- Installing PostgreSQL and PostGIS. Run the installer.
- Unzip the downloaded war file and install it in your java web containers (e.g., Tomcat) using the standard container methods (usually, you only need to copy the war file into the webapps subfolder). Then, using the hyperlinked URL (assuming the web container is listening on the regular 8080 port), you can access MapStore: http://localhost:8080/mapstore. Log in with the standard username and password (admin / admin) and begin generating your maps!

3.3.3. Software Packages and instruments

The hardware and software programs utilized in this study were chosen based on their accessibility and ability to operate on current difficulties in order to achieve the stated objectives. Table 3.2 shows a summary of all hardware and software applications used in this study.

Table 3.2: Software and instrument used

Software and instrument	**Function**
GIS Software	Spatial data creation
PostgreSQL 13 and PostGIS 2.0	Spatial database creations, Storage and Conversion
GeoServer 19	Data visualization
MapStore	Development of the geographic user interface
Apache Tomcat 9.0	Used to Store software
Handheld GPS (Garmin 64S)	Used for collection of coordinates of features and control points

The research methodology also specifies the data analysis methodologies and tools employed in the course of the study. The following flow chart illustrates the research methodology:

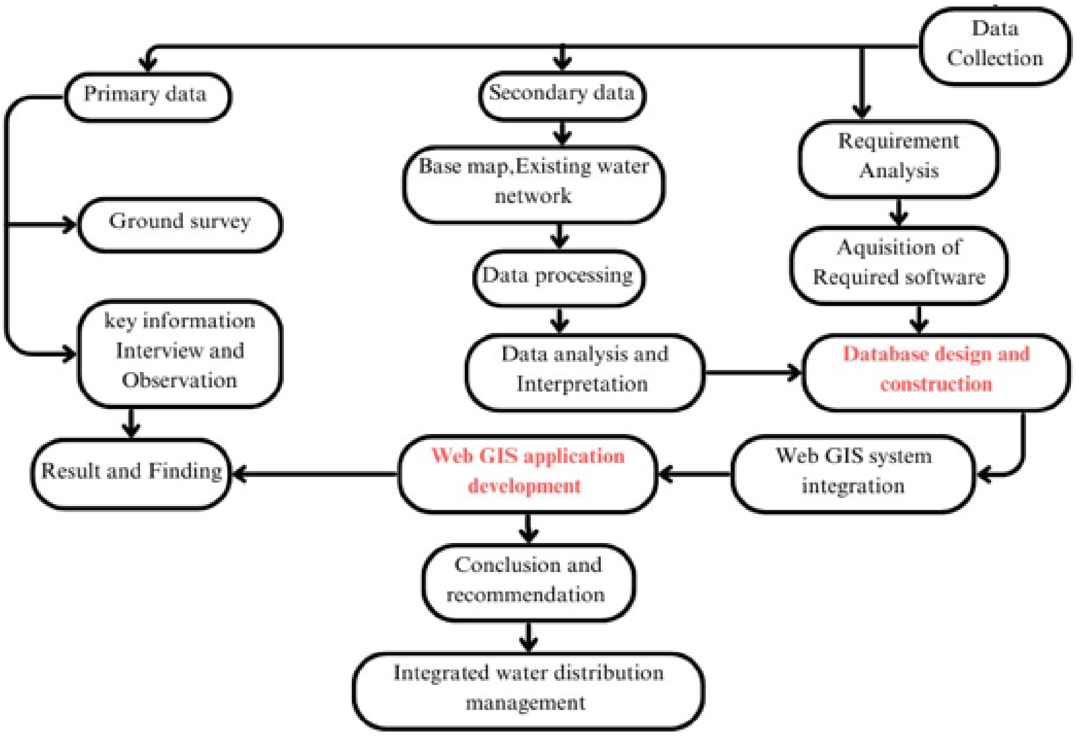

Figure 3.7: Methodology Flow Chart

3.3.4. Method of Data Analysis

The primary as well as secondary data's that were collected from different sources were analyzed using descriptive analysis method (percentages, averages). The primary data that were collected via informant interview were organized thematically and logically and analyzed in a narrative form. On the other side, secondary data that includes coverage, consumption, and distribution is analyzed mathematically through statistical formulas indicated below. In organizing and presenting data the researcher employs tables, charts, maps, and graphs.

3.3.4.1. Evaluation of Water Supply Coverage

The water supply coverage rate is the fraction of the population that has been provided with a reliable source of water. It can be computed using the total population and the overall water system's customers (or connections).

Depending on average per capita usage and service type, the sub- city's water supply coverage It had been evaluated. According to the annual usage the average per-capita consumption was computed using data from household water meters. The delivery of residential and public service fountains has also been assessed, Furthermore to average per-person water consumption (Welday, 2005).

The formula for estimating the percentage of water supply coverage is as follows:

Water supply coverage percentage= $\frac{No\ of\ people\ with\ access\ to\ water}{Total\ population} X\ 100$........... (1)

Where the overall population refers to the total number of people within the area under consideration, and the number of persons that have access to water refers to the total amount of individuals who have access to a reliable and secure water supply.

3.3.4.2. Average Consumption per capita on a daily basis

The average daily amount of water drunk by a person is calculated from total consumption and population. It can be calculated by divided the total amount of water consumed by population and the number of days in a specific time period. As an example:

Per capita water consumption= $\frac{\text{Total water consumption}}{\text{Total population/ Number of days}} X\ 1000$ .... (2)

Total population is the total number of people existing in a definite area, Total water use is the entire volume of water withdrawn or consumed by all sectors (such as agricultural, industry, or domestic) in that area, and Number of days is the length of the time under consideration. In order to convert the result from cubic meters to liters, multiply the value by 1000.

Depending on a region's climate, culture, and level of development, per capita water usage can vary greatly. The average volume of water consumed daily per person in the world in 2015 was 138 liters, based on the 2019 United Nations World Water Development Report. But in North America, this was 382 liters for each day, compared with 27 liters per day in sub-Saharan Africa.

3.3.4.3. Per capita water consumption from domestic consumption

Given the number of individuals and houses that have access to the supply of water, the per capita water consumption from domestic use based on population calculated from domestic connections is a measure of how much water each person uses on average at home. It may differ based on elements including climate, culture, level of wealth, size of the household, and water accessibility. According to the UNWWD Report 2019, the average quantity of domestic water consumed per capita worldwide in 2015 was 132 liters per day.

These averages hide significant differences between regions and nations, ranging from less than 50 liters daily in some African nations to more than 300 liters daily in some high-income nations (UN-Water, 2021). Because many water-consuming activities, such using washing machines, dishwashers, and cooking, benefit several household members, A household's per capita water use decreases as its number of people increases (UN-Water, 2019).

It can be calculated by figuring it out by dividing your household's water use by the number of days in a given period and your expected population. For example:

$$\text{Per capita water consumption From domestic consumption} = \frac{\text{Domestic water consumption}}{\text{Estimated population / Number of days}} X\ 1000 \quad \ldots\ldots (3)$$

Where estimated population is the number of people living in that area based on the amount of water withdrawn or consumed by the domestic sector is determined by the number of domestic connections and the average household size (such as households, public buildings, or commercial establishments), and number of days is the length of the period under consideration. In order to convert the result from cubic meters to liters, multiply the value by 1000.

To estimate the population from the number of domestic connections, you can use the following formula: Estimated population

Estimated population = No of Domestic Consumption X Average household Size………..(4)

Where number of domestic connections is the number of service connections to the water system for domestic use and the average household size is the number of people who live in a household in the area.

3.3.4.4. Per capita water consumption from public fountain

The average daily quantity of water drunk by a person from public fountains is calculated as per capita water consumption from public fountain consumption and population determined from the number of public fountains. It may be computed by dividing the amount of water used at public fountains by the corresponding period's expected population and number of days. For instance:

$$\text{Per capita water consumption from public fountain} = \frac{\text{Public fountain water consumption}}{\text{Estimated population/Number of days}} \text{X } 1000 \ldots\ldots\ldots\ldots\ldots (5)$$

3.3.4.5. Daily Water Supply Service Duration

This component is taken into account when calculating how long it will take to get an upgraded water supply and how long the city's water supply service will continue, or how reliable the water supply will be. Customers should have access to water every single day if the city is to be considered exceptionally secure in terms of water supply.

3.3.4.6. Non-Revenue Water Percentage (NRW)

In many developing nations, Water loss in the water distribution system has become a major issue. Water shortages for the customers and higher operating expenses are caused by high water loss. As a result, the city's water loss should be evaluated in order to determine its level of water security.

$$\text{NRW (\%)} = \frac{\text{Total water produced} - \text{Total water billed}}{\text{Total water produced}} X\ 100 \qquad (6)$$

Chapter Four

4. Results and Discussion

4.1. Current Water Supply Situation of Addis Ababa Water Supply System

Addis Ababa is quickly becoming one of Africa's fastest-growing cities. According to MEC, 2016 Serious water supply concerns exist in terms of water quality, supply security, non-revenue water losses, and a lack of service coverage throughout the city in general, and the Lemi Kura branch office in particular. As a result, water is no longer available 24 hours a day in several certain parts of the city. Some of the reasons of water scarcity have been identified as a lack of efficient operation and network management. The next section examines difficulties concerning water sources, production, distribution, and coverage in Addis Ababa in general, and the Lemi Kura branch in particular, capacity issues in terms of utilizing spatial data management, and finally conclusion and recommendations.

4.2. Current Water Supply Situations

According to data sources (Z&A Consulting Engineers 2018), Addis Ababa city has been supplied by both surface and ground water sources.

4.2.1. Source of Surface Water

Table 4.1: Existing Surface Water Source of Addis Ababa

Dam Name	Design capacity in m^3/year	Current capacity in $\mathbf{m}^3$/year	Design capacity in m^3/day	Current capacity in m^3/day	Built Year
Gefersa	8,000,000	7,400,000	30,000	30,000	1943
Legedadi	44,000,000	36,880,000	195,000	174,000	1970
Dire	19,000,000	17,860,000			1999

(Source: AAWSA Strategic Plan 2020-2025)

According to AAWSA (2022), formerly, a number of springs at the foot of the Entoto mountain crest served Addis Ababa, as well as a series of hand-dug wells. The Entoto water supply, which opened in 1938, processed some of the spring water. Later, the Gefersa Dam on the route to Ambo westward of Addis Ababa was connected to the Addis Ababa water delivery system, followed by the Legedadi & Dire dams. The original Gefersa Dam was built in 1943 and was a masonry structure around 10 meters tall. At this point, the supplied water had only been chlorinated. In 1955, the dam was enlarged to a crest height of 16 meters, increasing its capacity to 6,200,000m^3. The treatment plant began operations in 1960, with a design capacity of 30,000m^3/day. In 1966, the Gefersa III earth fill dam has a capacity of 1,200,000m^3 and a crest length of 220m was built to supplement the Gefersa main reservoir. In 2009, the Gefersa dam was completely rebuilt, and the reservoir capacity was increased to 7,390,000m^3 (AAWSA ,2022).

The Legedadi Dam is located east of Addis Ababa. According to a bathymetric survey conducted in 2010, the dam's impounding capacity is 42,170,000m^3. The dam is constructed up of a rock fill section that is 22 meters high and 600 meters long, as well as a concrete buttress 44 meters tall and 400 meters wide. Gates are used to manage overflow. The dam and a 50,000m^3/day treatment facility were completed in 1970. The plant's capacity was later increased to 165,000m^3/day, and it was recently increased again to its current level of 195,000m^3/day (AAWSA ,2022).

Dire dam is located around 10 kilometers to the north of Legedadi dam. It was built in 1999 to increase the Legedadi reservoir's water supply. The dam has a total capacity of 19,540,000m^3. With this additional storage, the Legedadi treatment plant can function at maximum capacity of 195,000m^3/day. Several studies have been conducted in order to raise the Dire dam by 2.5 meters, increasing the reservoir's capacity to 23,500,000m^3. The dam was eventually enlarged by 1.25m, resulting in an estimated capacity of 21,500,000m^3(AAWSA ,2022).

4.2.2. Sources of Groundwater

Table 4.2: Existing Ground Water Source of Addis Ababa

Well Filed	No of Well	Design Production capacity in M m^3/day	Current Production capacity in Million m^3/day	Built Year
Akaki Phase I	25	43,000	9,000	2001
Akaki Phase II	22	83,000	61,000-71,000	2012
Akaki phase IIIA	17	70,000	32,000-37,000	2015
Akaki phase IIIB	24	70,000	57,000	2014
Legedadi Phase I	10	42,000	40,000	2015
Koye Feche	10	44,000	22,000	2018

(Source: AAWSA Strategic Plan 2020-2025)

According to AAWSA, 2020 to improve water shortages within the city, as part of the Addis Ababa Akaki Deep Wells Water Supply Project, AAWSA dug deep wells in the city's southern outskirts and pumped water into the water supply system (Phases I, II, III).

The Akaki Deep Wells Phase I well field is about 22 kilometers south of Addis Ababa and southeast of Akaki town. The water well field is approximately 16 kilometers long. 35 wells are being dug in this area, including 25 production boreholes, 4 monitoring wells, 4 wells to supply Akaki town, 1 well for isotope sampling, and 1 deep test well. The Akaki well field began operations in 2001. The wells design production is 43,000m^3/day however; currently produce from this well is 9,000m^3/day.

The Akaki Phase II well field is located around 15 kilometers south of Addis Ababa, close to the Gellan condominium housing project. The Akaki Phase II well field began operations in 2012, with a capacity of around 73,000m^3/day, with an additional 10,000m^3/day available as an emergency supply. However, currently the city supplied from this well around 61,000-71,000m^3/day (AAWSA ,2022).

Addis Ababa Deep Wells Water Supply Project Phase III, as seen in the table above, construction of 41 new boreholes at the Akaki Phase IIIA (17 wells) and Phase IIIB (24 wells) well fields, each with a capacity of 70,000 m^3/day. The Legedadi deep wells water supply project (Phase I) is another new groundwater source. The combined yield of the ten wells is 40,000m^3/day. Additional boreholes placed across the city are used to supplement available supplies. Their combined capacity is expected to be 62,000m^3/day. Currently, the city receives water from the Legedadi and Gefersa treatment plants, as well as boreholes drilled in various regions of the municipality. Figure 4.1 depicts the locations of the city's principal water supply sources (AAWSA ,2022).

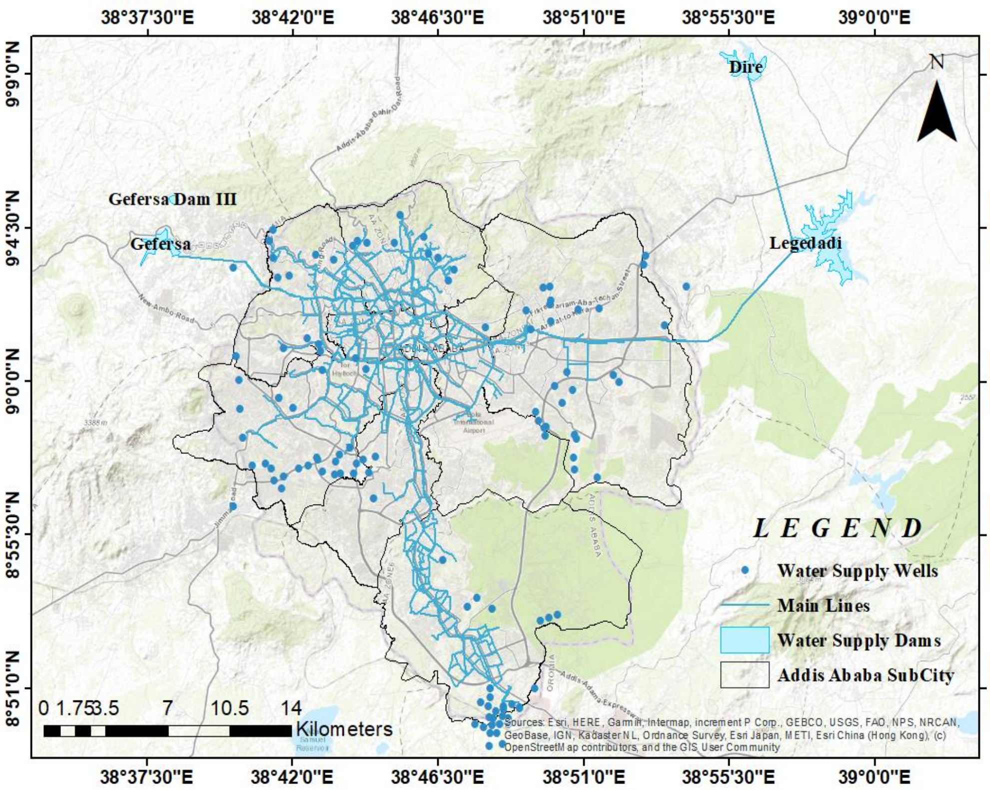

Figure 4.1: Addis Ababa water supply sources location map

Table 4.3: Addis Ababa's Existing Water Supply Source (Source: AAWSA)

Water Source Station	Estimated Production(m^3/day)	Cover Rate (%)
Legedadi and Dire Dam	174,000	30.04
Gefersa Dam	30,000	5.17
Akaki Old well Field phase I	6,000	1.03
Akaki phase II	66,000	11.39
Akaki phase IIIA	32,000	5.35
Akaki phase IIIB	57,000	9.84
Legedadi Deep Well Phase I	40,000	6.9
Koye Feche	22,000	3.79
Tulu Gudo	30,000	5.17
Legedadi Deep Well Phase II	12,000	2.07
Springs, Boreholes,Wells	110,200	19.02
Total	**579,200**	**100**

Source: Data obtained from AAWSA, 2023 and own result

As indicated in Table 4.3 above, the entire volume of water produced by the city from existing surface and groundwater sources is anticipated to be 579,200m^3/day year 2022/23. The authority has a potential to produce the total production of 725,000m^3/day of water per day. However, due to different challenges cannot produce this amount of water presently.

This amount correspond to the maximum production capacity might be achieved the end of in 2022/23, which is 579,200m^3/day from all water sources combined, as shown in table 4.1 above. It is obvious from the preceding that the current maximum daily water output from all existing water sources is, estimated at 579,200m^3/day, cannot meet the city's current maximum daily water demand, estimated at 1,140,235m^3/day.

According to the informant, the AAWSA's 2022/23 water production statistics demonstrate that the actual output is below the total capacity of every source of production. Sources are underutilized due to frequent power outages, significant water loss, faulty well pumps, output capacity decline of groundwater supplies, and continuous damage to water transmission mains caused by a lack of coordination among utility service providers. As a result of these factors, the average volume of water delivered is currently 579,200m^3/day.

According to the interview, the real yield of the borehole is limited due to a lack of power supply, faulty electromechanical equipment, protracted service, and excessive pumping. It is thought that full capacity can be achieved by rehabilitating and rebuilding boreholes, as well as repairing problematic electromechanical equipment.

Even if water production has increased from period to period as a result of rehabilitation of old projects and the boring of several well fields in the city, demand is far outstripping supply, with just 50.79 percent met in 2015. The amount of supply is insufficient to fulfill the needs of the city, and disruptions in supply have hampered reasonable water distribution. The existing plants have a high production capacity of 725,000m^3/day, but overall production is now 579,200m^3/day. As previously said, they are not producing as much water as they could.

According to the survey's findings, the Akaki well filled and pocket borehole supplies the city with the most water supply. AAWSA produced from ground water source 375,200m^3/day, which accounted for 64.77 percent of the daily production in 2015 E.C. Legedadi Dam produced 174,000m^3/day, which accounted for 30.04 % of total water output in the previous years, and 30,000 m^3/day, or 5.17 percent of the daily, output was provided by Gefersa Dam. However, as a result of the AAWSA's focus on the building of numerous boreholes and springs, which boosted the volume of water produced each day, Legedadi percentage contribution to total production has reduced. Due to the production statement for 2015 E.C. does not accurately reflect the entire year. From July 2014 through March 2015 E.C., the actual production statement was calculated, and the final three months were anticipated.

The total daily capacity of the water supply sources that are now accessible is roughly 570,000m^3/day. The summary of Addis Ababa city's entire current groundwater water and surface water production supply is shown in Fig. 4.2.

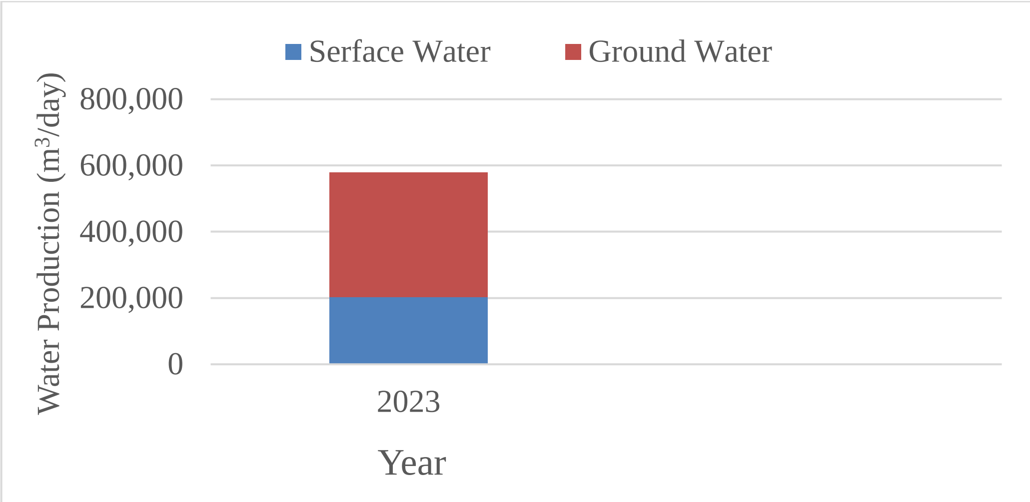

Figure 4.2: Water Production

4.2.3. Water Supply Network

The water supply system network, according to the NRW Project Report, consists of transmissions mains, service reservoirs and pumping stations. Accordingly, water supply network that started from Akaki to the city is having D800 DCI transmission mains, whereas the network line that connects Gefersa to Addis Ababa is about D700/D500 DCI pipe transmission mains, the Legedadi transmission mains network connected to the city has a D1400/D1200 and D900 Steel pipe. In addition, there are 91 service reservoirs throughout the city. The service reservoirs are a storage tanks used to store water before it is distributed to the customer. Moreover, in areas where the slope is high the distribution of water to households in supported by pumping stations. There are a total of 32 pumping stations in the city. On the other hand, in areas having gentle slope, the distribution of water is basically done through gravity. Lemi Kura branch area is supplied through gravity system. Various pipe materials and diameters are used in the distribution system, the construction of which started in 1938. The water supply network has pipes with diameters ranging from 50mm to 900mm. Steel, Ductile Iron (DCI), Cast Iron (CI), Galvanized Steel (GS), uPVC, and High-Density Polyethylene (HDPE) are examples of pipe materials. As the city's infrastructure develops, the distribution system is periodically upgraded and repaired. For instance, the utility is encouraged to install new pipelines as part of the city's road restoration program.

4.2.4. Distribution Network

4.2.4.1 Pipe Distribution by Material and Length

Survey conducted by MCE, 2017, AAWSA has 3,851 KM of distribution pipe in total. The majority of AAWSA's distribution line (19.74%) is made up of DN 63mm pipe, most of which are PE and PVC pipes. Then there are DN 100/110 pipes, primarily made of GS and PVC. A total of 9% of the distribution is made up of each of these pipes. Regarding the kind of construction, uPVC pipes make up around 50% of AAWSA's pipes, followed by PE pipes, which make up 22% of the entire distribution. The majority of the city's distribution pipes, or 55% of them, are between DN 50 and DN 90 millimeters in diameter. Of the remaining 16%, the 50-millimeter pipes are typically thought of as customer lines rather than secondary or tertiary distribution pipes. Only 29% of pipes have a diameter greater than DN100, despite the fact that these pipes are the principal and secondary distribution lines, which are meant to serve larger areas and longer distances. Given the wide range of distribution pipe diameters, it is difficult to provide water to all locations with the necessary and controlled pressure (See Appendix 2).

4.2.4.2. Distribution Network by Branch Boundary Areas

Addis Ababa is divided under eleven administrative sub-cities and ten AAWSA branch offices. According to table 4-4, each branch office varies from the others in terms of the space it covers, the number of clients it serves, and the length of pipe that is installed inside.

Table 4.4: No of customers, areal coverage and length of distribution of AAWSA branch

Branch	Area (km^2)	Customer (no)	Pipe length km	Pipe Length km^2
Adis Ketema	23.65	49,584.00	382	16.15
Akaki	122.3	81,368.00	404	3.3
Arada	15.16	49,294.00	292	19.26
Gurd_Shola	66.87	78,179.00	354	5.29
Gulele	44.83	56,709.00	445	9.92
Kolfe	52.02	42,884.00	271	5.2
Lemi Kura	62.74	74,854.00	425	6.77
Megenagna	54.41	41,763.00	384	7.05
Mekanisa	35.2	62,309.00	325	9.23
Nefas Silke	49.95	77,806.00	522	10.45

Source: AAWSA, 2023 and own result

The table provides information about the area covered, the number of customers, the total pipe length, and the pipe length ratio to the area for each branch of AAWSA. As can be seen based on the preceding tables, the highest number of connections and cover large area in city is found in the Akaki branch which 81,368 customer and 122.3km^2 covers followed by Gurd Shola and Lemi Kura branches 78,179 and 74,854 customer and 66.87km^2, 62.74km^2 respectively. On the other side Akaki branch in terms of pipe length km^2 is the lowest which is 3.3km^2 followed by Kolfe (5.2km^2), Gurd Shola (5.29km^2) and Lemi Kura branches (6.77km^2). The result from the table indicates that, the area and number of customer as well as development conditions vary between branch areas, it can be seen from table 4.4 that the pipe length per square kilometer area varies very much between branches. This could indicate that there may not be equitable water distribution to each branch. Therefore, there is need to improve the availability of pipe length in each branch area.

4.2.4.3. Distribution Network by Water Supply Sub-System Areas

Table 4.5: Existing Sub-system, Principal source and their areal coverage

S. No	Sub-system	Principal Source	Sub-system Area (km^2)	% Of the sub system area	Pipe Length (km)	Pipe % from total
1	Rufael	Gefersa Dam	10.89	4.23%	167.58	5.0%
2	Core-Kolifie		15.44	6.00%	340.19	10.1%
3	St. Paul		3.68	1.43%	80.8	2.4%
4	Legedadi	Legedadi Dam	155.39	60.38%	1,918.11	56.7%
5	Gebriel Palace		1.3	0.51%	25.98	0.8%
6	Jan Meda		14.78	5.74%	253.07	7.5%
7	Teferi Mekonnen		4.14	1.61%	59.99	1.8%
8	Interconnection		0.83	0.32%	14.88	0.4%
9	Mercato		3.27	1.27%	65.2	1.8%
10	Entoto/Ras Kassa		6.34	2.46%	85.19	2.5%
11	Belay Zeleke		6.74	2.62%	113.83	3.4%
12	Ras Kasa		6.73	2.62%	88.49	2.6%
13	Akaki	Akaki Well field	27.83	10.81%	171.05	5.1%
All Pressure Zones			**257.36**	**100%**	**3,381.36**	**100%**

Source: (MCE, 2017b)

According to report made by MCE, 2017 the city is divided in 13 water distribution sub-systems although it is not clear how these sub-systems are delineated, but practically the pipe networks are interconnected to each other. As shown in table above, the existing 13 sub-systems are separated into 3 groups based on their primary supply of water. Presently water is distributed to consumers by gravity from dedicated and dominating tanks (reservoirs) located at higher grounds and also directly from pumping in some cases. Table 4.5 shows the existing sub-system in the city and their area coverage and also the sub-system boundaries are presented below in Figure 4-3. The Lemi Kura branch is supplied by the Legedadi water supply reservoir and underground water.

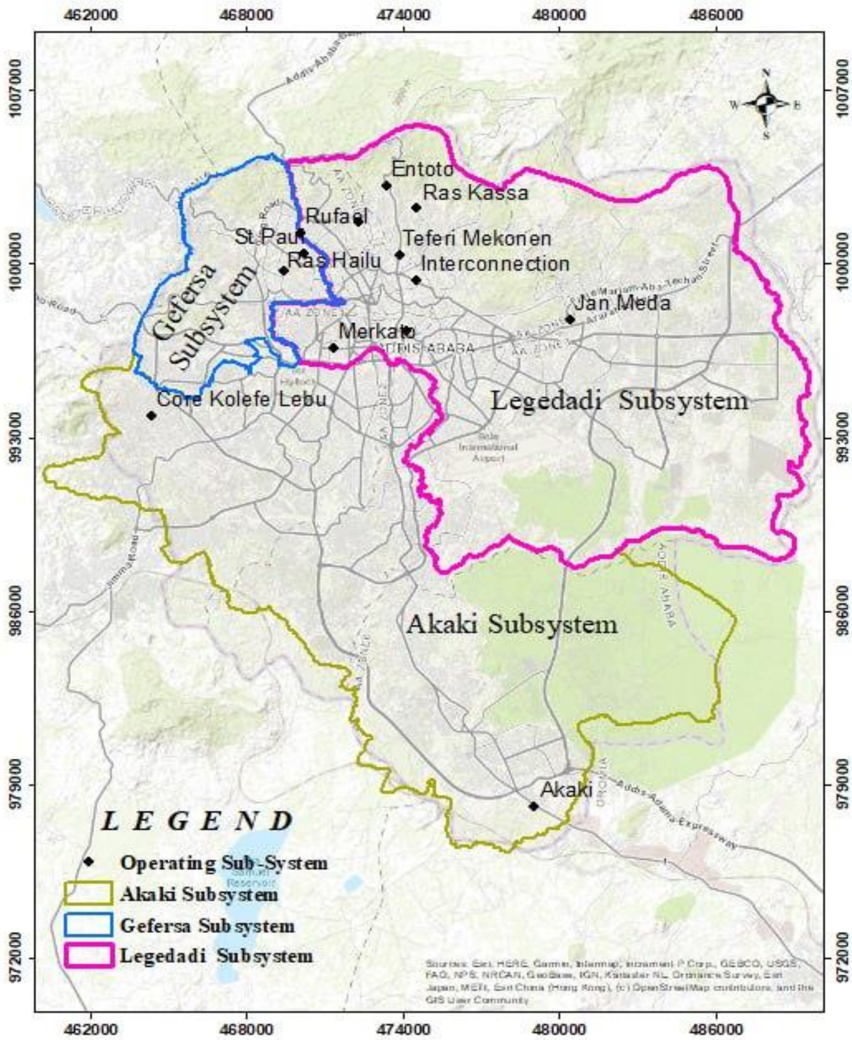

Figure 4.3: AAWSA distribution network sub-system areas (Source: AAWSA)

Currently ten (10) peripheral Branch Offices are in operation (Addis Ketema, Akaki, Megenagna, Nifas Silk, Arada, Gulele, Gurd Shola, Mekanissa, Lemi Kura, and Kolfe Keraniyo). Lemi Kura and Kolfe Keraniyo newly opened branch office. Lemi Kura Branch opened in 2013 E.C. It must be noted that AAWSSA's Branch Office area boundaries are based primarily on the administration division (Addis Ababa Weredas) therefore they do not always coincide with the distribution network subsystems boundaries (hydraulic network boundaries).

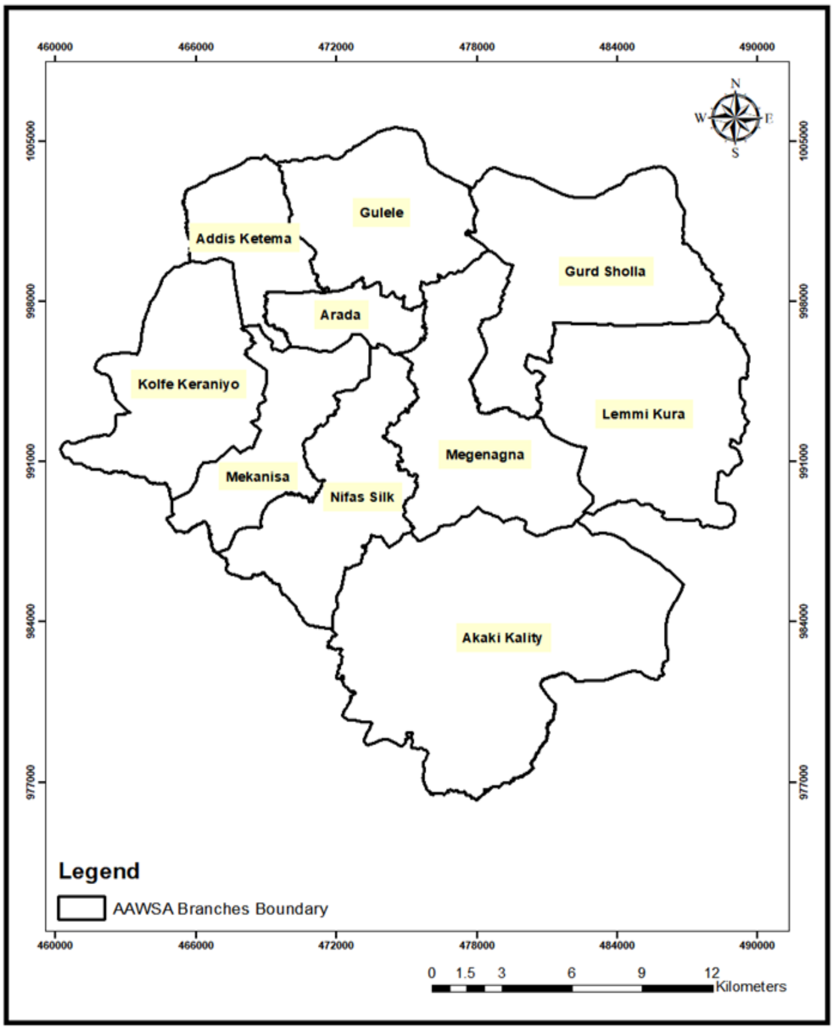

Figure 4.4: Boundary of AAWSA branch utility areas (Source: AAWSA)

4.2.5. Distribution of the Population by Mode of Service

Based on its water rate structures, AAWSA has classed consumers as domestic or non-domestic. The mode of service is a significant consideration when assessing the degree of water supply coverage which was the focus of this section. Tables 4.6 are covered below:

Table 4.6: Customer distributions by mode of service in Lemi Kura branch office

Type of Connection	No of Connection	Population served	Percentage (%)
Domestic	65831	276,490	79.39
Non-Domestic	8657	36,359	10.44
Public Fountain/Tap	337	35,385	10.16
Total	**74,854**	**348,234**	**100**

Source: AAWSA, 2023 and own result

As seen in the table above, AAWSA has three consumer categories such as: domestic, non-domestic, and public fountain. In 2022/23, the branch has around 74,854 registered customers spread across the branch's service area. Based on the data in the table, we can conclude that the majority of the population is served by domestic connections, accounting for approximately 79.39% of the total population. Non-domestic connections and public fountains/taps serve smaller proportions of the population, with percentages of 10.44% and 10.16% respectively.

4.2.6. Current Water Supply Coverage of Lemi Kura Branch

4.2.6.1. Water Supply Coverage Based on Total Population and Total Customers

Water supply coverage is typically evaluated using characteristics such as quantity, quality, price, closeness, and others. However, rather than evaluating all of these aspects comprehensively, the goal of this research is to particularly focus on the relationship between the total population and the level of connection. Divide this amount by the total study area population to get the proportion of people that have access to water. The household sizes used in the calculations are 4.2 persons per household from CSA data for the city of Addis Ababa. Look at equation 1.

Table 4.7: Water Supply Coverage Percentage

Branch Name	Population (2022)	Domestic customer (no)	Non-Domestic customer (no)	Public fountain (no)	Calculated no of population served	Water Supply Coverage (%)
Lemi Kura	435421	65831	8686	337	314386	72.2

Source: AAWSA, 2023 and own result

The branch's water supply coverage is 72.2%, as seen in the tables above. The informant claims that different branches have different water supply coverage. This shows that the coverage in the various areas of the city is not consistent. As mentioned above in table 4.8 and key informants Lemi Kura branch receives more water service coverage than the other branch. This analysis highlights the reach and coverage of the branch in meeting the water supply needs of both domestic and non-domestic customers, as well as providing access to public fountains for the community.

4.2.6.2. Average Daily Consumption per-capita

Per capita water consumption refers to the average daily amount of water utilized by each individual. It can be calculated by dividing total water use by population and the number of days in a specific time period. Depending on a region's climate, culture, and level of development, per capita water usage can vary greatly. The average volume of water consumed daily per-capita in the world in 2015 was 138 liters, in accordance with UN World Water Development Report 2019. Compared to North America, this was 382 liters per day, related to 27 liters per day in sub-Saharan Africa. AAWSA under the GTP II and Business Plan, for Addis Abba City established the 110 liters per capita demand for water domestic consumer category.

AAWSA is keeping records of number of customers and water consumption by customer for each month and the data for the year 2022/23 is obtained and utilized in estimating average water supply per capita usage based on total population and total water consumption by all customers. (See the equation 2)

Table 4.8: Average Per Capita Consumption on total Population

Branch	Population 2022/23	Total Consumption (m^3/year)	Per Capita Consumption (l/c/day)
Lemi Kura	435,421	10,141,848	63.81

Source: AAWSA, 2023 and own result

According to Table 4.8, Lemi Kura branch has a total population of 435,421 individuals in 2022/23 the branch's average daily per capita water consumption in 2022/23 was 63.81 l/capita/day. The branch consumes a significant amount of water each year, count 10,141,848 cubic meters (m^3). This represents the total volume of water used by the population for various uses such as domestic, commercial, and public consumption. Each person in Lemi Kura drinks approximately 63.81 liters (L) of water per day on average. This number shows the average daily water consumption per individual and is used as a metric to assess the branch water consumption patterns. The average standard for the city, according to the AAWSA GTP II, used 110 l/capita/day for residential demand. It shows that actual consumption is less than half of what the as AAWSA business plan prediction, indicating that demand is not being satisfied. According to the findings, Lemi Kura Branch serves a sizable population with significant water consumption needs. This emphasizes the need of efficient water management and providing a sustainable water supply to suit the community's needs. It may be able to optimize water usage and promote water conservation habits in Lemi Kura by monitoring per capita consumption and thinking about conservation solutions.

4.2.6.3. Water Consumption Per Capita from Domestic Consumption based on Population estimated from Domestic Connections

The typical amount of water used by a person each day for domestic uses is called per capita water consumption from domestic consumption based on population estimates from household connections. You may figure it out by dividing your household's water use by the number of days in a given period and your expected population. (See equation 3).

Table 4.9: Average Domestic Per Capita Consumption

Branch Name	Domestic Customer	Population from domestic connection	Domestic consumption (m^3/year)	Per Capita from domestic Consumption (l/c/day)
Lemi Kura	65831	276,490	7,103,796	70.39

Source: AAWSA, 2023 and own result

As show in above Table there are 65,831 domestic customers in total in Lemi Kura branch these customers represent the households or individuals receiving water supply specifically for residential purposes, and indicate that domestic connection serves a 276,490 people in the study area this figure represents the number of people who have access to water through domestic connections within the branch. The total domestic water consumption in Lemi Kura is 7,103,796 cubic meters (m^3) per year. This volume of water is utilized by domestic customers for their daily household activities such as drinking, cooking, bathing, and cleaning. On average, each person in Lemi Kura consumes approximately 70.39 liters (L) of water per day from domestic sources. This metric provides an insight into the individual daily water usage within the residential context. As show above table water conception per capita from domestic connection is 70.39 l/c/day it indicates that, the study area in terms of consumption is good relative to the AAWSA plan.

4.2.6.4. Per Capita Water Consumption from Public Fountain Consumption and Population estimated from Number of Public Fountain

The product of per capita water consumption from public fountains and population defined by the number of public fountains yields the average daily amount of water drunk by a person from public fountains. One way to figure it out is to divide the amount of water used at public fountains by the estimated population and the number of days in a given period. According to AAWSA GTP II Plan average population used in public fountain is 105 persons.

Table 4.10: Average Public Fountain Per Capita Consumption

Branch Name	No. of Public Fountain	Population from Public Fountain	Public fountain consumption (m^3/year)	Per Capita from public fountain (l/c/day)
Lemi Kura	337	35385	915,756	70.9

Source: AAWSA, 2023 and own result

This table show there are 337 public fountains found in Lemi Kura branch. The public fountains serve 35,385 populations in the study area. The value specified is "915,756" cubic meters per year, indicating the amount of water used by the public fountains in that time frame and the value specified is "70.9" liters per capita per day, reflecting the average amount of water consumed by each individual each day from the public fountains. The tables mentioned above show that per capita water consumption is nearly the same between domestic (70.39 l/c/day) and public fountains (70.9 l/c/day) under various scenarios, indicating that there is uniform per capita consumption throughout the study area, even though this may be significant for the degree of development and quality of life of the household in that area. The research area is close to the source of the water, the most of the places, and the building of contemporary homes Perhaps the branch is performing well.

4.2.7. Water Supply Service Availability

It is essential that customers always have access to water, which also serves as a reliable sign of quality service delivery and satisfied customers (Assefa et al., 2018). According to key informant the water delivery system in Addis Ababa is intermittent, and each branch operates on its own timetable. In light of this, the researcher made an effort to get data from the branch office regarding the availability of water supply on a daily and weekly basis to the branch utility border. Tables 4.11 provide a summary of the branch office's findings.

Table 4.11: Water availability on average in hours & days

Branch Name	Average hours/day	Average days /week
Lemi Kura	15.2	4.3

Source: AAWSA, 2023

The tables mentioned above show the water supply service availability. Average hours/day column represents the hours worked on average of water availability per day at the Lemi Kura branch. The value specified is "15.2" hours/day. This shows that, on average, this branch's there is a water supply accessible for 15.2 hours per day. Average days/week column represents the average number of days of water availability per week at the Lemi Kura branch. The value specified is "4.3" days/week. This indicates that, on average, water is available for duration of 4.3 days each week at this branch.

The service duration in the Lemi Kura branch currently have access to water for about averagely 15 hours per day and 4 days per week so that the customer will have access at least 15 hours and have advantage to consume more water. According to informant and data from the branch offices, the branches' performance in terms of the accessibility of water services is satisfactory compare to another branch in the city.

4.2.8. Non-Revenue Water (NRW)

Non-Revenue Water (NRW) is an important issue in the low coverage of water supply since the produced water possibly not efficiently delivered to customers due to a variety of factors like pipe leaks, unauthorized connections, inaccurate water meters, etc. (Assefa et al., 2018). The net revenue difference (NRW) is the difference in the amount of water produced and the quantity of water billed to or used by the consumers. The Lemi Kura branch was used to acquire NRW data at the branch level.

Significant amounts of water have been lost from the system without generating any revenue for AAWSA. The NRW for AAWSA in the year 2022/23 for the entire city amounted to 38–40% of the overall system input volume of water injected into the distribution system, according to the study report. In addition, the distribution system has physically lost 31% of this sum.

The average water system input in the branch for the year 2022/23, according to the water consumption data utilized in this study, the system input volume was 14,274,144.20m^3/Year. The contrary side, consumers' total daily consumption of water for the in-branch 2022/23 was 10,141,848m^3/year. The disparity is attributed to water losses, which account for 29% of all water generated and are equal to (4,139,501m^3/year). The Yearly Water Production or System Input Volume, Consumption, and Loss in Cubic Meters for 2022/23 they are portrayed in Table 4.12.

Table 4.12: Non-Revenue Water (NRW) Lemi Kura branch on 2022/23

Year	SIV	NRW %	NRW (m^3)
2022/23	14,274,144m^3/Year	29	4,139,501

Source: AAWSA, 2023 and own result

As show in Table 4.12 from total system input volume from Legedadi sub-system for Lemi Kura branch yearly 14.2 Mm^3/year. From this input of water due to physical and economical loss average 29% (4,139,501m^3/Year) of water waste from the branch. One-third of the water produced in 2022/23 was wasted, as seen in the table. According to Mckenzie & Wegelin (2009), The total amount of water lost in the present study was calculated represents a total of apparent (management /economic) and true losses (physical). The amount of water for which no money is collected is indicated by the NRW, which is a metrics for water distribution efficiency. In Addis Ababa, water loss is a major issue that contributes to both a severe water deficit and significant financial losses.

The reduction of NRW from it's the present situation between 36% and 40% to 20% by various mechanisms is the focus of AAWSA's final GTP II. By 2020, it was intended to lower NRW to 20% in accordance with the utility aim (Z&a Consulting Engineers, 2014). However, it is well known that there are significant water losses from the water delivery network, with NRW levels exceeding 40% of the town's total a supply of water in general and 29% of water loss in 2022/23 in the Lemi Kura Branch. Water shortages and high NRW levels should be seen as a serious problem that requires attention.

4.3. Cause of water supply problems in terms of spatial data management

This research analyzes the underlying reasons for the scarcity of urban water supply, paying particular attention to the function of spatial data management. The study emphasizes how crucial it is to manage spatial data effectively in order to preserve functional water supply systems in study areas. In order to conduct this research, interviews with 15 water managers and engineers were conducted from head office and Lemi Kura branches, as well as a thorough review of a variety of literature, reports, and case studies on urban water supply and the management of spatial data. The research concentrated on uncovering widespread geographic data management problems that are a factor in the problem of water supply.

Based on interview result, study discovered the fact that the problem of Addis Ababa's water supply has presented themselves in terms of data management, the causes of the limitation of water supply are: inadequate data collection methods, insufficient data dependability, and quality, poor data integration and sharing, limited data analysis, and application, and a problems of data governance and security.

4.3.1. Data collection and quality

According to the key informant one of the challenges to collect the data about infrastructures asset is informal settlement. Addis Ababa has a significant number of informal settlements (Gelet et al., 2023), which can make it difficult to access and collect accurate spatial data. Informal settlements often lack formal infrastructure and can be located in densely populated or hard-to-reach areas, making data collection challenging. On the other side Addis Ababa is experiencing rapid urbanization, leading to continuous changes in the city's landscape and water supply infrastructure (World Bank, 2021). Keeping up with these changes and ensuring up-to-date geographical data can be difficult to work with, particularly AAWSA data collection method is infrequent or not comprehensive.

According to the interview conducted AAWSA has limited resources and expertise to collect relevant data. Limited budgets and a shortage of skilled personnel can restrict the implementation of advanced spatial data collection methods, leading to outdated or incomplete data.

According to the respondent, the collected spatial data in AAWSA has a problem with data accuracy and resolution. AAWSA collects data through various methods that have limitations in terms of accuracy and resolution. GIS is a particular kind of system of information that uses methods to gather spatial data storage, retrieval, analysis, and display source of data from a geographically organized database dispersed property (Shamsi, 2005). In other words, the information's position in relation to other geographical features and things crucial to the information used by utilities. GIS technology is the best option for efficient management of the infrastructure used by the water sector because it combines the power of geography and information technologies.

Making a computerized database and managing important assets properly issues that AAWSA is currently facing due to aging water. A scenario has arisen in which, despite the fact there is enough although there is water accessible, it fails to reach the end user due to inadequate management and the availability of information managers of water authority. This is due to unscientific methods in addition to a shortage of finances, inconsiderate pipeline lying, and an insufficient database of these essential services. According to personal observation, no organized data can be discovered in the AAWSA headquarters, and the data that is distributed across the teams has not been centralized. Literature findings show that data management is essential for guaranteeing a sufficient supply of municipal water. Data management can assist water utilities in making better decisions, simplifying operations, enhancing service delivery, reducing costs, raising revenues, reducing risks, and achieving goals (Shamsi, 2005).

There is unorganized data can be discovered in the AAWSA, and the data that is found in different teams has not been centralized. Because of this difficulty, managing assets, operations and maintenance of the system is challenge to the branch office.

Since big data management can result in malfunctioning technology, data inaccuracies, increased storage requirements, potential cyber security threats, and a lack of uniform standards, it presents a huge issue for water utilities (Cahn et al., 2023). According to a Water Research Foundation (WRF) survey conducted in 2018, "data quality" was the biggest impediment to the adoption of Water utilities will use big data first, after which "lack of talent to implement big data processing and analytics" and "data security". In line with the above sources, the interview result of this study discloses that, AAWSA Lemi Kura branch has little access to high-quality data, and it lacks a database for the majority of problems or the ones that are present are out-of-date. The water supply services are made more difficult by the Lemi Kura branch's extremely poor data recording system.

According to an interview with branch offices, AAWSA have no implemented standard data collection method across various branch areas. They all collected data individually due to this difficult to maintenance, management, demand prediction and so on. Data related to customer used for the calculation of water supply coverage and related indicators are poor. As a result, coverage calculation based on number of connections, family size of the customers and water consumption is highly affected. However, AAWSA did not register their customers properly. One of the reasons for this is that numerous clients that use the water supply for business and industrial purposes continue to be billed as household customers due to AAWSA's inability to timely update its customer profiles database. The findings demonstrate that water utilities lack standardized and coordinated data collection methods, which results in inconsistent and incomparable data.

As a result, there is now a significant reliance on data at the global level, which frequently results in local interventions that are not appropriate. Most national and international data collection, analysis, and reporting systems are only effective at the city or country level. In tiny geographic areas, information is hardly ever de-aggregated to a local level. Data that was unavailable, missing, incomplete, or inconsistent made this study difficult to conduct. The water supply services are made more difficult by the Lemi Kura branch's extremely poor data recording system. Water shortages are a result of incomplete or data on the availability of water, allocation, and utilization by different user categories, water quality, and water management strategies are all inaccurate.

4.3.2. Data Integration

Based on the respondent AAWSA in general and Lemi Kura branch in particular and also service providers have no realistic integration in Addis Ababa. Roles and duties that are not clearly defined a lack of organizational commitment, a lack of knowledge that makes it difficult to set rules and standards, and a lack of documentation for design, building, maintenance, monitoring, and assessment. The project office and the operator, AAWSA, do not work well together. Due to the lack of cooperation, deep wells have been drilled close to shallow and medium wells without obtaining information from the AAWSA about whether ones are malfunctioning, abandoned, or reducing yield.

In some well fields, this tendency is causing groundwater abstraction that is above the capability of their dwindling recharge. The efficient operation of the utility is being hampered by the clear lack of coordination between and within the many AAWSA teams, surface water, groundwater, non-revenue water control, water quality executives, planning, and other factors are all considered. According to this study, AAWSA faces a significant challenge due to weak or nonexistent sectorial coordination among and between service providers, which contradicts UNESCO's (2015) assertion that effective communication among urban service providers at various stages, as well as coordinated planning including multiple stakeholders, are critical for long-term water planning and management.

The findings of Gebremichael et al., (2014), which showed an extensive institutional and professional gap in the domains of water management and governance, are consistent with the absence of cooperation that has resulted in inadequate facilities resulting to insufficient water quality. This issue has led to frequent water pipe damage while installing telecom infrastructure and building roads, insufficient capital and incompetent infrastructure, unusual, combined infrastructure as well as housing development methods have limited the accessibility of infrastructural services in high-altitude places, as have frequent breakdowns of water-supply engines and pumps caused by blackouts of electricity. The same results were found by Damhaug et al., (2016). The primary challenge to coordinated water administration is issues of sustainability and integration (De la Harpe, 2008). Other than providing technical support and carrying out water construction projects, which are its responsibilities, the ministry of water resource has no coordinated links with the major players in the Addis Ababa water supply activities.

Data integration also depends on effectively sharing information across different departments. The findings demonstrate a lack of data integration and sharing amongst various urban water supply players, including water utilities, governmental organizations, corporate sector partners, civil society organizations, and consumers. Fragmented data systems that have information spread across several departments or agencies make it difficult to integrate and analyze data effectively. The exchange and sharing of essential information required for thorough water supply management are made difficult by incompatibility between various data formats and systems. Effective planning and decision-making face obstacles by essential parties having limited access to geographical data, such as water utilities, local governments, and researchers.

According to interviews with some personnel and AAWSA documentation, Addis Ababa's water service struggles with a severe lack of expertise and competency. Water services are usually delivered in "silos" involving several copies of the same data sets, resulting in redundancy, misinterpretation, or contradicting approaches (Masci et al., 2019 al; Giffoni et al., 2022). The findings show that there are growing concerns about data accuracy and quality. Inaccurate or missing geospatial data might provide incorrect analysis and poor water supply management decisions. Errors made during data collection, problems with data integration, or a lack of quality control methods can all lead to poor data quality.

In order to understand the complexity of water systems, administrators must synthesize and evaluate a wide range of data and information (Chang et al., 2006; Bakker , 2012; Vogel et al., 2015). Although providing data does not guarantee that it will be used for better and more sustainable handling of water, current technology, at least in principle, offers the opportunity to enable such multidimensional integration. It consists of both actual data and data from model outputs. The findings indicate that AAWSA only sometimes analyze and employ data for developing and managing water resources. This suggests that data analytics and visualization, which can offer information and solutions for issues with water supply, need to be strengthened.

It is clear that issues related to cyber security have the capacity to influence the course of the 21st century. Water utilities are becoming more vulnerable to cyber threats as a result of the recent growth in the adoption of developing digital technology by several water businesses in their daily routine operations (Alabi et al., 2020). The findings show that AAWSA lacks data governance and security policies, putting them at risk of different dangers such as data loss, corruption, theft, or misuse. To ensure data safety and accountability, it is necessary to establish data policies and regulations. Collaboration and creativity are vulnerable by strong data-sharing procedures and ineffective data distribution methods.

4.4. Database Development

For the current study, the database was created using PostgreSQL. PostgreSQL, being a powerful relational database management system, pgAdmin is a graphical frontend offers that can be utilized to access the database.

By using the pgAdmin tool, users have the flexibility to create multiple tables within the database. This allows for the organization and structuring of data according to the specific requirements of the study. Users can declare column and data type specifications, constraint settings, and linkages between tables as needed. They can also build table schemas. The graphical interface of pgAdmin simplifies the process of managing the database by providing a user-friendly environment for creating, modifying, and querying tables. Users can take advantage of the visual tools and wizards offered by pgAdmin to streamline their database operations.

Overall, the combination of PostgreSQL as the database management system and pgAdmin as the graphical frontend offers a robust and efficient solution for creating and managing the database. It empowers users to design and structure the database with the necessary tables, ensuring seamless data management and accessibility throughout the study.

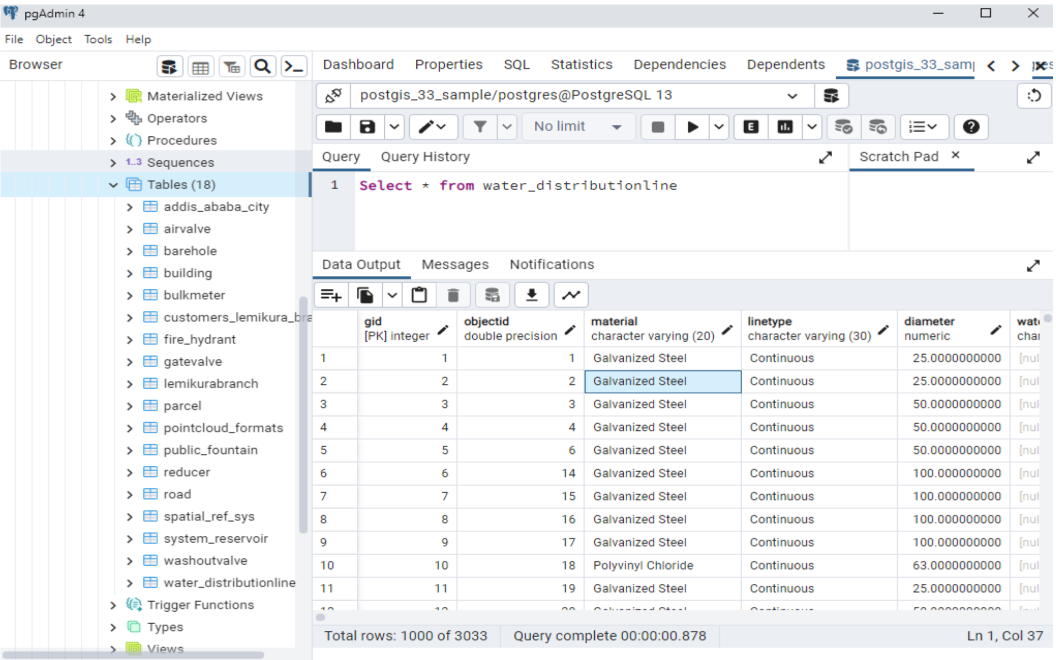

Figure 4.5: Data from developed data base shows pipe line attribute information

4.5. Publication of a database of Water networks on the web

Web-GIS apps were built totally from scratch for the study's purposes utilizing open-source tools Apache Tomcat, PostGIS, GeoServer, OpenLayers, and MapStore. Software intermediaries known as APIs make it possible for two apps to communicate with one another. All necessary software was downloaded, set up, and designed to align with the objectives of the research. As an illustration, spatial databases were created, shape files were eventually uploaded through PostGIS databases, and Apache Tomcat was utilized as a webserver to host the remainder of the applications. Several users can utilize the supplied URL to visit the GeoServer that was deployed to Apache Tomcat at any time and from any location.

GeoServer was the default username, while admin was the default password. URLs (Uniform Resource Locators) are used by browsers to access all open resources on the internet Data layers from multiple sources, including vector data sources (including shape files, PostGIS databases, and so on), were added to project-specific workspaces upon downloading, installing, configuring, and deploying GeoServer using Apache Tomcat.

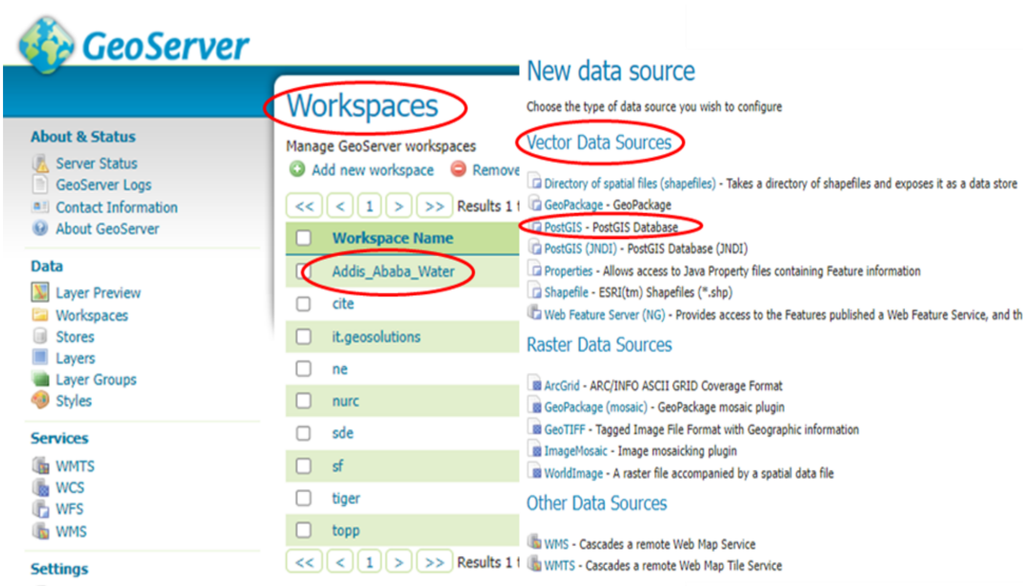

Figure 4.6: GeoServer workspace and data sources

Figure 4.7 showcases the components of the water distribution network data that have been published on GeoServer. It provides an overview of the various features available to clients through the web platform, offering a multitude of uses for different purposes. The published water distribution network data on GeoServer serves as a valuable resource for clients accessing the web platform. It encompasses a wide range of features and functionalities that cater to diverse needs and objectives.

Clients can leverage these features for various reasons, depending on their specific requirements. They can utilize the data for network analysis, spatial querying, asset management, infrastructure planning, and decision-making related to water distribution systems. The web platform allows clients to interact with the data, access detailed information about the network components, and extract valuable insights to support their activities.

Whether clients are from governmental organizations, non-governmental entities, or commercial enterprises, the developed web platform provides a user-friendly interface to explore and utilize the water distribution network data effectively. Clients can access the features and functionalities based on their access privileges and objectives.

In conclusion, Figure 4.7 illustrates the components of the water distribution network data published on GeoServer and highlights the diverse features available to clients through the web platform. These features offer extensive capabilities for clients to utilize the data for various purposes, ranging from network analysis to decision-making, contributing to efficient and informed water distribution management.

water_distributionline

fid	objectid	material	linetype	diameter	watertype	lastupdate	lasteditor	shape_leng
water_distributionline.1147	1184.0	Polyvinyl Chloride	Continuous	63.0000000000	Potable Water	6/2/23 12:00 AM	Our Agency	65.0995462990
water_distributionline.1148	1185.0	Polyvinyl Chloride	Continuous	63.0000000000	Potable Water	6/2/23 12:00 AM	Our Agency	7.97830366290

Figure 4.7: OpenLayers-published water distribution networks

Figure 4.8 provides an overview of the Water Network, serving as a comprehensive repository of data regarding the actual condition and assessment of the water networks within the study area. The developed web page incorporates a diverse set of features that allow users to execute queries and retrieve both geographic and non-spatial information. Any web user with an interest in accessing up-to-date data on the water network infrastructure specifically for the AAWSA's Lemi Kura Branch can conveniently visit the designated sites. These sites provide a user-friendly interface where users can interact with the system, access the desired information, and gain insights into the current state of the water network infrastructure.

By visiting these sites, users can explore various aspects of the potable water network, such as its type of pipe material, diameter, installation year, and other relevant attributes. The web page empowers users to query the system and retrieve specific information based on their requirements. This enables users to access valuable data regarding the Lemi Kura Branch's water network infrastructure effortlessly.

In summary, Figure 4.8 presents an overview of the Water Network, serving as a central repository of data. The developed web page incorporates a wide range of features that allow users to execute queries and obtain both geographic and non-spatial information. Interested web users can visit the designated sites to access the current data on the potable water network infrastructure for the AAWSA's Lemi Kura Branch.

URL http://localhost:8080/mapstore/#/context/AddisAbabaWaterDistributionMap/68

The Username: admin and the password also admin, and users may readily access the resources by using the internet and web technology, as shown in Figure 4.8.

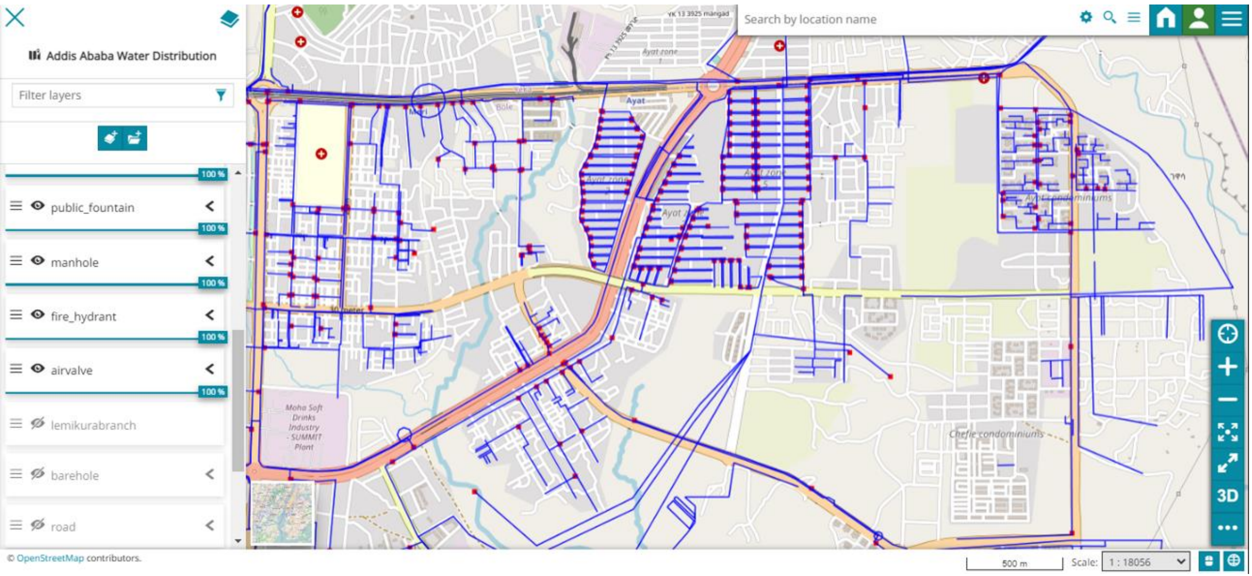

Figure 4.8: Water distribution networks on MapStore app

To facilitate management decisions, the required data was accurately organized within a PostgreSQL/PostGIS database. This database not only stores the data but also leverages the geospatial capabilities of PostGIS, enabling the storage and analysis of geographic information. Furthermore, the data was made readily available through a WebGIS platform, ensuring easy access and visualization for stakeholders involved in the management process.

The WebGIS platform, integrated with the PostgreSQL/PostGIS database, offers a user-friendly interface that allows authorized stakeholders to explore and interact with the data seamlessly. The privileges and access rights are managed by the database administrator, ensuring that only relevant individuals or groups can access the data based on their roles and responsibilities. By utilizing this setup, stakeholders can effortlessly retrieve and interpret the information they need for maintenance decisions. They can view geographic data, perform spatial analyses, and gain valuable insights into the water infrastructure or assets being managed. This transparent and accessible approach fosters effective collaboration among stakeholders, enabling them to make well-informed decisions that contribute to efficient and proactive maintenance and operation practices.

Overall, the combination of a PostgreSQL/PostGIS database and a WebGIS platform provides a robust and user-friendly solution for organizing, accessing, and visualizing the data necessary for management decision-making. It empowers stakeholders with the ability to leverage geospatial information effectively and enhances the overall management process.

Once logged in, users gain access to the comprehensive list of layers by simply clicking on the layers button located in the upper left corner of the website. This intuitive interface allows users to explore the available layers, add new ones, access attribute tables, create interactive widgets, import/export layers, compare data across different layers, and generate graphs and charts. However, the extent of these functionalities depends on the privileges assigned to each user.

To provide a visual representation, a screenshot was presented, showcasing the website's overall design. Furthermore, the collaborative aspect of the platform was highlighted, as multiple users can view, comment on, and modify water network maps, layers, and associated attributes. This collaborative environment is facilitated through the MapStore's homepage, accessible by navigating to the URL provided in Figure 4.8.

Overall, the WebGIS platform offers an intuitive and feature-rich interface, empowering users with the ability to seamlessly navigate through layers, visualize data, analyze information, and collaborates with other stakeholders for effective decision-making in distribution line management and other relevant processes.

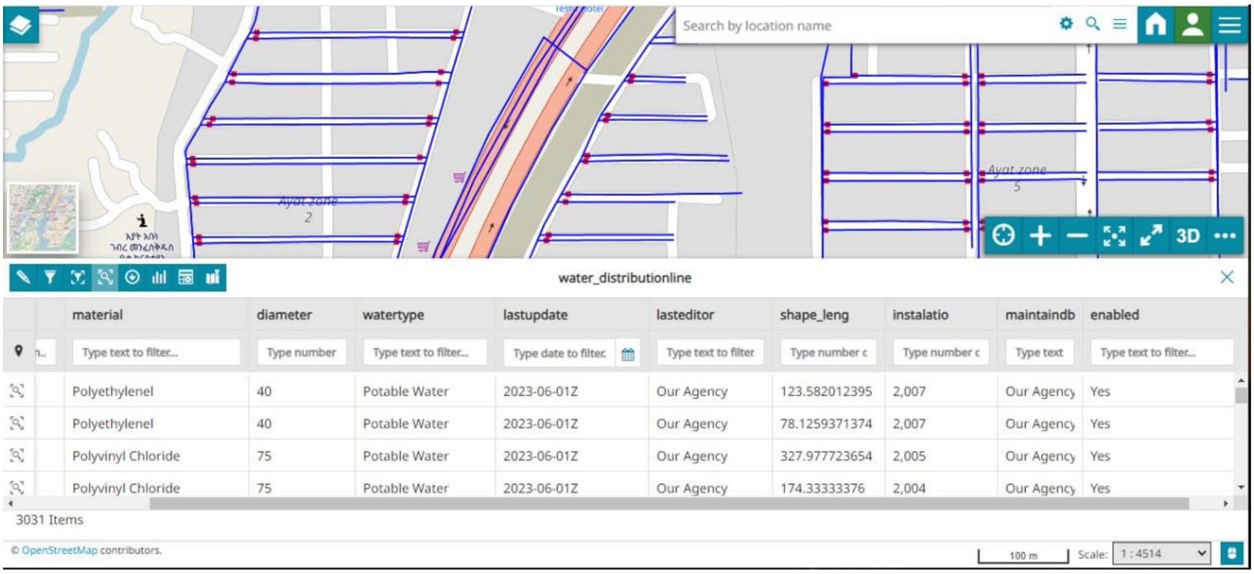

Figure 4.9: Water distribution networks with attribute table

The development of websites varies based on their specific purpose and objectives. Websites can be designed with various intentions, such as providing information, supporting decision-making processes, serving commercial interests, facilitating governmental operations, or furthering the goals of non-governmental organizations. Each of these purposes requires different considerations and approaches during the development process. For websites focused on information dissemination, the primary goal is to present content in a clear and user-friendly manner. Design elements, such as intuitive navigation, organized layouts, and relevant visuals, play a crucial role in effectively conveying information to users.

Websites aimed at supporting decision-making often require interactive features and data visualization tools. These sites may incorporate databases, data analysis capabilities, and visualization techniques to enable users to explore, analyze, and interpret information to make informed decisions. Website development involves considerations such as user experience, responsive design for various devices, security measures, search engine optimization, content management systems, and integration of relevant technologies. Ultimately, the development of a website is tailored to its specific purpose, ensuring that it effectively serves the intended objectives and provides a seamless and engaging experience for its target audience.

In this study, the development of the website involved the utilization of a MapStore and other supporting open-source programs. The central component of the website was a modular open-source WebGIS platform known as MapStore. This platform was specifically designed to create, organize, and securely share maps and mashups. MapStore adheres to the standards set by the Open Geospatial Consortium (OGC), including Web Feature Service (WFS), Web Map Service (WMS), Catalog Service for the Web (CSW), and Tile Map Service (TMS). These standards enable seamless integration and interoperability with various mapping services and data sources. Within the MapStore platform, content from popular mapping services such as Google Maps, OpenStreetMap, and related servers can be utilized as the base map. This provides users with familiar and widely-used mapping data to serve as the foundation for their maps and mashups.

By leveraging the MapStore platform and its compatibility with OGC standards, the website development process was able to tap into a robust and versatile WebGIS solution. This allowed for the creation of interactive and dynamic maps, incorporating both base maps and custom layers, while ensuring data compatibility and adherence to industry standards. The use of open-source programs, including MapStore, exemplifies the collaborative and community-driven nature of the development process, harnessing the collective efforts of developers and adhering to open standards for enhanced functionality and data integration in the website.

Web-based spatial information systems offer a lot of benefits, providing extensive information and support to users irrespective of their location. These systems simplify information exchange; reduce data mining costs, enable customer feedback collection for water infrastructure maintenance planning and operations, and much more. The information provided includes network inventory and physical condition assessment outputs stored in a relational database management system.

The main objective behind developing this WebGIS platform was to ensure that decision-makers and users have access to crucial information regardless of their geographical location. By leveraging the power of the web, this platform breaks down geographical barriers and enables seamless access to data, thereby facilitating informed decision-making and effective management of water infrastructure.

In conclusion, the creation of a WebGIS platform has proven to be instrumental in offering essential information to decision-makers and users involved in urban water network maintenance management. This platform ensures the availability of comprehensive data, enabling stakeholders to gain valuable insights and make informed decisions, regardless of their physical location.

Chapter Five

5. Conclusions and Recommendations

5.1. Conclusions

The concept of connectedness and the momentum that the web has created have been extremely beneficial for GIS. The power of GIS has been awakened via the web. GIS is now accessible across all industries and in the homes and hands of billions of people. Water utilities may gain a lot by deploying Web GIS platform. This technology offers solutions that are inexpensive and simple to use, accessible everywhere in the business at any time via any device.

The objective of the research was to examine the area of water supply coverage and to develop a Web GIS platform for the Lemi Kura branch's water distribution system. The analysis focuses on assessing the branch's current water supply coverage based on billed use and population.

By utilizing the population data of the branch, an evaluation was conducted to examine the average water supply coverage based on the number of connections and daily per capita usage. The research findings revealed that the average water supply consumption in the branch is 64.70 liters per capita per day (l/c/day). This average per capita consumption falls below the AAWSA plan's corresponding figure for water supply investment.

The study reveals a significant disparity between water demand and supply within the Lemi Kura branch. This imbalance can be attributed to two primary factors: inadequate management of the city's water service and the rapid expansion of the population, economy, and housing developments. On one hand, the city's water service management has been ineffective in meeting the growing demands. On the other hand, the AAWSA lacks the necessary institutional, financial, and technical capabilities to invest in the city's water development, aggravating the problem.

According to the majority of respondents, there was an improvement in the water service, while a respectable percentage reported a decline. This study indicates an overall expected increase in water demand due to various factors. These include the gradual decline in water system performance, an outdated distribution network, the absence of a well-organized asset data management system, inadequate pipes leading to frequent bursts, damages caused to service pipes during road construction and other land use activities, frequent technical failures, insufficient infrastructure, and high demand resulting from rapid population growth, urbanization, improved lifestyles due to higher income, and water-intensive modern homes.

Immediate replacement or extensive renovation of the outdated pipelines in the current Legedadi subsystem configuration is crucial to maintaining appropriate static pressure conditions. Additionally, the branch region's demands will require the utilization of more surface and groundwater sources. To address the issue of insufficient water supply volumes and sudden pressure drops, the utility must improve and strengthen the effectiveness of its water distribution and management systems. This will ensure that customers receive a satisfactory water supply and that their demands are adequately met. The frequent disruptions in the distribution network can be attributed to AAWSA's lack of a unified strategy, absence of standards, presence of multiple institutions, institutional weaknesses, and lack of integration among the various service-providing entities at the city level. To overcome these challenges, it is imperative for the institutions to integrate their action plans and programs effectively.

The analysis conducted on the current water distribution system revealed the presence of spatial data in CAD digital format for various components such as water pipelines, bulk meters, appurtenances, and cadastral borders. To facilitate efficient storage, management, and retrieval of this spatial data, a dedicated database was developed. This centralized database ensures the effective storage, management, and retrieval of spatial data. Furthermore, a WebGIS system was created, incorporating several useful GIS tools for tasks such as spatial data display, analysis, querying, and map printing. The WebGIS system is designed to be user-friendly, convenient, and intuitive, catering to individuals without prior GIS knowledge. Additionally, it supports concurrent multi-user access. The study also highlights the extensive capabilities of free open-source software, which can be instrumental in implementing mapping and spatial analysis tools, particularly for organizations with limited budgets for proprietary software. However, for the newly developed WebGIS system to accommodate simultaneous access by a large number of users, improvements in performance and scalability are essential.

The management of water distribution networks using WebGIS also increases asset management's effectiveness and efficiency. Utilities can build a comprehensive database that offers a comprehensive perspective of the network's operation by combining data from numerous sources, such as sensors, SCADA systems, and customer feedback. This makes it possible to schedule preventative maintenance, lowers the chance of system failures, and maximizes resource allocation. WebGIS-based systems can also send out real-time warnings and notifications, enabling operators to take immediate action in the occurrence of leakages, pressure changes, or further anomalies, minimizing water loss and service interruptions.

The presence of an outdated database has ultimately resulted in less effective and inefficient management. These inefficiencies stem from the limitations in infrastructure and the absence of effective management systems. It is crucial to address these issues as they continue to be highly relevant and require resolution. By upgrading the database and implementing efficient management systems, the overall effectiveness and efficiency of operations can be significantly improved. This will help overcome the existing limitations and ensure better management practices for enhanced performance and operational success.

In conclusion, the implementation of WebGIS-based technology to construct a water distribution network management system has substantial advantages for managing and maintaining water distribution networks. As a result of the integration of spatial data and real-time information made possible by WebGIS, water utilities are better equipped to make decisions and react to operational difficulties. The network infrastructure may be seen on a digital map, which allows operators to keep track of the health of their assets, spot problem regions, and organize their maintenance and repair tasks. Additionally, WebGIS offers a user-friendly interface that promotes stakeholder engagement and communication, supporting efficient decision-making and resource allocation.

5.2. Recommendations

A unified data collection and storage methodology can be incorporated to increase the scope of managing water distribution. To analyze and execute various models based on organized information, water utilities require a centralized web-based GIS platform.

Enhancing the socioeconomic welfare of the residents of the study area entails improving the present water supply service there in terms of quantity, dependability, and sustainability. In order to achieve the aim of ensuring that every member of society has appropriate access to water supplies, there is a requirement for significant government and other stakeholder participation.

The following sets of suggestions are derived from the conducted investigation and modeling outcomes as a result of the findings above:

Data Collection: For proper planning, AAWSA should undertake a thorough inventory of all water system infrastructure at the municipal and branch levels, as well as maintain correct and update data on production and supply status, asset GPS locations, and other information. The authorities may think about building an updated GIS database for SCADA integration and hydraulics modeling.

Loss reduction and demand reduction: AAWSA should take proactive measures to address the supply-demand imbalance by implementing various programs. There must be reduced leakage through ongoing efforts for leak detection, repair, and replacement of aging pipes.

AAWSA should implement of an integrated water management hydraulic model by recording data from the city water network in a modern GIS database system for decision-making on the amount of water needed now and in the future.

Continuous Improvement and Evaluation: AAWSA should analyze the efficiency and performance of the distribution system and water source on a regular basis to identify areas that might be improved.

Investment in Data Integration and Interoperability: AAWSA should make investments in data integration and interoperability if wants to fully realize the promise of Web GIS-based water distribution network management. To enable seamless information sharing across various systems and stakeholders, standard data formats and protocols must be developed.

Training and capacity building: AAWSA operators and decision-makers should get training in the features and uses of a Web GIS-based system in order to use it successfully.

Collaboration and stakeholder involvement: AAWSA should set up methods for sharing spatial data and information with these stakeholders. Web GIS-based systems present chances for enhanced stakeholder collaboration and involvement, including employees of water utility companies, administrators, and customers. AAWSA can improve their methods for managing their water distribution networks, allocate resources more effectively, and provide better customer service by adopting WebGIS-based technology and putting the aforementioned suggestions into reality.

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Appendices

Appendix 1 Interview questions for key Informants

Questions in general concerning the professional's background and the sector in which they work.

Interviewer Name________________ Date_______________

Respondent's responsibility: ____________________________ Office location: _____________

Detailed questions to be made during the interview

1. What are the primary apparatuses of the water supply and distribution system in?

2. What technical, institutional, and economic difficulties does the AAWSA office in Lemi Kura branch encounter?

3. What are the causes of the problems observed in the main parts of the Lemi Kura branch water distribution system mentioned above?

4. How will these effects affect the quantity and level of service?

5. Among the causes that affect the quantity and service level of the water produced, which one is related to the Authority?

6. Have any actions/remedial measures been taken to address these problems/challenges in the main parts of the water supply and distribution system in Addis Ababa?

7. How much percent of water loss after release to the system and what are the reasons for the loss of water?

8. What are the possible solutions to solve the water distribution problems regarding to spatial data?

9. What are the standards and principles that AAWSA follows to in terms of water supply infrastructure installation, maintenance, and operation?

10. How to engage and integrate with stakeholders in development of utilities infrastructure and how to share utility infrastructure data with other providers and users?

11. How to collect, store, manage and utilize spatial data?

Appendix 2

Appendix 2: Distribution Network Diameter, Length by Pipe Material in the City

Pipe Diameter	Pipe Material and Length (m)								% Of total
	DCI	GS	HDPE	ISOPE	ISOPVC	ST	NA	Total	
DN12	-	2,212	-	74	-	-	-	2,286	0.1%
DN15	-	114	-	-	-	-	-	114	0.0%
DN20	-	12,722	-	2,375	98	-	-	15,195	0.4%
DN25	-	134,635	-	20,566	8,756	-	84	164,041	4.9%
DN32	-	17,075	252	40,426	10,109	-	57	67,919	2.0%
DN35	-	5,455	-	167	1,013	-		6,635	0.2%
DN38	-	119,598	-	808	-	-		120,406	3.6%
DN40	-	132,060	589	36,561	2,614	-	164	171,988	5.1%
DN50	-	3,915	5,900	202,715	501,909	-	191	714,630	21.1%
DN63	-	-	27,732	258,205	381,555	-		667,492	19.7%
DN65	-	8,086	-	313	36,339	-		44,738	1.3%
DN75	-	56,868	1,426	47,803	124,178	-	516	230,791	6.8%
DN80	-	596	-	-	5,718	-	106	6,420	0.2%
DN90	-	3,903	2,831	42,643	141,980	-	4,696	196,053	5.8%
DN100	202	139,171	3,198	42,545	120,259	-		305,375	9.0%
DN110	-	387	26,894	47,549	226,671	-	2,375	303,876	9.0%
DN125	5,405	119	-	-	-	4,060	-	9,584	0.3%
DN150	65,590	1,296	-	-	25,249	5,670	-	97,805	2.9%
DN160	-	-	-	-	18,125	-	-	18,125	0.5%
DN200	67,434	1,085	-	-	19,515	4,658	-	92,692	2.7%
DN225	3	-	-	-	24,161	-	-	24,164	0.7%
DN250	24,454	-	-	-	9,994	-	-	34,448	1.0%
DN280	-	-	-	-	10,008	-	-	10,008	0.3%
DN300	29,972	-	-	-	1,520	793	-	32,285	1.0%
DN315	56	-	-	-	5,823	-	-	5,879	0.2%
DN350	11,640	-	-	-	-	398	-	12,038	0.4%
DN400	22,971	-	-	-	-	-	-	22,971	0.7%
DN450	3,851	-	-	-	-	-	-	3,851	0.1%
Total	**231,578**	**639,297**	**68,822**	**742,750**	**1,675,594**	**15,579**	**8,189**	**3,381,809**	100.0%
% Of total	6.8%	18.9%	2.0%	22.0%	49.5%	0.5%	0.2%	100.0%	

Adapted from Technical Evaluation and Situational analysis Report, MCE

Appendix 3

Appendix: 3 Coordinate Points of Water Service Reservoirs in Lemi Kura Branch

X_ Coordinates	Y_ Coordinates
484169.482	992680.514
484206.526	992680.283
484242.301	992680.283
484288.693	992680.283
484320.544	992680.514
483009.354	994981.094
480992.34	994385.487
480247.364	995425.971
485976.686	996113.996
487350.507	994298.679