GIS Based Geometric Network Modeling of Water Pipelines Infrastructures: A Case of Adama Town

Bedada Guyasa

A Thesis Report Submitted to the Department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfilment for the Requirement of the Degree of Master of Science in Geo-Informatics Engineering

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

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Advisor: Daniel Alemayehu (PhD, Asst. Prof.)

Co-advisor: Getachew Birhanemeskel (PhD)

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defence by Bedada Guyasa Gocholo have read and evaluated his thesis entitled *"GIS Based Geometric Network Modeling of Water Pipeline Infrastructures: A Case of Adama Town"*, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Master of Science in Geoinformatics Engineering.

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CANDIDATE'S DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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This MSc Thesis has been submitted for examination with our approval as thesis advisor.

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To: .Geomatics Engineering Department

Subject: Thesis Submission

This is to certify that the thesis/dissertation entitled *"GIS Based Geometric Network Modeling of Water Pipeline Infrastructures: A Case of Adama Town"* submitted in partial fulfillment of the requirements for the degree of Master's Geoinformatics Engineering, the Graduate program of the department of Geomatics Engineering, and has been carried out by Bedada Guyasa Gocholo Id. No PGR/18032/11, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

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LIST OF ACRONYMS

AAWSA	Addis Ababa Water and Sewerage Authority
AIA	Adama Industry Area
ASTU	Adama Science and Technology University
AWSSE	Adama Water Supply and Sewerage Enterprise
CAD	Computer-Aided Drafting/Computer-Aided Design
CSA	Central Statistical Agency
DEM	Digital Elevation Model
DSS	Decision Support System
ECDSWC	Ethiopian Construction Design and Supervision Works Corporation
EELPA	Ethiopian Electric Light and Power Authority
ESRI^{TM}	Environmental Systems Research Institute
FDRE	Federal Democratic Republic Of Ethiopia
GIS	Geographical Information System
GPS	Global Positioning System
GWM	Gross Water Meter
MoWR	Ministry of Water Resource
OWD	Otway Water District
RDBMS	Relational Database Management System
RS	Remote Sensing
TDSWS	Transport Design and Supervisions Works Sector
ULGDP	Urban Local Government Development Project
UML	Unified Modelling Language
USDA	United States Department of Agricultures
USGS	United State of Geological Survey
WWDE	Water Work Design Enterprise

ABSTRACT

Adama Water Supply and Sewerage (AWSSE) is the owner to utilized and installed water pipelines infrastructures such as; water pipeline, individual customer water meters, water control valves, water fittings, fire hydrants, reservoirs and supplying water for the people of the Adama Town. However, the Enterprise has no well-designed geodatabase for water pipelines infrastructures that enables to easily manage in cost effective, efficient and time manners. Due to this, the Enterprise faced a problem that had led to fail in properly managing those infrastructures such as: maintenance issue, controlling illegal use and leakage of water resources. In addition, with the currently existing management condition the Enterprise is unable to have the appropriate location for the Gross water meter to manage wastage of water. Nowadays GIS had led to overcome such problems if used in managing water network infrastructures. So, ArcGIS was implemented to increases water resource management involves activities like planning, developing, distributing and managing the optimum use of water pipelines infrastructures. Therefore, this study was aimed at developing GIS based geometric network model of water pipeline for Adama Town. The study starts with identifying requirement analysis and collecting primary data such as GPS data spatial location water pipelines infrastructures and secondary data such as CAD files. The need of the Enterprise was identified through requirement analysis, and geodatabase design was done through conceptual, logical, physical design phase by using enterprise architecture UML diagram software. The designed UML was exported to XML schema and the geodatabase model was developed using ArcGIS software based on the requirement of the water utility geometric model. Primary and secondary data is populated in developed geodatabase for test the model. Geometric network was developed in geodatabase through connectivity rules. This study is developed GIS based geometric network model for water pipeline of Adama Town, prototype was selected in specific area in the Adama Town kebele 05 around Adama Industry Area used for validation of the model, to test the developed model, but the study recommended AWSSE to implement the model for the whole Adama Town and tested for spatial analysis based on, different scenarios such as valve isolation and maintenance scenarios and identify the configuration of pipeline network was identified, in order to evaluate the efficiency of the developed geometric model and validate through field observation. To control illegal use water the enterprise should collect manholes and water control valves to select suitable place of gross water meter. This study recommends the developed model can be utilized by the enterprise for effectively managing and updating information of pipelines infrastructures.

Key Words: GIS, Geometric Modeling, Water Pipeline Infrastructure, Adama Town

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

All water utilities are created of assets, the physical assets of a water distribution system embrace pipelines, reservoirs, water, pump stations, hydrants, valves, meters, manholes, and any different elements that form up the system (John, 2012; Avhad, 2016). One of the backbones of socio-economic development is water; so that asset management involves the balancing of costs, opportunities and risks against the desired performance of assets to achieve the organizational objectives and water is one valuable resource and is a primary necessity for the people, agricultural and for the industries (Patel, 2014). Asset management[1] is the systematic process of maintaining, upgrading and operating physical assets. Management and maintenance of underground water pipeline is very difficult task. Many researchers have worked on this problem. Leakage and burst in water pipeline causes billions of litres water loss (Avhad, 2016).

The key advantage of asset management is that it enhances the knowledge of the engineers of the various assets and their details and it helps in logical decision making process. In addition, it acts as a framework that provides a measure of the network performance and links it to both short term and long term planning, helping in optimal improvement of assets at the least cost. Because of this GIS is used in the utility industry to help meet today's needs and it begins with a brief discussion of how GIS has evolved in water utilities assets management's to its current technological state including a description of GIS data sources, critical traditional and non-traditional applications, and costs and benefits (Echelai, 2016).

Geometric networks consist of edge network features and junction network features. An edge features are water main line and water lateral line, and a junction features are water fitting, water control valve system, water hydrant, reservoirs, individual water meter, etc. Edges must be connected to other edges through junctions and edge features are related to edge elements in the network, and junction features are related to junction elements in the logical network (Sherbrooke, 2008).

[1] Asset Management (AM): coordinated activity to realize asset value.

According Steven Folkman (2018) in the United States and Canada population growth during three main time periods – 1800s, 1900–1945, and post 1945 – led to the installation of underground water infrastructure and pipes constructed in each of these three eras could all start to fail at nearly the same time over the next couple of decades for a number of reasons ranging from age and corrosion to inadequate design and poor installation. Additionally, the life span of the materials used has become shorter with each new investment cycle. The water industry has seen many types of academic surveys and studies on water main replacement programs and the benefits of asset management, condition assessment and prioritization. However, many utilities have not historically tracked all of the elements of water main break data. Over the past 20 years, most utilities have come to realize the importance of tracking all aspects of their infrastructure in a GIS-centric platform and have collected records on the types, sizes, and repair histories of their pipes.

Beside Samir Mahmud Adam and Magdy Shayboub Ali (2013) they started with the goal to introduce a framework based on Geographical Information Systems (GIS) to integrate geographic information of Khartoum State. The framework is used to support the information integration and data exchange between facilities using the base maps to solve the problem of distributing water networks. Entities in the Khartoum State (KS) infrastructure link information sources and lead to integration and exchange of associated information. The methodology used to in this case the existing urban systems specially water network using geodatabase concept that are analyzed by observing and comparing the related earlier work using different criteria. Geodatabase of the system was defined, designed and build using ArcGIS software. The main result obtained by the research is the development of a framework based on Geodatabase concept for the integration of geographic information of Khartoum State infrastructure network facilities.

As Medhin Shimelis,*et al* (2017) most water supply services of cities in Ethiopia are unreliable, particularly in providing an adequate amount and also his dissertation work stated, almost all cities in the country have frequently experienced service failures and a lack of supply. For instance, Addis Ababa, Adama, Dire Dewa, Bahirdar, Harar, Hawassa, and Mekele and other small cities usually report for residents' complaints about water scarcity. The reasons could be complex, diverse and many, but the most common factors are a lack of proper operation and maintenance, and poor asset management practices of the systems. The damage of the water pipeline causes a shortage of water for demand.

More than 60% of the urban world population lives with water problems and this number is increasing every year (Tundisi, 2015). So, increasing in population as well as demand for portable pipe-borne water in most of the cities of developing countries and the activities of the people greatly affect the pipes networks quietly laid beneath the ground (A.M. Pindiga and M.J. Sani, 2015). The total water requirement is on the increase and the per capita water consumption is also on the increase due to the increase in population and civilization (Al-layla, *et al*., 1978; Audu, *et al*, 2010; J. Van, 2014). Towns and cities in developing countries are currently facing serious challenges of efficiently managing the scarce water resources, urbanization, and infrastructural decay, as well as the issue of sustainability of conventional water management (Zeraebruk, *et al.*, 2014). In Adama Town, there is an increment of population comes with an increment of water demand for their daily life. According to African Development Bank (2015) report 337 million Ethiopian birr was allocated to for four Ethiopia Cities; Adwa, Bichena, Adama and Gode. And also the Ethiopian government allocated budget 2019/20 for Water & Energy the fourth largest budget 17.5 billion birr, and covers funding for irrigation, water development, and energy projects FDRE (2019) from these Adama Town for Water Supply and Sewerage Enterprise (AWSSE) Improvement Program is one. These invested budgets are an asset for government and society. AWSSE responsible for supplying and managing water for Adama Town population.

However, the Enterprise has no well-documented and designed geodatabase that stores both spatial and non-spatial information of these infrastructures. And the available data's are stored in different departments, by different persons in various hardcopy, large file cabinets. Moreover, the Enterprise has no update digital thematic map which shows these portable ware pipeline infrastructures. These above mentioned challenges had led the Enterprise to fail in managing the pipelines infrastructures in efficient, cost effective, and time saving, etc. manner. Nowadays, GIS has led to overcome such problems if used in water pipeline infrastructures network management. In a such way that, it enables to retrieves spatial and non-spatial information digitally, tracing water network analysis and display it digitally for decision making, sharing information for other sectors and etc. ArcGIS implementation has benefit in a water utility, in a way that it is naturally based on location for the infrastructures such as distribution and collection networks, customers, facilities, service areas, pressure zones, and crew locations (Esri, 2014). A key element of the information used by utilities is its location relative to other geographic features. GIS technology that offers the combined power of both geography and information systems is an ideal solution for effective management of water industry infrastructure (Shamsi , 2005).

Therefore, the objectives of this study was to develop GIS based geometric modeling for water pipeline infrastructures for Adama Town. The study start with requirement analysis that meets the need of the Enterprise and GIS and followed by geodatabase design phases on the basis of ESRI geodatabase design. Using, Adama Industrial Area as a prototype the geodatabase is populated to build geometric network and the efficiently of the model is tested by different scenarios using network tracing analysis. Finally, the configuration of pipeline is identified by the model and suitable site for placement of gross water meter is selected by fuzzy overlay analysis, and recommended for the whole city in the future.

1.2 Statement of the Problem

Adama Town is one of the most growing regional urban in Ethiopia. Following the growth (development) of the Town, urbanization is also taking place dynamically in the Town. To make sustainable development of the Adama Town it needs a full filled infrastructure management such as; water supply, road networks, electric utilities, etc. Currently, Adama Water Supply and Sewerage (AWSSE) is supplying water for people of Adama Town. To supply water for the people of the City, the Enterprise has utilized and installed water utilities infrastructure such as; valves, pipelines, fire hydrants, reservoirs. However, the Enterprise has absence of well-organized geodatabase for existing water pipelines infrastructure to manage the existing assets and there is no well-documented information both spatially and non-spatially of these infrastructures that may help to identify the location at which these assets are found and their detail, which needs maintenance. As a result, the Enterprise where unable to have the appropriate location for Gross water meter to manage water leakage and illegal installation. In addition, the Enterprise fails to handle the maintenance issues both at the immediate and annual time scale. Most of the City water pipelines infrastructures installations known by persons that installed it before. This had to bring a great problem (challenge) in identifying the location of those assets, especially when experts leaves the Enterprise. Besides, the configuration of these existing water pipelines is not known to resilience the affected customer. This has led the Enterprise to fail in handling and managing water utility infrastructures.

As information sourced from Mr Hassein Ture, the Enterprise's team leader by interviewing on the date 23/08/2011 E.C in his office, there is lack of Geodatabase. The Enterprise were facing the following problems; 1) the spatial detail or location of all the water network pipelines are not known and they are known on the site only by the expert that installed the pipelines, 2) the spatial detail of pipeline water network to individual customer is not known, 3) the Enterprise is unable to control the amount of total water utilized because of non-existence of Gross water Meter that controls total amount of water utilized by individual customers within the same distribution pipelines, 4) Illegal use of water by some customers by installing/connecting pipeline to their home before their own meter, 5) Unable to plan maintain water network pipelines. The Enterprise has CAD files of infrastructures such as; valves, pipelines, fire hydrants, reservoirs. In Addition, water networks infrastructures of the Enterprise has no well design geodatabase and don't have the location and spatial information of gross water meters and customers meter that are used to measure the amount of water used. Also, there is no well documented information about these water network infrastructures (Appendix-A). The essential difference between GIS and CAD is the handling of the spatial aspects rather than the non-spatial aspects (Pilouk, 1996). Besides, The Enterprise fails to manage and handle these assets because of the absence of spatial detail and well-documented information of these existing water pipeline infrastructures.

Lack of systematic communication among service providers among construction while installing their infrastructures, one service provider damages the infrastructure of the other. This causes the service providers to disrupt their services to society and not to meet their service goals and incur high maintenance costs (Debela Z. M., 2015). By applying modern tools in the system, the existing problems will be minimized and give one step ahead for the making of the smart city (D. Babubhai and B. Vijaykumar, 2017). Data handling of the Enterprise was creating confusion about the data files' relevance and management of data files has constrained information for the stakeholders, due to their inabilities to capture and store large amounts of an attribute. Nowadays, sub-surface infrastructures of service providers expand continuously and unless geospatial information of utilities is also updated accordingly, it will be unsuitable for decision-making. The specific person only knows pipelines that distribute to individual customers, which causes the gap in infrastructures locations and spatial information. Finally, unwell-document of water pipeline infrastructure comes with gap of management of spatial and non-spatial data, and also not well planned in immediate and annual.

1.3 Objective of the study

The general objective of this study was to develop GIS based geometric network model of water pipeline for the study area.

The specific objective of this study was to:

- build geometric network model for water pipe network infrastructure.
- test the model by using different scenarios.
- identify the configuration water pipeline.
- determine Gross water meter sites that control the amount of water resource in a specified pipeline.

1.4 Research Questions

1. What are the requirements for developing geometric network model?
2. How much efficient is the geometric model?
3. What is the configuration of water pipelines network infrastructures?
4. Which sites are suitable for Gross Water Meter Placement?

1.5 Significance of the Study

- ***The Enterprise*** know the detail information about water utilities, such as type of material used, utility locations, installed date, up-to-date, etc. daily work activities of the utility assets by more effective and efficient by using developed Geometric Model of Water Pipeline Distribution. Additionally, know how many customs affected when one valve closed and plan how to resilient-affected customers based on maintenance and operation time duration (short-time, long-time) by using developed geometric network model.

- ***Service providers*** can enable to access asset data quickly and efficiently by save time, money and effort and improve on-site safety and protecting sub-surface/underground assets from accidental damage. The developed model help to optimize the engineering design and analyses to greatly assist in the understanding of the network behaviour and identifying the critical zones in the network.

- ***The enterprise*** use the developed model to identify problems (in case of pipe breakage, service areas) in the system followed by quick solutions to optimize network maintenance work, and provide a framework for continuous improvement.

- ***The Enterprise*** storing information in ArcGIS software; these techniques was become saved time and cost when researching the existing water pipe information to employers and clients and more effective to up-to-date daily activities.

- Based on the findings of these study ***stakeholders and subsequent researchers*** can be used to decide to alleviate the water scarcity problem in the study area.

1.6 Scope of the Study

This study was delimited to cover in Adama Town and validated the model as prototype specifically in kebele 05 around Adama Industry Area (AIA) because of the availability of data required for the study. Also, the study wide width contents including requirement analysis, design model water for water pipeline infrastructures, developed water geodatabase model for Adama Town, populate the collected primary and secondary data (such as; GPS data, CAD, Parcel ID, image, etc.) to geodatabase, developed geometric network model, test the model, identified the configuration of pipelines and select suitable place for placement of Gross Water Meter.

1.7 Limitation of the study

In this study, certain limitation have been encountered. One of this limitation were during secondary data collection the AutoCAD obtained from the Enterprise doesn't constitutes water pipelines infrastructures network of selected prototype area. So, this limitation is overcome by collecting the spatial location of these water pipeline infrastructures network using Garmin 60CSx handheld GPS. The other limitation was, the spatial location of water pipeline infrastructures are collected using handheld GPS with accuracy of ±3m. So, to overcome the variation in or shift in position of those features, their spatial distribution were cross checked by overlaying with aerial orthophoto of Adama Town of resolution 10cm.

1.8 Thesis Organizations

This thesis is presented in to five chapters. The first chapter introduction part, it includes the problem statements, research questions, significances of the study, objectives, delimitations and limitations of the study. The second chapter is literature review, and it also includes the theoretical framework, such as definition, methods; empirical framework which includes previous studies related to this study and finally, the conceptual framework developed from the existing theories and previous works to achieve the objective of the study. Third chapter materials and methods. In this chapter the overview of description of the study area, materials used and data analysis methods. In forth chapter results obtained from the data analysis to achieve the objectives of the study follows together with interpretation of results and discussion. Fifth chapter is the conclusion and recommendations for future studies based on the result of the study.

CHAPTER TWO

2. REVIEW OF LITERATURE

This chapter presents the related literature and studies after a thorough and in-depth search done by the researchers. This also presents as the theoretical, empirical and conceptual framework.

2.1 Theoretical Framework

2.1.1 Geographic Information Systems (GIS)

GIS, technology began in the 1960s, computer systems based on hardware, software, and georeferenced data that can be used to collect, store, manage, process, analyse, and visualize both spatial and non-spatial information representing real-world geographic phenomena (Shamsi U. , 2005; Burrough and Mcdonnell, 1998; Neteler and Mitasova, 2008; Stephanie R Rogers & Benno Staub, 2013). A GIS is a special type of information system in which the data source is a database of spatially distributed features and procedures to collect, store, retrieve, analyse, and display geographic data (Shamsi U. , 2002). GIS applications for the water industry did not evolve until the late 1980s. In the early 1990s, the water industry started to use GIS in mapping, modeling, facilities management and work- order management plans. By the end of 2000, approximately 90% of the water utilities in the United States were using GIS technology in some form (Shamsi U. , 2005; John, 2012).

GIS can use in typical Automated Mapping Facilities Management tasks such as planning, Engineering Design, and Fault Tracing and GIS is being used for infrastructure management, operations, and maintenance, planning and engineering, finance and administration, among other uses in water utilities (S. Mahmud and M. Shayboub, 2013). The ability of GIS to analyses a water reticulation network for efficiency, and subsequently aid planners, decision-makers and service technicians, by means of software such as a network analyst, can potentially transform an existing water reticulation system into an efficient one (Maina, 2012). The use of GIS in the water/wastewater industry may also be efficiently linked with hydraulic models and GIS is being used for infrastructure management, operations and maintenance, planning and engineering, finance and administration, among other uses in water utilities (Dangermond, 2003; Woghiren, 2005). You use the desktop applications ArcMap™ and ArcCatalog™ to view, edit, and manage your geodatabase. You use the included map templates, layers, and styles to symbolize features and create maps of your facilities for a variety of purposes. You can use all of the powerful functions in ArcGIS to build your own maps, layers, and styles, as well (Steve Grise,*et al*, 2001).

2.1.2 GIS Application in Asset Management

As mentioned in previous chapter water and water's pipeline infrastructures are assets. An information system is a framework that provides answers to questions, from a data resource (Shamsi U. , 2005). An effective asset management system can reduce the cost of system operation and maintenance (O&M) and also modern management practice requires a full knowledge of the infrastructure assets, including not only attributes, but also location in a geospatial frame and the relationship among all those components. This is clear if we know that more than 80 percent of all the information used in utilities is geographically referenced. A key element of the information is its location relative to geographic features, other objects, and established boundaries (Shamsi U. , 2005; Ramiro, 2009). Due to these, GIS has power in asset management requiring authoritative repositories to store, manage, and maintain accurate spatial and descriptive information about assets. Then GIS is one of the most powerful of all information technologies that focus on integrating knowledge from multiple sources and creates a crosscutting environment for collaboration and also GIS is a system for the management, analysis, and display of geographic knowledge, which is represented using a series of information sets (Esri, 2014).

Geographic Information Systems (GIS) have been used in various fields and disciplines to summarize and analyse spatial patterns and distributions, for the purpose of understanding how geographic and non-geographic entities interact with each other over space and time (Stephanie R. & Benno Staub, 2013). Besides Patel (2014) GIS saves time and money in developing water distribution system hydraulic models for simulating flows and pressures in the system and also helps in presenting the model results to non-technical audiences. There are three primary components used in predictive modeling for asset management. GIS is the first. GIS maintains what the asset is and where it is located. The second is a work/asset management system, which records the asset's historic information: its composition, installation details, age, past repairs, costs, etc. The third is the predictive model itself, which uses the data from the first two components for calculation and analytical purposes, as well as the subsequent plotting of asset condition degradation curves. Those plots help decision-makers visualize the condition of an asset so that they can take remedial action if necessary (Totman, 2013).

2.1.3 The Role of GIS in Water Resource Management

According to Avhad (2016) GIS play role in water utility management like the asset creation and management, infrastructure capital improvement, planning and analysis, optimizing field operations, water conservation and etc. GIS increases public awareness, stricter measures and promulgation of the latest laws in the area of water resources have created the utilization of advanced technologies indispensable; to conserve and reduce wastage of water, many people plan and regulate the distribution of water. Water resource management involves activities like planning, developing, distributing and managing the optimum use of water resources. Ideally, it should allocate water in such a way, so as to satisfy all demands for water without wastage and explains how the mapping of Water pipeline in Aurangabad city, and management using distance measure function from various sources such as utility surveys, scanned maps, CSV files etc. Beside Ganesh S Ragade, *et el* (2016) GIS is one technique to have an efficient adaptation to manipulation of spatial and non-spatial data and provide decision support system to government dignitaries and modelling of underground infrastructure is one of the most crucial among other government activities. GIS is a technology that offers data processing in appropriate forms for analysis, management and presentations of results based on different requirements (ESRI, 2015).

A GIS can locate the exact position of a utilities infrastructure such as valves, hydrants, meters, pumps, and fiber optics covers displaying them on a computerized map. It can also store important data about each utility, including manufacturer, year of installation, repair history, size volume, water quality data or almost any other type of information. Efficient management must include location information so good decisions can be made relative to the surrounding area and affected utilities. With the use of GIS in the area of utility management, it is possible to visualize and understand the geographical context of an asset and improve the efficiency of underground utility management (Debela Z. M., 2015). RS & GIS is efficient tools to such type of routing. During last decade lots of works have been done to determine optimum pipeline routing i.e. deterministic techniques, stochastic techniques implemented using GIS in literature (Ganesh S, Ajay Nagne and Bharti W., 2016). GIS provides quick answers to many issues regarding water networks such as, Provisioning of Service, Planning and Maintaining Network Infrastructure, Managing Existing Customers, Finding New Customers, Administering network Coverage (S. Mahmud and M. Shayboub, 2013). Modern management of water infrastructure should also encompass the use of geospatial information systems and the systems provide valuable data for master planning or water infrastructure rehabilitation to enable the utility manager to select, rehabilitate, renew, or remove the right component at the right time, with the right technology, and thus save money (Saegrov, 2006; Ramiro, 2009). An effective water distribution system requires adequate supply of water into the system, functional pumping facilities as well as efficient distribution network. Factors such as effective water distribution system, rapid population increase and scarce resources largely affect the prevalent water stress in mostly urban areas of developing countries (Zeraebruk *et al.,* 2014).

According FDRE Ministry of Water and Energy (2013) GIS map of the system is help full in asset management of the utility which is intern a base for implementation of sound financial system leading to full cost recovery. Preparation of GIS maps for their systems shall be either immediate or long term plan of each utility depending their capacity. This map is also major tool to have specific information for each customer like the line of connections and some more. During the preparation of maps, marker posts, which indicate the name, location and sizes of each scheme components, shall be installed on the ground aside to the element.

2.1.4 Historical Modeling Concepts of ArcGIS

According to ESRI Modeling Our World, (2003) the CAD data model, the very first computerized mapping systems drew vector maps with lines displayed on cathode ray tubes and raster maps using overprinted characters on line printers. From this genesis, the 1960s and 1970s saw the refinement of graphics hardware and mapping software that could render maps with reasonable cartographic fidelity. In this era, maps were usually created with general purpose CAD (computer-aided design) software. The CAD data model stored geographic data in binary file formats with representations for points, lines, and areas. Scant information about attributes was kept in these files; map layers and annotation labels were the primary representation of attributes. The coverage data model, in 1981, Environmental Systems Research Institute, Inc. (ESRI), introduced its first commercial GIS software, ArcInfo, which implemented a second generation geographic data model, the coverage data model (Zeiler, 2007). ArcInfo 8 introduces a new object-oriented data model called the geodatabase data model. The defining purpose of this new data model is to let you make the features in your GIS datasets smarter by endowing them with natural behaviors, and to allow any sort of relationship to be defined among features.

2.1.5 Need (requirement) analysis in GIS Environment

Steve Grise, *et al*, (2001, p. 3) water and wastewater utilities are realizing the benefits of geographic information system (GIS) technology for engineering, construction, and operations purposes. The typical requirements of these utilities reflect business needs to:

1. Update GIS databases with as-built data,
2. Produce standard and custom map products,
3. Integrate computer-aided design (CAD) drawings into the GIS environment,
4. Integrate with other enterprise systems, such as work management systems (WMSs), document management systems (DMSs), infrastructure management systems (IMSs), materials management systems (MMSs), and customer information systems (CISs),
5. Analyze installed network for capacity planning and capital improvement projects,
6. Manage operations activities, such as leaks, repairs, and inspections.

The purpose of a geographic information system (GIS) is to provide a spatial framework to support decisions for the intelligent use of earth's resources and to manage the man-made environment (Zeiler, 2007). According A. Abdul-Rahman and M. Pilouk (2008) spatial data stored in GIS by three components: geometric data, thematic data, and a link identification (ID) for the geometric and the thematic component. GIS technology that offers the combined power of both geography and information systems is an ideal solution for effective management of water industry infrastructure (Shamsi U. , 2005). Identify the enterprise needs, evaluate the system for feasibility, perform economic and technical analysis, allocate functions to system elements, establish schedules and constraints, create system definitions (Girma, 2019).

According ULGDP (2016) The Ethiopian approach to Asset Management Planning took the concept behind the Canadian approach, which was based upon the use of a step-based process, and adapted it to the needs of Ethiopian Cities. Recognizing that all approaches to asset management have a common outcome, namely the development of an Asset Management Plan, the difference with the step-based approach is that it also recognizes the need for a second outcome, which is to use the process of developing the asset management plan to grow the Cities' institutional knowledge base. This second outcome is achieved in two ways. The first is through the use of incremental learning. This means that each step of the process has a clearly defined outcome in its own right, which provides valuable information to the City Administration as well as building knowledge and understanding of each component of the wider asset management plan (Table 2.1). The second is by ensuring that information, once gathered, is retained. Here the step based approach encourages Cities to think about how they will store the information collected so that it will be available for future use. Together these provide the basis for institutional knowledge for urban infrastructure. And this knowledge in turn can then be used to provide added value to the wider urban spatial and economic development of the City.

Table 2.1 Water Utility Entities and Its Relation

Entity	Spatial Type	Arcinfo Type
Pump	Point	Object
Meter	Point	Point Feature
Meter Box	Point	Point Feature
Valve	Point	Simple Junction
Water Main	Line	Complex Edge
Treatment Plant	Point	Complex Junction

2.1.6 Coordinate Systems

Consider a standard topographic map, which actually has three different coordinate systems marked on it. The corners are marked with degrees of latitude and longitude, meters and feet which are representing Geographic Coordinate System (GCS), Universal Transverse Mercator (UTM), and State Plane Coordinate System (SPCS) respectively. Any location on the map can be represented by three different *x*-*y* pairs corresponding to one of the three coordinate systems. Developed geodatabase projected coordinate system is a system that defines locations on a flat map based on x, y coordinates, the x, y coordinates of any given point depend on the map projection, the units of measure (meters, feet, or whatever), and on which point the map is centered. To understand how certain map projections work, you will also need to know how geometric objects are used to construct a flat map.

Imagine a piece of paper being shaped to fit against a lighted globe in three configurations: a cylinder, a cone, and a flat plane (see the graphic). A cylindrical projection is possible when a cylinder is used, a conic projection when a cone is used, and an azimuthal projection when a flat plane is used (ESRI, 2015). This study adopted ESRI common projections used in ArcMap are the state plane and universal transverse Mercator (UTM) systems. The State Plane Coordinate System (SPCS) divides each state into manageable regions for large-scale mapping and bases it on three projections: Lambert conformal conic, transverse Mercator, and oblique Mercator.

The UTM system divides the world into 60 zones; each one is 6° and designated by a number and a letter N (northern hemisphere) or a letter S (southern hemisphere) (Girma, 2019). The UTM system works best for maps that include small areas that are entirely encompassed by a zone. It attempts to minimize distortion, is useful for mapping areas that extend in a north-south direction, and provides a standardized method for projecting data (appendix-C). Depending on the geographic location of your data, a suitable map projection is most likely available in ArcMap. You can locate the coordinate system of a dataset in ArcCatalog, on the Description tab (to view its metadata). You can also find it in ArcCatalog on the feature Properties dialog box (right-click a feature class and click Properties), on the XY Coordinate System tab. In ArcMap, you can find it on the Layer Properties dialog box, on the Source tab. alternatively, find coordinate system information for a data frame in ArcMap by clicking the Coordinate System tab on the Data Frame Properties dialog box.

2.1.7 File Geodatabase in ArcGIS

File Geodatabase is; single-user and small workgroups, many readers or one writer per feature dataset, stand-alone feature class, or table. Concurrent use of any specific file eventually degrades for large numbers of readers see the detail in Table 2.2 comparison Geodatabase. Geodatabase used to organize geographic data into a hierarchy of data objects; those data objects are stored in feature classes, object classes, and feature datasets. A feature class is a collection of features with the same type of geometry and the same attribute. An object class is a table in the Geodatabase that stores non-spatial information and a feature dataset is a collection of feature classes that share the same spatial reference. Feature classes that store simple features can be organized either inside or outside a feature dataset. Simple feature classes that are outside a feature dataset are called standalone feature classes. Feature classes that store topological features must be contained within a feature dataset to ensure a common spatial reference (Sherbrooke, 2008).

Geodatabase model is a new data model allowing smarter features to be made in the GIS dataset by endowing them with natural behaviours and allowing relationships to be defined among features. The geodatabase model contains many benefits over prior GIS data formats:

- A uniform repository of geographic data in a central database
- Increased accuracy in data entry and editing using validation rules

- Data objects are more intuitive instead of generic features
- Features have a richer context by relating to other features
- Better mapping products by adding intelligent behaviour
- Dynamic features in a map display by custom queries or analytical tools
- Better defined feature shapes using many options
- Continuous features by accommodating large sets
- Edit data simultaneously (Zeiler, 2007; ESRI, Geodatabase, 2018; Girma, 2019).

There are three type of geodatabases; which are personal geodatabase, file geodatabase and enterprise geodatabase see below Table 2.2 comparison of geodatabases source Esri documentation

Table 2.2 Comparison the three types of Geodatabase (ESRI, 2018)

Key characteristics	Enterprise geodatabase	File geodatabase	Personal geodatabase
Description	A collection of various types of GIS datasets held as tables in a relational database (This is the recommended native data format for ArcGIS stored and managed in a relational database.)	A collection of various types of GIS datasets held in a file system folder. (This is the recommended native data format for ArcGIS stored and managed in a file system folder.)	Original data format for ArcGIS geodatabases stored and managed in Microsoft Access data files. (This is limited in size and tied to the Windows operating system.)
Number of users	Multiuser: many readers and many writers	Single user and small workgroups: many readers or one writer per feature dataset, stand-alone feature class, or table. Concurrent use of any specific file eventually degrades for large numbers of readers.	Single user and small workgroups with smaller datasets: some readers and one writer. Concurrent use eventually degrades for large numbers of readers.

Storage format	• Oracle • Microsoft SQL Server • IBM DB2 • IBM Informix • Postgre SQL	Each dataset is a separate file on disk. A file geodatabase is a file folder that holds its dataset files.	All the contents in each personal geodatabase are held in a single Microsoft Access file (.mdb).
Size limits	Up to DBMS limits	One TB for each dataset. Each file geodatabase can hold many datasets. The 1 TB limit can be raised to 256 TB for extremely large image datasets. Each feature class can scale up to hundreds of millions of vector features per dataset.	Two GB per Access database. The effective limit before performance degrades is typically between 250 and 500 MB per Access database file.
Versioning support	Fully supported across all DBMSs; includes cross-database replication, updates using checkout and check-in, and historical archiving	Only supported as a geodatabase for clients who post updates using checkout and check-in and as a client to which updates can be sent using one-way replication.	Only supported as a geodatabase for clients who post updates using checkout and check-in and as a client to which updates can be sent using one-way replication.
Platforms	Windows, UNIX, Linux, and direct connections to DBMSs that can potentially run on any platform on the user's local network	Cross-platform.	Windows only.

Security and permissions	Provided by DBMS	Operating file system security.	Windows file system security.
Database administration tools	Full DBMS functions for backup, recovery, replication, SQL support, security, and so on	File system management.	Windows file system management.
Notes	Requires the use of ArcSDE technology; ArcSDE for SQL Server Express included with • ArcGIS Desktop Standard and Desktop Advanced • ArcGIS Engine • ArcGIS Enterprise Workgroup ArcSDE for all other DBMSs included with ArcGIS Enterprise	You can optionally store data in a read-only compressed format to reduce storage requirements.	Often used as an attribute table manager (via Microsoft Access). Users like the string handling for text attributes.

Beside Kufoniyi (1998) database design and creation is one of the fundamental process in every GIS work executed. It is the process by which real world entities and their relationships are analysed and modelled in order to solve specific problems and find solution to questions of interest. A database is designed to service the need of a group of users. Such needs are called the information needs of the users or the user requirements. The heart of a geographic information system is a well-structured database i.e. spatial database. The process of designing a database is called data modeling. The design phase consists of three levels, i) Conceptual Design, ii) Logical Desig, and iii) Physical design (Kufoniyi, 1998). Figure 2.1 shows phases in database design and inside Geodatabase respectively. It gives a breakdown of the design phase to include conceptual, logical and the physical designs, while the construction phase is as a collector of the logical and physical designs data stored in the spatial database.

This is the presentation of human conceptualization of reality in a simplified manner to meet the information requirement of the application (Kufoniyi, 1998). The objective is to determine the basic entities, the spatial relationships among the entities and the attribute of each entity that support the process and application for which the database is designed. Conceptual design is a modeling of the projected system that is independent of implementation of the data method that is to be used for the conceptual modeling and it must enable analyst to express the structure of information in the system (data type and relationship). It is an arrangement of human conception of reality and is decided by the human on how to present it in a simpler manner but still will satisfy information required of the GIS concerned. One of the following three types of representation scheme is adopted, these are;

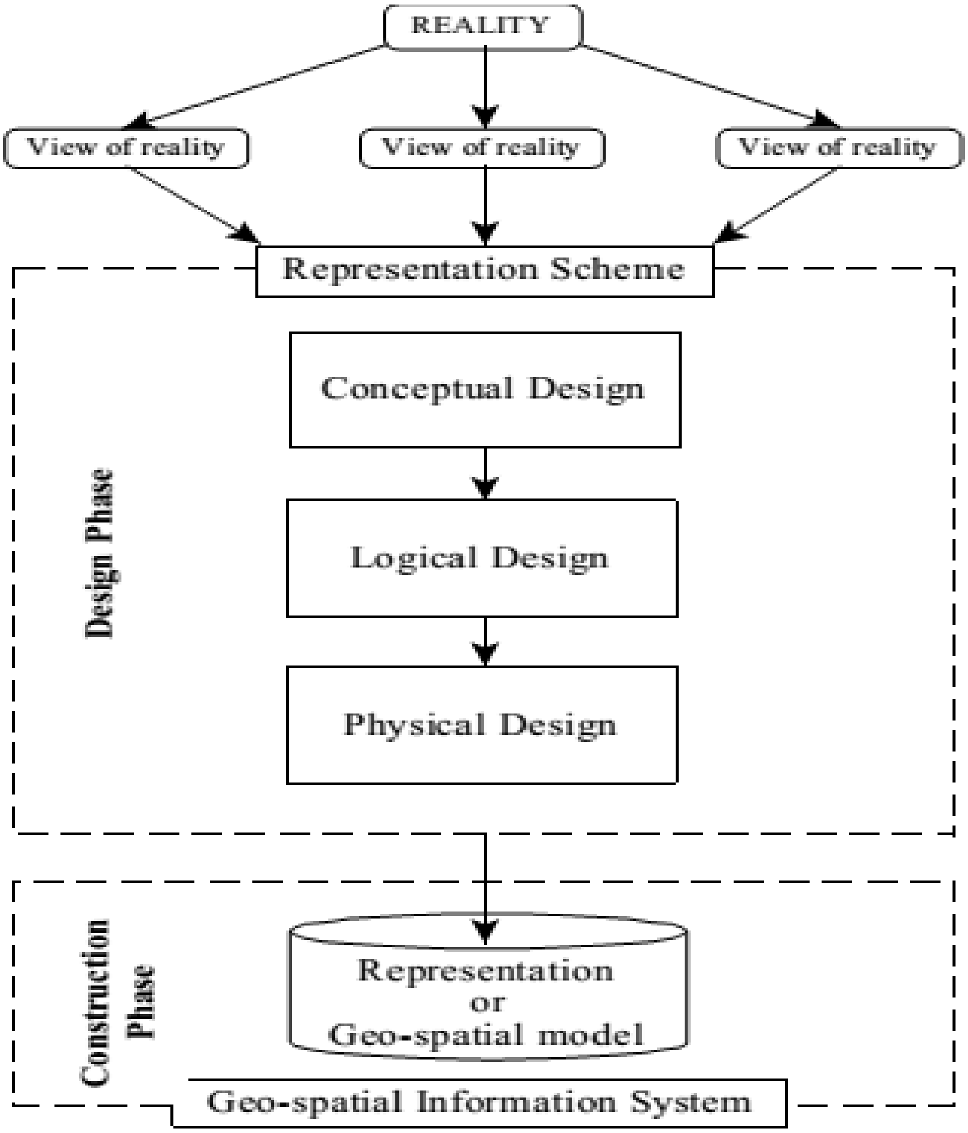


Figure 2.1 Data design phase sourced (A. Abdul-Rahman and M. Pilouk, 2008)

2.1.8 Building Geometric Networks Model in ArcGIS

A geometric network is a set of connected edges and junctions along with connectivity rules that used to represent and model the behaviour of a common network infrastructure in the real world. Geodatabase feature classes used as the data sources to define the geometric network. You define the roles that various features will play in the geometric network and rules for how resources flow through the geometric network. Geometric networks offer a way to model common networks and infrastructures found in the real world. Water distribution, electrical lines, gas pipelines, telephone services, and water flow in a stream are all examples of resource flows that can be modelled and analysed using a geometric network (ESRI, 2006). Models also allow engineers to quickly assess the distribution network during critical periods such as treatment plant outages and major water main breaks (Shamsi U. , 2002). Even failure of an asset is a data point. As a result, every water main break, every pavement analysis, every electric conductor outage is an opportunity to collect data about why it failed, which allows the continued refinement of the predictive model, increasing both its accuracy and usability (Echelai, 2016). Same of ArcGIS tools used for building geometric networks utility network analysis, water utility network editing, water utility report etc. see Figure 2.2.

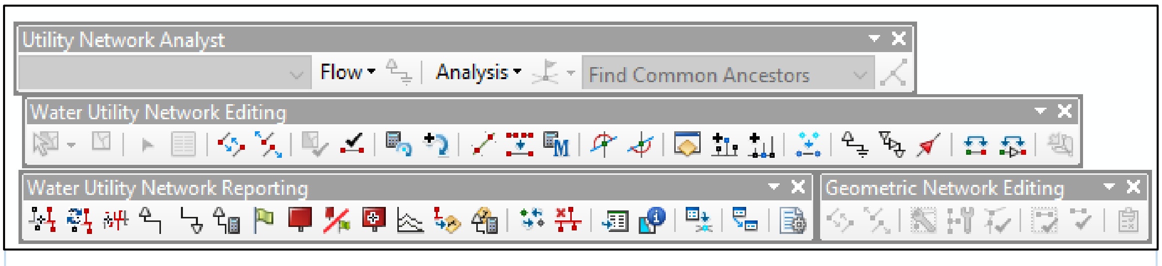


Figure 2.2 ArcGIS tools Used for Water pipelines Infrastructures Geometric Network

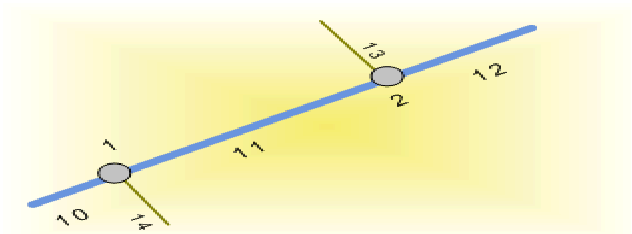
According Totman (2013) there are three primary components used in predictive modeling for asset management; GIS is the first, GIS maintains what the asset is and where it is located. The second is a work/asset management system, which records the asset's historic information: its composition, installation details, age, past repairs, costs, etc. The third is the predictive model itself, which uses the data from the first two components for calculation and analytical purposes, as well as the subsequent plotting of asset condition degradation curves. Those plots help decision makers visualize the condition of an asset so that they can take remedial action if necessary (Table 2.3).

Table 2.3 Benefits from Each Kind of Analysis (Source; ESRI, 2019).

Analysis	**Application**
Calculate the shortest path between two points.	Various kinds of utility companies use this as a method of inspecting the logical consistency of a network and verifying connectivity between two points.
Determine flow direction of edges when sources or sinks are set.	Managers or engineers can see the direction of flow along edges, and ArcGIS can use the flow directions to perform flow-specific network analyses.
Trace network elements upstream or downstream from a point.	Water utilities can determine which valves to shut off when a pipe bursts.

Calculate the shortest path upstream from one point to another.	Environmental monitoring stations can hone in on a source of pollution in streams.

Geodatabase feature classes used as the data sources to define the geometric network. Geometric networks offer a way to model common networks and infrastructures found in the real world. Water distribution, electrical lines, gas pipelines, telephone services, and water flow in a water pipe networks are all examples of resource flows that could be modelled and analysed using geometric network (ESRI, 2006; A.R.AYAD, *et al*, 2014) (Figure 2.3). GIS is used to provide graphical display of results obtained from both hydraulic simulation, and optimization models; linking tabular data with geographic locations, and graphical drawing (Sherbrooke, 2008).



Water junction fittings (Points)

OID	Shape	Equip ID	Valve Type
1		816-32	T203
2		816-45	Y53

Water mains (Lines)

OID	Shape	Diameter	Material
10		8	Concrete
11		10	PVC
12		8	Concrete

Water services (Lines)

OID	Shape	Service ID	Material
13		1001	Cast iron
14		1002	Copper

Figure 2.3 Water Geometric Network (sourced ESRI, 2006)

2.1.9 Isolation Valve and Maintenance

The process of identifying the nearest valve when there is a problem in the pipeline is valve isolation. Isolation valves are designed to start and stop the flow of water within the distribution network (and isolate portions of the network for maintenance or repair). Isolation valves are the predominant type of System Valve installed in a distribution network. They are commonly intended to be either fully open or fully closed. They are not intended to throttle flow by being partially open. A system valve is a facility that is fitted to a pipeline or orifice in which the closure member is either rotated or moved transversely or longitudinally in the waterway so as to control or stop the flow. System valves are used to regulate pressure, isolate, throttle flow, prevent backflow, and relieve pressure. System valve types include Gate, Plug, Ball, Cone, and Butterfly. These specific types may be classified as isolation valves (Steve Grise, *et al*, 2001). According to Wilke (2018) isolation valves are non-modulating valves that are used to section off or partition a distribution grid or pipe within a common pressure zone. Applications may include maintaining seasonal water supply regimes and limiting the risk posed by threatening water mains see Table 2.4.

Table 2.4.The annual maintenance service year (ULGDP, 2016)

Component	Service Year
Reservoirs	60
Water Treatment Plant	50
Water Pipeline	35
Pumps	10
Meters And Gauges	8

The separation provided by Isolation valves is significant in the way it alters the water circulation through a pressure zone. Additional intermediate line valves are required between grid connections, such that any single shutdown segment will be no more than one block or 500 feet (150m) in length, whichever is less, except in single family land use zones (Wilke, 2018) see Figure 2.4.

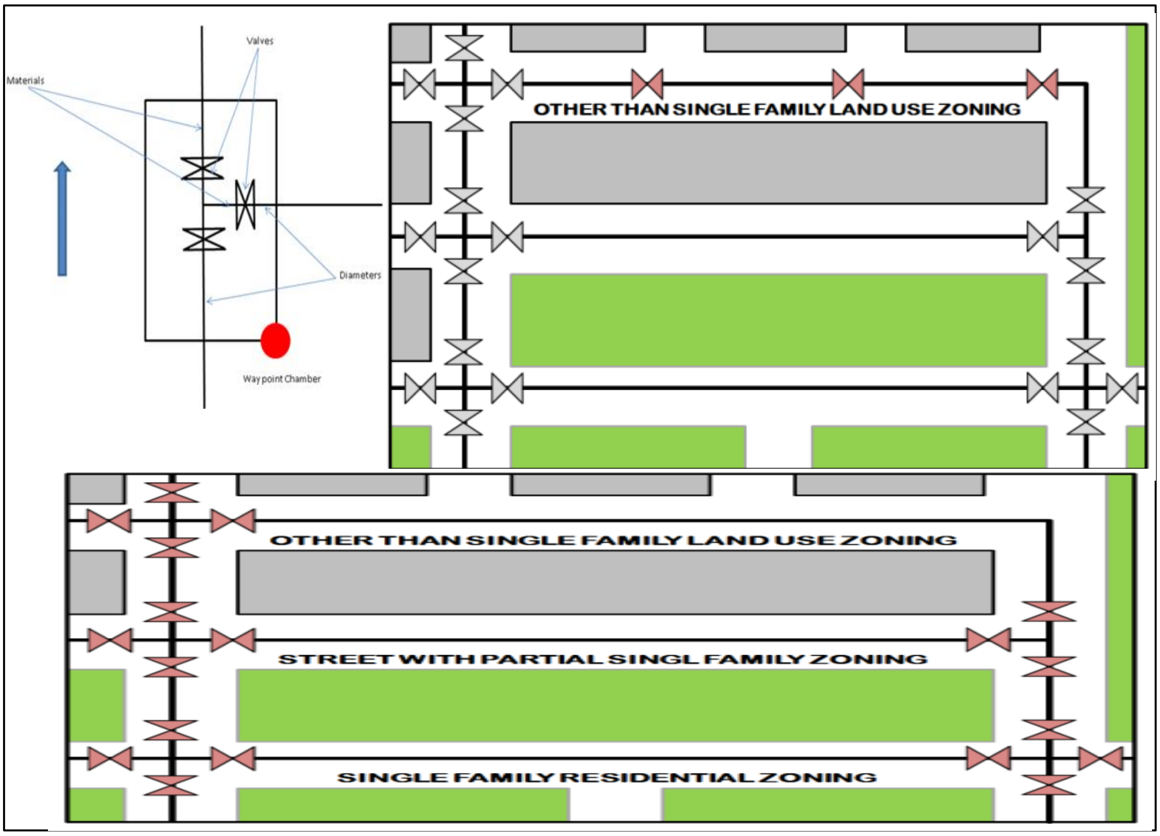


Figure 2.4 Intermediate valve sourced (Wilke, 2018)

According W. Meehan, *et al* (2012) leak detection and outage management. Using GIS, you can identify, isolate, and map areas of concern during a leak or outage. With a map interface, organizations can select valves or structures that need to be closed, referred to as a valve isolation trace, in order to separate a leak area from the rest of the network to mitigate loss. Organizations can also use GIS to trace the network to specify parcels and associated customers downstream of a main break, create leak reports for use in notification and pilot relight activities, and reroute resources to ensure that the number of people impacted by an outage is as small as possible. A GIS database can also be used to catalogue and analyse all system leaks to create a better diagnostic system for predicting leaks. The results of this analysis are used in risk assessment and integrity management planning.

While, FDRE Ministry of Water and Energy (2013) Types of leaks are surfacing leaks and Non-visible leaks, leaks that come out to the surface are called surfacing or visible leaks. They can be seen emerging from the sub-surface to the top ground or pavement. This type of leak normally finds its way through a relatively loose backfill in a trench and will probably surface at the break point. Leaks that do not come out to the surface but percolate to the surrounding ground are called non-visible or hidden leaks. Leaking water will take the path of least resistance and may not necessarily surface. The first thing to deal with leak repair is to get the water loss under control as quickly as possible by complete or partial shutdown of the line. After the leak is found, it is promptly marked with stakes or otherwise with white markers or chalks on surfaces. Shutdowns should be planned so that the area affected is kept as small as possible and the out-of-service period is minimized. Customers should be notified about the interruption and the period of time it would take to repair the break. Isolation processes are difficult and time consuming without accurate maps showing the supply network and other appurtenance in the system. An up-to-date system map with accurate valve locations and main sizes, is valuable at this time. Therefore, as-built maps and drawings of the network must be available during repair work. This helps the repair crew to locate the isolating valves so that the shutdown of the line where the leak is spotted could be done without wasting time. It also helps to avoid damage of an underground line while working on another.

2.1.10 Water Flow Network Systems

Depending on configuration of water pipelines, there are two primary types of networks: radial and looped. Stream drainage and storm drainage networks best represent radial networks. Flow always has an upstream and downstream direction that branches out/in.

Looped networks, on the contrary, frequently self-intersect. Water distribution networks are looped networks by design to ensure that service interruptions affect the fewest customers. Sewer and storm-water networks are typically radial networks, but there are often flow splits and overflow capabilities to provide additional capacity for times of peak network load. Sewer and storm-water networks are also unique because streets and pavement are specially designed to function as a secondary storm-water system during flooding and heavy rainfall (Steve Grise, *et al*, 2001).

Beside National Research Council (2006) there are two basic configurations for most water distribution systems are the branch and grid/loop. A branch system is similar to that of a tree branch, in which smaller pipes branch off larger pipes throughout the service area, such that the water can take only one pathway from the source to the consumer. This type of system is most frequently used in rural areas. Whereas, grid/looped system which consists of connected pipe loops throughout the area to be served, is the most widely used configuration in large municipal areas. In this type of system there are several pathways that the water can follow from the source to the consumer. Looped systems provide a high degree of reliability should a line break occur because the break can be isolated with little impact on consumers outside the immediate area. In addition, by keeping water moving looping reduces some of the problems associated with water stagnation, such as adverse reactions with the pipe walls, and it increases fire-fighting capability. However, loops can be dead-ends, especially in suburban areas like cul-de-sacs, and have associated water quality problems. Most systems are a combination of both looped and branched portions see Figure 2.5 below. The distribution system typically involves a much smaller geographic area, but the complexity of the network is much higher than the transmission network. Water distribution systems are considered looped networks because they are designed to provide a continuous flow of pressurized water throughout the network, even when some sections of the network are temporarily isolated for repair and replacement activities. The looping of the network also tends to provide for pressure equalization throughout the water network. Operating water system valves can isolate areas of the water network. The looping of the water mains requires fittings such as tees and crosses to connect multiple pipes at a junction. Other fittings, such as couplers, bends, and reducers, permit the connection of separate physical pipe segments (Steve Grise, *et al*, 2003).

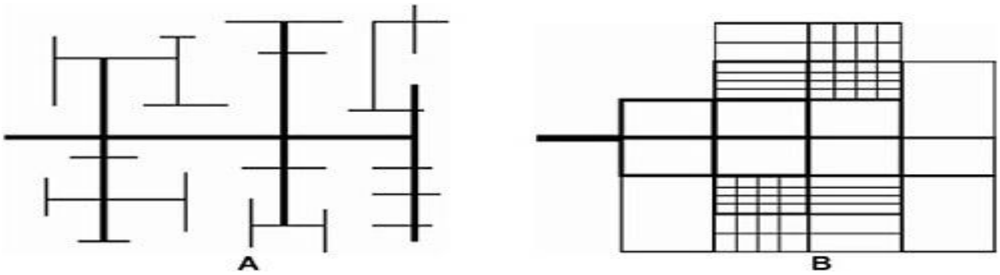


Figure 2.5 configuration of water line sourced **(**National Research Council, 2006**)**

2.1.11 Geocoding in GIS

Geocoding is the process of assigning location coordinates in a continuous, global reference system (Latitude and Longitude, for instance) to pipelines infrastructures in these case. Turning descriptive location information such as an address into an absolute geographic coordinate is generally referred to as geocoding. Geocoding is widely used in industry, for example, to enable spatial analysis of a customer base in relation to outlet planning or marketing campaigns, as well as in the public sector, for instance, to ensure that the locations of voting stations meet the legislated requirements of capacity and proximity to the voters. Geocoding large data sets of customers or voters are a process that has to be automated, and automation in turn requires the input addresses to be standardized.

The annotations (labels) shown on the source map are the most common source of attributes. The source document ID (e.g., drawing number) is one of the most important attributes that should always be captured during data conversion. Features such as valves and hydrants have unique IDs, which can be easily captured from labels (annotations) on source maps. The features without IDs should be assigned new IDs during data conversion. Some data conversion application software allow automatic ID creation during data conversion. Most source maps show pipe sizes as labels or legends, which can also be easily captured during data conversion. Geometric properties like length, area, and perimeter of features can be internally calculated by GIS and entered as an attribute (Shamsi U. , 2005).

According FDRE MUDHC (2015) to Urban Landholding Registration Proclamation No. 818/2014 Article 8, each parcel shall have a unique parcel identification code which may not be duplicated on another parcel in any urban center. For this purpose a national standard is required to assign a code for each parcel .i.e. The unique parcel identification code shall take the following form: Region code + city/town code + + Woreda code + Neighborhood code City block number + parcel number:-

a. Region code (type= Alphabetic;2 digit)

b. City/Town code (type= number;3 digits)

c. Woreda (type= number; 2 digits)

d. Neighborhood (type= number; 2 digits)

e. City Block number code (type = number ; 2digit)

f. Parcel number code (type = number; 3 digit) Total No. of digits:- 14 Example: OR001062314112 (Oromia region, Adama City, Woreda 06, Neighborhood 23, city block 14 & parcel no. 112)

2.1.12 Thematic Map in ArcGIS

The days of the slide rule are long gone. Word processors are no longer considered cutting-edge technology. Now a day, we are living in the information age, which requires us to be more than visionaries who can sketch an efficient infrastructure plan and to be excellent communicators who can keep all the stakeholders such as the public, the regulators, or the clients. New information and decision support systems have been developed to help us become good communicators. GIS is one such tool that helps us to communicate geographic or spatial information. In fact, a carefully designed GIS map can be worth more than a thousand words. Sometimes the visual language of GIS allows us to communicate without saying a single word, which is the essence of effective communication (Shamsi U. , 2005).

2.2 Empirical Framework

Steven Folkman (2018) conducted his Doctoral thesis on the title of *"Water Main Break Rates In the USA and Canada: A Comprehensive Study by Asset Management Planning Tool for Water Utilities"* based on the complex of infrastructure networks located above and below the ground this study compares and examine the water pipe distribution system of the USA and Canada. The researcher of this study himself similar survey was done in 2012 and examine in 2018 water management planning by using GIS platform. This comprehensive water main break rate study for the USA and Canada compiles the collective experience of 308 utilities, which should be used for making future pipe replacement decisions. It was the desired for the researchers and participants to offer data and analysis that utility managers, engineers and elected officials can apply to the circumstances of their own operations to facilitate water infrastructure asset management planning and pipe replacement decision making. The objective this study was to reduce operating costs, service level impacts and health risks to their customers. Highlights of the water main break study include aggregate data on pipe material break rates, the analysis of age and corrosion in failure modes, related observations on pressure, delivery demands, effects of soil corrosively, and new national metrics for pipe replacement rates and population served per mile of pipe. The comprehensive nature of this study has provided a national water infrastructure condition assessment and review comparing pipe material performance. Additionally, several national-level metrics which utilities can use for asset management benchmarking purposes are included.

American Society of Civil Engineers (2017) Grand Challenge aims to enhance the performance and value of water infrastructure by 2025 with a focus on innovation, life cycle costing and transformational change from design to delivery. The water industry has seen many types of academic surveys and studies on water main replacement programs and the benefits of asset management, condition assessment and prioritization. However, many utilities have not historically tracked all of the elements of water main break data. Over the past 20 years, most utilities have come to realize the importance of tracking all aspects of their infrastructure in a GIS-centric platform and have collected records on the types, sizes, and repair histories of their pipes. As this trend continues, more data and analysis will be available to the industry to improve water distribution system repair and replacement decision making. This comprehensive report based on statistically significant experiences from 308 utilities also draws from other relevant studies to be the most complete and authoritative study of water main break data based on pipe material. Many water utilities consider pipe breaks to be a crucial factor when deciding which pipes to replace. According to a Water Research Foundation (WaterRF) study, 75% of water utilities cited pipe breaks as a key criterion in pipe replacement decisions. Other common factors noted, were pipe age (45%), low flows (40%), condition or material type (30%), and need for pipe size changes (30%). In addition, pipe breaks in a water distribution system are one of three critical metrics that can be used to measure the degree of optimization in the system. The other two metrics are chlorine residual (measuring water quality integrity) and pressure management (measuring hydraulic integrity). Breaks reflect the physical condition of a distribution system (Water Research Foundation , 2017; Steven Folkman, 2018). Finally, this comprehensive study concluded as water main break report for 2018 surveyed a statistically significant number of utilities that have collected data on underground infrastructure and material used in water mains across the USA and Canada identified. PVC has the lowest break rate of all the pipe materials considered. Compared with the 2012 survey results, break rates for asbestos cement and cast iron pipes have increased significantly and should therefore be cause for concern for policy makers and utility officials alike. It is hoped that this study will be helpful to utility managers in comparing their experiences with the survey results and thereby make better decisions regarding possible changes in their asset management and procurement practices. Through greater understanding of the risks and issues surrounding the performance of our underground water infrastructure, utilities will be better able to manage our pipe networks and ensure their cost-effectiveness and sustainability.

Salah Muamer Aburawe and Ahmad Rodzi Mahmud (2011) study on the title of *"Water Loss Control And Real-Time Leakage Detection Using GIS Technology, Geomatics Technologies in the City Symposium, At Jeddah, Saudi Arabia."* This study stated cause of leakage of water and use of GIS in locating leakage area and also state the importance of water, is the most important natural resources for the human being and the most influence on his life in its various aspects, and with the large scarcity in drinking water experienced by most countries worldwide, the specter of drought and water shortages became overshadows on the most human societies, compounding the aggravate of this problem and its impact on the economic aspects the continued of water loss from distribution networks, requiring decision-makers take necessary measures to reduce its effects and solve it as soon as possible. Most water utilities worldwide Suffer from the problem of water loss due to its large affects rather than on operational processes of the water system, but even on the financial, social and environmental aspects. This paper covers the problem of water loss in general and the problem of leakage in the distribution networks in particular, with an explanation of its causes and its impact on various aspects of life, and a clarification of the possibility of effectively using of Geographic Information Systems (GIS) to contribute in the management of this problem. This paper will present an initial perception of an innovative method for real-time leakage detection in water distribution networks depends on the use of SCADA system for providing a real-time pressure measurements at different points on the network and analyse them using one of the hydraulic analysis software .

John (2012) conducted with the title of *"The Role Of GIS in Asset Management:Integration at The Otay Water Distict";* this study was started with the objectives; 1) to demonstrate and evaluate the integration of GIS and utility asset management, 2) to develop and implement an asset management program plan to extend the useful life of the capital assets, and 3) to develop and test a criticality analysis (composed of measures of consequence and risk of failures) for the 79 potable pumps within the district's 20 pump stations in Otay Water District (OWD). In order to achieve those objectives, methodology used for this study was start with created the database design in Visio and later exported to Universal Modeling Language (UML). The database structure was imported into an empty geodatabase. Using the account detail spreadsheet and integration concepts, Nader AlAlem and Ming Zhao created a UML diagram that was finally integrated with the existing ESRI GIS data water model. See the figure below how a feature class is linked to the abstract classes that feature class inherits the abstract class attributes (Figure 2.6).

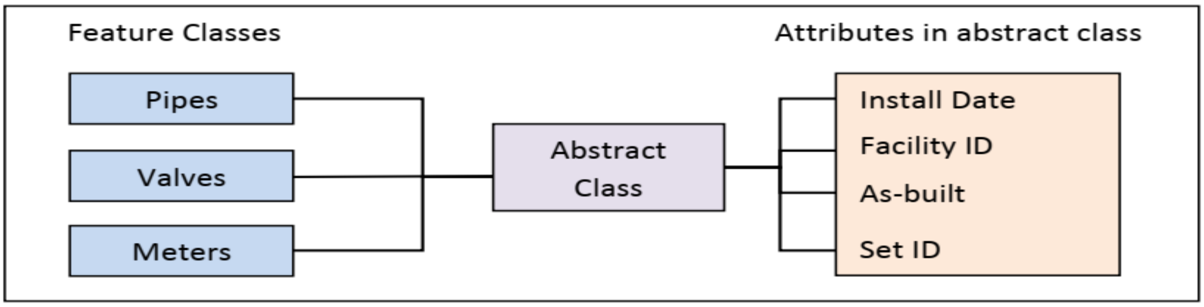


Figure 2.6 Example of how feature classes inheriting abstract class attributes. (Source: Alexander Schultz,2012)

Henriette Tamasauskas, *et al* (2009) have published journal article on *"Using GIS In Water Supply and Sewer Modelling and Management"* Geographical Information Systems (GIS) are becoming the universal backbone in most information systems managing data for water and wastewater systems. Using GIS is a great aid in graphically presenting geo-referenced information and providing the necessary tools to accurately locating needed information and linking water supply and sewer modelling systems using the spatial position as the main indexing mechanism. This ability to work with vast amounts of spatial data in a visual and easy to understand way means that otherwise slow and cumbersome processes such as building hydraulic models of water or sewer network systems can become much more efficient. This presentation will describe examples of how GIS can be a good partner for hydraulic modelling and integrating with asset management systems to form an efficient work bench for building, maintaining, and graphically presenting accurate water supply and sewer models. DHI's modelling tool MIKE URBAN combines DHI's 20 years of innovation in urban water distribution and collection system modelling with ESRI's ArcGIS technology, thus providing a complete urban water modelling environment based on GIS. Management and display of spatial data hence takes place in a GIS environment, allowing MIKE URBAN to utilize GIS features for building, maintaining and graphically presenting accurate water supply and sewer models.

D. Babubhai and B. Vijaykumar (2017) puplished journal on *"Modernization in Water Distribution System"* for the distribution of pipelines are generally laid below the road pavements, and their layouts generally follow the layouts of roads. There are four different types of pipe networks. They are: dead-end system, grid iron system, ring system and radial System. Distribution reservoirs, also called as service reservoirs, are the storage reservoirs, which store the treated water for supplying water during emergencies (such as during fires, repairs, etc.) and also to help in absorbing the hourly fluctuations in the normal water demand.

Beside Avhad, (2016) the water is that the life line for nature and human. The water wastage is main Concern across the country. The most important reason behind the water wastage is poor water system and dangerous management. Recently the importance of the management technologies for prevention will increase. There are several types of pipelines below the bottom of cities that have pipelines for waterworks, wastewater, oil, gas, electronic power, communications, energy, and so on. And these underground pipelines have totally different roles in offer the essential resources for citizens of cities and can be a lot of necessary for citizens more and more. So we call these pipelines as "LifeLine."And it is very important to manage these pipeline systems to avoid water loss. This paper presents a summary of the research and implementation works carried out by the authors in their research.

When come to Ethiopia, according to FDRE Ministry of Water and Energy, (2013) prepared manual on *"Operation and maintenance manual-Urban Component for Urban Water Utilities."* Operation & Maintenance Scenario in this country is given less attention. Due to this interruption of services, uneconomical operation of systems, and inequitable distribution of water during shortage, prevailing of water borne diseases, and prevailing of continuous shortages of water are the common phenomenon in most towns of the country. Most Utilities are not staffed with skilled and experienced personnel to operate and maintain their system. Adequate tools and equipment are not also available in most utilities. The day to day actions by most utilities are not well planned and are not according to the required standard to achieve the objective of the service. Almost all utilities in the country do not reach to the full cost recovery level. It has been observed that lack of attention to the important aspect of Operation & Maintenance (O&M) of water supply schemes in several towns often leads to deterioration of the useful life of the systems necessitating premature replacement of many system components. Some of the key issues contributing to the poor Operation & Maintenance have been identified are lack of finance, inadequate data on Operation & Maintenance, inappropriate system design; and inadequate workmanship, multiplicity of agencies, overlapping responsibilities, inadequate training of personnel, lesser attraction of maintenance jobs in career planning, lack of performance evaluation and regular monitoring, inadequate emphasis on preventive maintenance, lack of operation manuals, lack of appreciation of the importance of facilities by the community and lack of real time field information etc. therefore the most preferably method is GIS based drawings with all the required geographical, physical and capacity related etc. information included.

According to Ethiopia's Growth and Transformation Plan I (GTP, 2011-2015), which focuses on inclusive accelerated and sustained economic growth and eradication of poverty, underpins water service expansion as one of the priority growth-enhancing pro-poor sectors. It has targeted to achieve 98.5% national water supply access coverage (98% for rural and 100% for urban) by the year 2015 based on the Universal Access Plan (UAP) minimum standard. Though the country made significant strides, the target was not achieved, mainly due to the discrepancy in the original baseline which led to its rebasing, and the financing gap. According to the performance report for 2013/14 of the GTP (4th year), access to potable water supply reached 76.7% nationally, disaggregated at 75.5% for rural and 84.5% for urban areas.

As Medhin Shimelis, *et al* (2017) have published journal article on *"GIS Based Decision Support System (DSS) for Systematized Water Distribution Network Asset Management System: Case of Harar Town, Ethiopia".* Most water supply services of cities in Ethiopia are unreliable, particularly in providing an adequate amount. The reasons could be diverse and many, but the most common factors are a lack of proper operation and maintenance (O&M), and poor asset management practices of the distribution systems. These bottlenecks of service provisions have significantly influenced the overall progress of the national development, in particular, the lives of citizens. Therefore, this study aimed at alleviating water distribution related problems through providing Geographical Information System (GIS) based Decision Support System (DSS) to systematize the existing O&M method for sustainable water distribution in the Harar city. To achieve this duty, None Revenue Water (NRW) of the Harar city was analysed using International Water Audit (IWA) method. The pipe burst rate was analysed using excel based on pipe burst history data as well. Pipe risk assessment was performed based on a new approach called T-MALDP tactic, using GIS Index modeling. Sensitivity analysis was carried out for comparison. Database was prepared and suggested DSS for the water distribution O&M process. Map removal sensitivity analysis was indicated that as the amount of pipe failure factors increase, the chance of getting the riskiest pipe will increase. Applying GIS and DSS in the proposed O&M method will increase the efficiency and assist the water network management. The output of the research showed that, in order to improve the efficiency of the Harar town water network management, GIS, DSS and Hydraulic modeling based asset management is highly applicable. Applying GIS and DSS with hydraulic modeling in pipe asset management system in all zones of Harar is mandatory due to advantages of it for raising efficiency and improvement of management of water network by lowering the lost water very much. Harar water supply and sewerage service authority should make its staff to use the software package by choosing some of the expected staff to attend a training course in implementing GIS and hydraulic modeling in the field of water service. Finally, for the suggested O&M system to contribute to water conservation, it should form a part of the effective total management system in the city. Any amendment or change in the data to relate water network facility must be supported by the database system for water network so as to help the manager to manage water networks and can make a good decision on utility's asset management.

According to FDRE Ministry Of Urban Development & Construction gives the project to ARS Progetti SPA In association with MH Engineering PLC (2012) on title of *"Asset Inventory and Management Plan for Addis Ababa City Government"* with Project Reference *RFP ULGDP/ADD/C01/10IDA CREDIT NO: 4456-ET*. There are a number of individuals, working primarily in Addis Ababa Water and Sewerage Authority (AAWSA), who have learnt, or been taught, to use ArcGIS. However, they tend to work independently and create their own database structures. An example would be the way in which they define the attribute fields within the ArcGIS database. When individuals do this they generally build such structures to meet their own needs, which is not necessarily the same as building a structure to meet the needs of an organization. It also has the weakness that knowledge on how to use the data structure, as well as the GIS operating system itself, lies with individuals as opposed to the institution. In other words, there is a lack of institutional knowledge. As a result, the GIS expertise that does exist in the major organizations is continually at risk. There is the need to create a management framework for GIS that defines the protocols on its use. This requires a metadata structure; user accessibility permissions; storage systems; licensing agreements and inter-relationships with other GIS users in different operational units within the city. None of these things currently exist within the sphere of infrastructure management. Finally, AAWSA has author on managing and supplying water of Addis Ababa City water suppliers, but there is skill gap on ArcGIS database model, which was most effective, and efficient managing water utilities infrastructure.

While FDRE Ministry of Water and Energy (2013) the first thing to deal with leak repair is to get the water loss under control as quickly as possible by complete or partial shutdown of the line. After the leak is found, it is promptly marked with stakes or otherwise with white markers or chalks on surfaces. Shutdowns should be planned so that the area affected is kept as small as possible and the out-of-service period is minimized. Customers should be notified about the interruption and the period of time it would take to repair the break. Isolation processes are difficult and time consuming without accurate maps showing the supply network and other appurtenance in the system. An up-to-date system map with accurate valve locations and main sizes, is valuable at this time. Therefore, as-built maps and drawings of the network must be available during repair work. This helps the repair crew to locate the isolating valves so that the shutdown of the line where the leak is spotted could be done without wasting time. It also helps to avoid damage of an underground line while working on another.

Finally depending up on different researchers, books and reports ArcGIS software has make significant change in managing portable water pipelines infrastructures'. Finally this study conclude by implementing an asset management system using GIS; can be a very powerful tool for managing and predicting risk factors for both vertical and horizontal assets, and also asset management can be very beneficial and cost efficient for water utilities. The model generated in this study brings some immediate benefits to the AWSSE and also demonstrates the value of integrating GIS with asset management for other utilities.

2.3 Conceptual Frameworks

As mention under theoretical and empirical framework different researchers, books, reports used different methods and different results to solve the problems of for water pipelines infrastructures management. Under conceptual framework this study brief explain how the gap that the study identified and solved, which materials and method was used. GIS based geometric water pipeline network is more effective and efficient in time managements, data storage, up to dating daily activities. GIS used to organize the data for usage in water distribution networks design, and analysis. In addition, GIS is used as a tool for number of created applications for network management; such as identifying valves to be closed in case of pipe break, fire hydrants locations, and installation date.

AWSSE was responsible on supplying and managing water for the Adama Town populations, but the Enterprise have problems on handling and management data of portable water infrastructures. But, they can't automate their daily activities in geodatabase for handling spatial and non-spatial data of water pipeline infrastructures. So, to full-fill the gap of data management of the Enterprise the study selected material and develop method to achieve the objectives. Assessing primary and secondary data including literature reviews. Based on the problems and needs of the Enterprise requirement analysis was made.

Geodatabase design done through three phase; conceptual, logical and physical design phase. For validation of geodatabase prototype site was selected depend upon the availability water pipelines infrastructures. Primary data and secondary data was collected on the site and populated to geodatabase. Then, geometric network was created through connectivity rules. The develop model is tested through different scenarios.

Gross water meter (GWM) place was selected depending upon need of the enterprise. The Enterprise need to place gross water meter to control illegal usage of water. The study is select fuzzy overlay analysis to select suitable place for gross water meter.

Finally, in this study develop a model to perform network analyses by tracing pipelines utilities networks flow direction to determine which valves to shut off when a pipe bursts. And locate the exact spatial location of a water utilities infrastructure by using GIS based water pipeline utilities such as valves, fire hydrants, pipe diameters, nodes, pumps, and manhole covers and store spatial and non-spatial information about each asset, including manufacturer, year of installation, repair history, etc. see Figure 2.7.

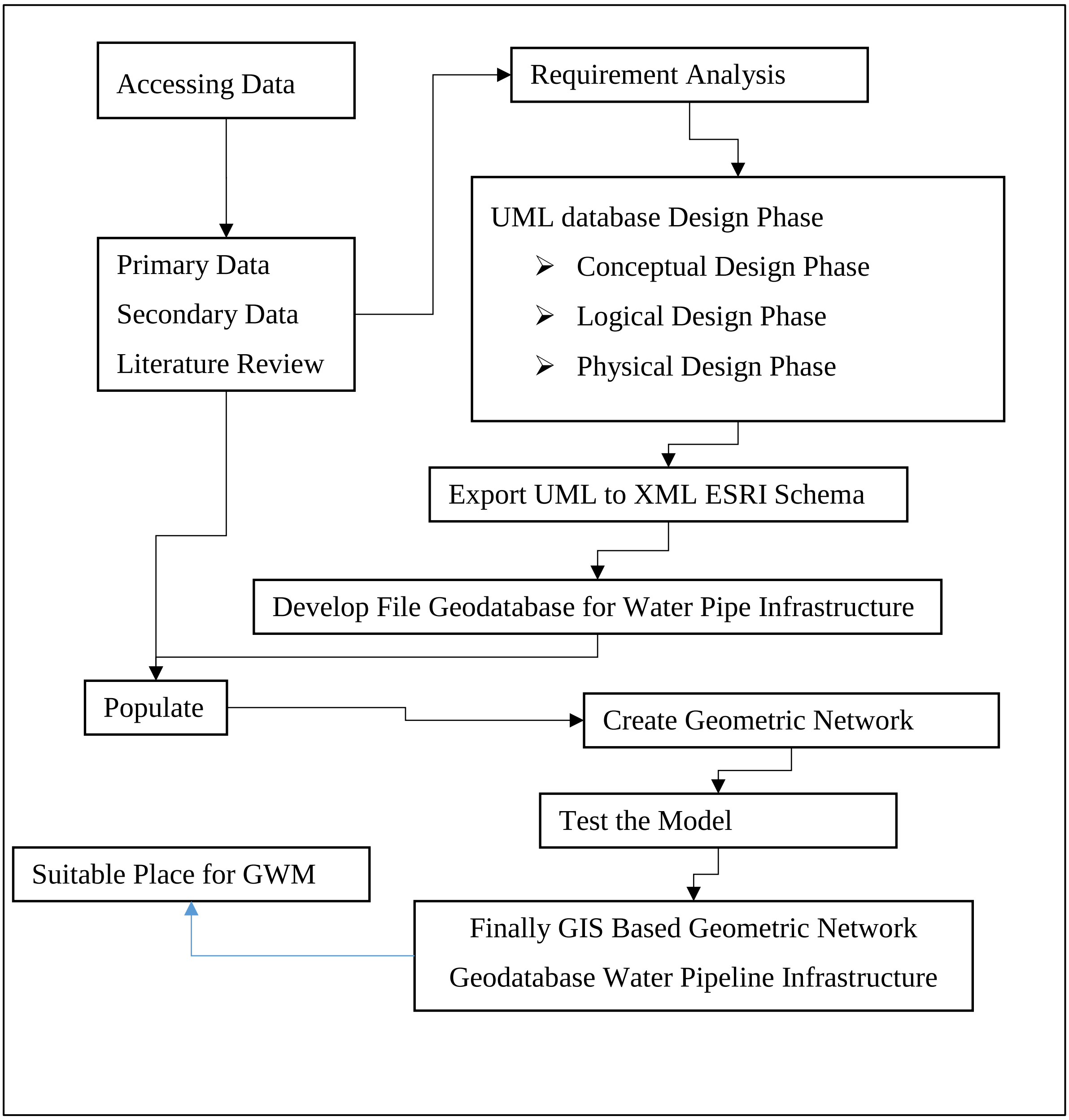


Figure 2.7 Conceptual Framework Diagram

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Introduction

In this chapter the study area was described and in order to achieve the objectives of this study select materials and develop methodology to achieve the objectives discussed in detail.

3.2 Study Area Description

3.2.1 Location and Topography of the Study Area

Adama was full fill city criteria, but the government can't give city name still. Adama is located in geographical coordinate in stretches between 8^0 35'00" to 8^0 36'00'' latitude (N) and 39^0 11' 57" to 39^0 21' 15" longitude (E). And located 100 km to the south east of Addis Ababa, capital city of Ethiopia. And also additional expressway was constructed due to this travel time from Addis Ababa (Tulu-Dimtu) to west Adama 60km which was minimized travel to 45 minutes. The City is accessible by a good asphalt road from Addis Ababa, located on the main road leading to the eastern part of the country and the Republic of Djibouti. Now a day Adama town is made up of 14 urban and 4 rural kebeles which organised under 6 sub-cities. Adama is the modern urban that has road crossing to the sea port and has a rail way line. All these natural and manmade attributes make Adama and its surroundings a base for investment in several sectors, such as hotels, recreations centres, small and heavy industries (Berhanu Keno , *et al*, 2019) (Figure 3.1).

The elevations of the Adama vary from 1,595 to 1,750 meters above mean sea level (MSL). Topography of Adama is characterized by very flat and plain of low land rounded by a lot of mountainous. Thus, because of its topographic features Area of the city is deeply deselected by numerous valleys formed by the seasonal rivers crossing the Town. These streams are irregular in nature. Areas with higher altitudes are found from the central to the northern and on the southern verges of the town (Senbeto, 2016). In 1936, the municipality of Adama was accredited only for a total area of 120 hectares ($12km^2$). Adama has shown sustainable and fast progress and in 2020 of will cover a total area of about 324 hectares ($32.4km^2$).

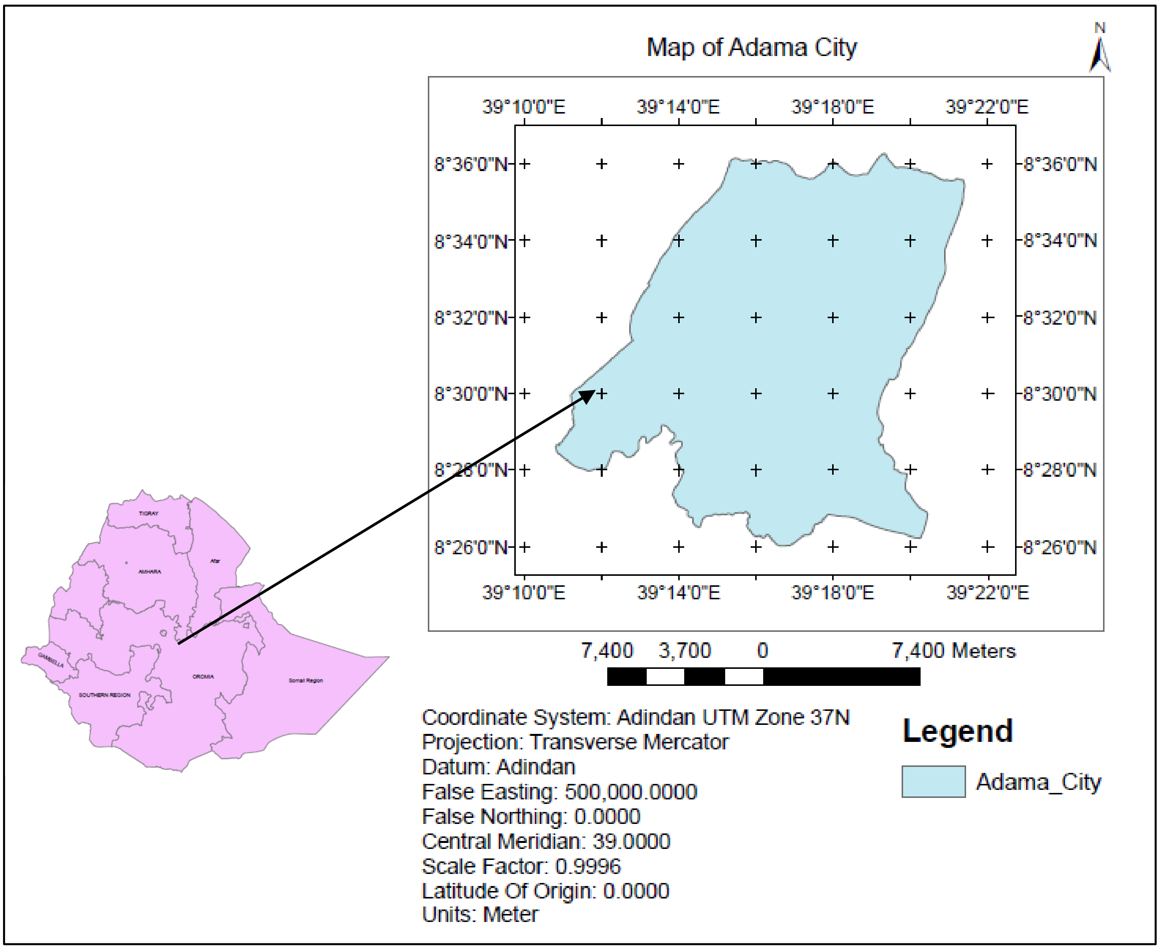


Figure 3.1 Location of the Study Area

3.2.2 Population

Based on figures from the 2007 Population and Housing Census results of Central Statistical Agency (CSA), Adama town has an estimated total population of 222,035 of whom 109,659 were males and were 112,376 females. In 1994 National Census report, this city had a total population of 127,842 of whom 61,965 were males and 65,877 were females. The total population of the city is about 351,000 in 2015 years. The demographic and population study of Adama master plan Revision project shows that the population of the City will continue to increase at a rate of 3.8% which means approximately 364,338 until the end of master plan period 2020 presented in Figure 3.2 which was sourced from CSA.

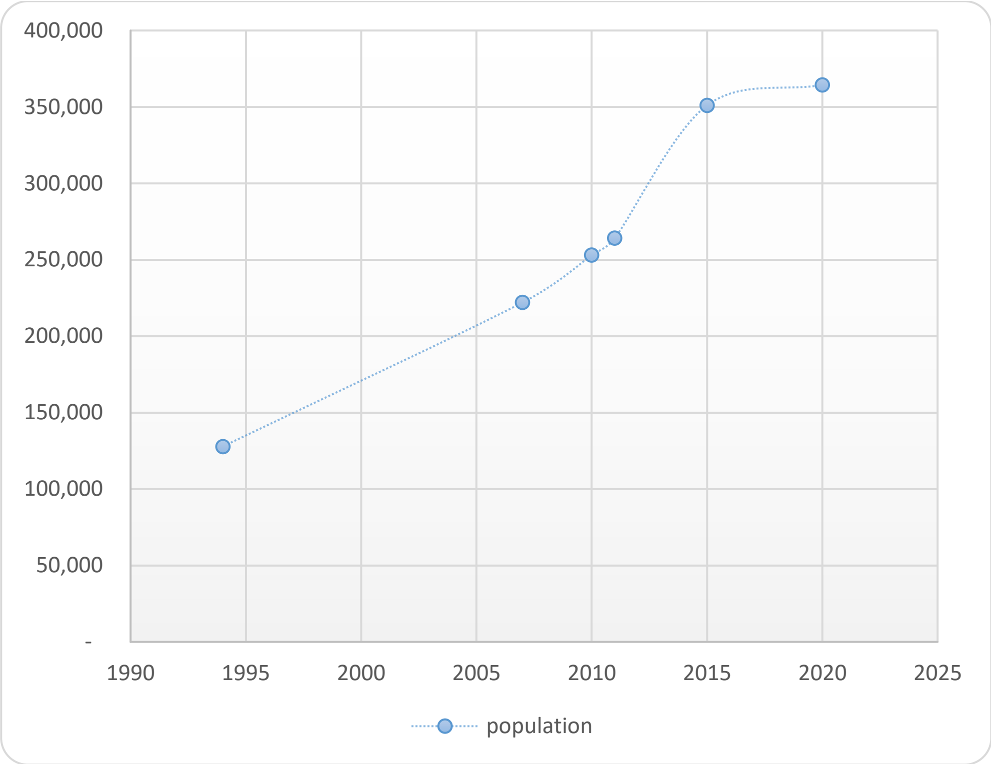


Figure 3.2 Adama Town Population Growth (1994-2020) (Source: CSA, 2019)

3.2.3 The history of Existing Adama Town Water Supply System

Adama Water Supply began in 1942E.C (1950 G.C) with the water service given by the former Ethiopian Electric Light and Power Authority (EELPA) which was started by drilling about 10 boreholes at the place called Melka Hidda in South-West of Adama Town, some 11km on the road leading down to Wenji Sugar Factory. The yield of the Melka Hidda 10 boreholes (sources) was estimated to 2.0 – 7.7 l/s at the depth of min. 36 m and max.145 m (SENBETO, 2016). As the development and population number of Adama is getting higher and higher, the Oromia Water, Mineral and Energy Bureau is also competing to keep pace with supply of clean water to the existing and projected figures. At the moment rehabilitation of existing treatment plant is underway and expected output from the improved system (to complete in 2015/16) is estimated to over 43,000 m^3/day.

In addition the study and design for the new borehole system is also completed and budget is requested for further improvement. This new system will be in service until the year 2035. It is predicted that this system will be in action in 2015/16 and may be able to deliver an estimated amount of 33,000 m^3 of clean water per day. Thus, the city will be reached by 43,000 + 33,000= 76,000m^3/day of water supply, which will be serving until the next phase takes over. Quantity of water to be distributed in the last year of 2035 can also be estimated as existing 43,000 m^3/day plus yield of the new project 143,000m^3/day.

Rehabilitation of the old boreholes is also budgeted for about 50 l/s or other source 4,320m^3/day which may give rise to a total of over 190,000 m^3/day for the then population of over one million, provided everything continues healthily. If we further accept the quantity as 200,000m^3/day it must be easier to calculate for the return wastewater provided criteria are established by the consultant, hence wastewater treatment and disposal system can easily be designed and further and detailed study, elaboration, and design is left to the consultant.

3.2.4 Weather Condition

In general, the city has sunny and windy weather conditions. Its average annual weather conditions are 21^{0}C with small amount of rain from June to September. The warmest month in Adama is May, average high temperature of 30.5^{0}C and low temperature of 14.6^{0}C. The coldest month in Adama is July with an average high and low temperature is 24.4^{0}C and 12.5^{0}C respectively (Table 3.1).

Table 3.1 Annual Temperature of Adama (Source: NMA, 2019)

Month	Maximum Average Temperature	Minimum Average Temperature
Jan	27 ^{0}C	11.4^{0}C
Feb	28.1^{0}C	12.8^{0}C
Mar	29.6^{0}C	14.3^{0}C
Apr	30.1^{0}C	15.2^{0}C
May	30.5^{0}C	14.6^{0}C
Jun	29.6^{0}C	15.3^{0}C
Jul	24.4^{0}C	12.5^{0}C
Aug	26.1^{0}C	15.1^{0}C
Sep	27.5^{0}C	14.7^{0}C
Oct	27.9^{0}C	12.3^{0}C
Nov	26.7^{0}C	10.8^{0}C
Dec	25.7^{0}C	10.6^{0}C

3.3 Data Type and Sources

To achieve the objective of this study, both primary and secondary data was collected and used which are tabulated in Table 3.2.

Table 3.2 Data Type and Its Source's

S/No	Data	Format	Data type	Source	Remark
1.	CAD file	.dwg	Secondary data	AWSSE	Shape file existing water network
2.	Adama Town parcel ID. Shape file	Vector	Secondary data	Adama Town Land Administration	To assign parcel UPID for individual customers water meter
3.	Spatial data of water pipe infrastructures data	.xlsx	Primary data	Collected on site	Location of customers water meter, valve, joints, Gross Water meters etc. Primary data collected on site
4.	Ortho-photo (10cm*10cm resolution)	Raster	Secondary data	AWSSE	To cross check spatial distribution of network

3.4 Software/Instrument

This study was used software and instrument which listed under Table 3.3 below.

Table 3.3 Software's and Instrument Used

S/N	Software/ Instrument	Version	Description
1.	ArcGIS	10.5.1	To build geometric network, to populate prototype in geodatabase, to test the efficiency of model, to select suitable site for Gross Water Meter etc.
2.	AutoCAD	2007	To use existing CAD data
3.	Handheld GPS	Garmin60	To collect the location of not up-to-dated customers water meters, valves, fire hydrant, pipelines, etc.
4.	Microsoft word, excel, e	2016	To write reports
5.	Toshiba laptop	CORE^{TM} i5	To manipulate data, to write reports
6.	Architecture Enterprise	15	To design UML model

3.5 Methods

In order to achieve the objective of this study the following systematic steps was proceeded; present requirement analysis, assessing data and database design by different studies, geodatabase design phase, built geodatabase, primary and secondary data collected and populating, and test geodatabase of the ATWSS by different scenarios was done (Figure 3.3).

3.5.1 Requirement Analysis

Requirement analysis is the first stage in any designing phase for geodatabase. Prior to geo-database design, requirement analysis was made and it was two folds. The first one is to identify enterprise need (geodatabase and placing Gross Water Meter) and secondly data requirement of GIS is identified. As discussed in chapter two sub-title 2.1.5 there are different methods of requirement analysis from those the study made through interview and observation for identification of the Enterprise needs. Manager of the Enterprise were interviewed using the interview questions prepared on the basis of the objectives of the study and problems the Enterprise is facing. Additionally, observation was made to identify the data management and handling system of the enterprise. On the other hand, data requirement of the GIS is made on the basis of Enterprise need. And, it involves; spatial reference and water network features required in design for the GIS.

3.5.2 Data Collection

Water pipelines infrastructures that the Enterprise have installed and currently giving service are identified in office. The Enterprise have CAD file of water pipelines which doesn't include all network. Due to these, this study selected prototype, the area that constitutes these water pipelines infrastructures are assessed by an expert in the Enterprise. This expert also have installed and knows the detail of these infrastructures. So, Adama Industry Area in kebele 05 was selected on the basis of above mentioned criteria and the spatial location of water pipelines infrastructures were collected by using handheld GPS. The detail of these infrastructures are assessed obtained from the expert that install before and the details of individual customer water meter is from the customers and hard-copy documented file in the office. To overcome the inconsistency in spatial location of these features due to the accuracy of handheld GPS used, they are checked by overlaying with an ortho-photo with a resolution of 10cm captured in 2016 using ArcGIS software.

3.5.3 Geodatabase Design

In this study, Geodatabase design, was done on the basis of ESRI, through three phases; conceptual, logical and physical design phase. In conceptual design phase, the features classes required for the design are identified. Following, logical design phase was made and it involves identification of attributes with the associated domains for the features identified in conceptual design phase. Then, in Physical design phase ArcGIS workspace was created and in the workspace feature classes are established and their identified attributes and domains in the logical phase are implemented. Moreover, the spatial reference identified in requirement analysis is defined for the workspace. This is done by UML (Unified Modelling Language) in Enterprise Architect software environment. A physical geodatabase model created is then exported to XML schema and imported to ArcCatalog in ArcGIS environment. This physical database includes a geodatabase with coded domain values, feature datasets, feature classes and a geometric network present for the feature data sets.

3.5.4 Populate Geodatabase

The physical geodatabase model is populated using the data collected in the field as a prototype in kebele 05 around Adama Industry Area of Adama Town. This features are populated through digitization and their associated attributes are interred using ArcGIS software. Population of geodatabase was made to build geometric network for water network feature and testing the model for the intended purpose using different scenario, discussed in succeeding section.

3.5.5 Creating Geometric Network

Geometric network, was created after all features classes are populated in feature dataset, the feature classes must already exist in the feature dataset. Connective rule was defined and used edge-junction rule applied.

3.5.6 Test the Model

3.5.6.1 Valve Isolation and Identifying Customer Affected

As discussed in chapter two subtitle 2.1.8 isolation valve, this study used ArcGIS software features of the geometric network; a network analysis, based on water flow identified and collected data on site digitalization was done following the direction connectivity for the water pipeline feature to identify the valves that have to be closed. This application is performed when there happens affected/ leakage/ maintenance/ on pipeline by assessing the nearest valve on the connected line and how many customers affected when that valve is closed. Isolating a point on the network is used to identify the valves that need to be closed to repair a leak in the main. The study assesses the placement valves with customers' served from it.

3.5.6.2 Immediate and Annual Maintenance

By using ArcGIS software tools entities (points, polylines, etc.) have own attribute table. In the attribute table, there is material type, diameter, installation years, etc. based on this, if pipeline burst maintenance crew know the material type, diameter, which valve have to be closed. And, also based on the lifespan of pipelines infrastructure the Enterprise forecast the budget to maintain it. Maintaining public infrastructure; is an ongoing process that requires both short-term and long-term planning and appropriate budgets, together the GIS, asset management system, and predictive models provide an accurate snapshot of the condition of the entire infrastructure of a city or county at any specified time, which is a key factor in the planning and budgetary processes and in many cases can help reduce costs (Totman, 2013). Based on the duration of maintenance the Enterprise find the solution for resilience the affected customer. ULGDP (2016) there are standard maintenance procedures and the components of the network do deteriorate slowly over time, and the teams responsible for pipe breakages, together with the cost of breakages, forms part of the normal maintenance budget as discussed in chapter 2 sub-titled 2.1.11 (Table 2.4).

3.5.6.3 Configuration of Water Pipelines

To identify whether the configuration of water pipeline network loop or series this study used ArcGIS software tool. This was done if, series water pipelines there is no water backflow, and loop there is water backflow when leakage or maintenance was there.

3.5.7 Selecting Suitable Site for Gross Water Meter

To control illegal use of water the Enterprise need to place water meter, due to these this study made requirement analysis. The Enterprise need to place gross water meter in where manhole and water control valves are there. So, primary data of manhole and control valve are collected on site and the collected vector data was converted to raster data by using ArcGIS software tools. Fuzzy overlay analysis, was selected for selecting suitable site of gross water meter.

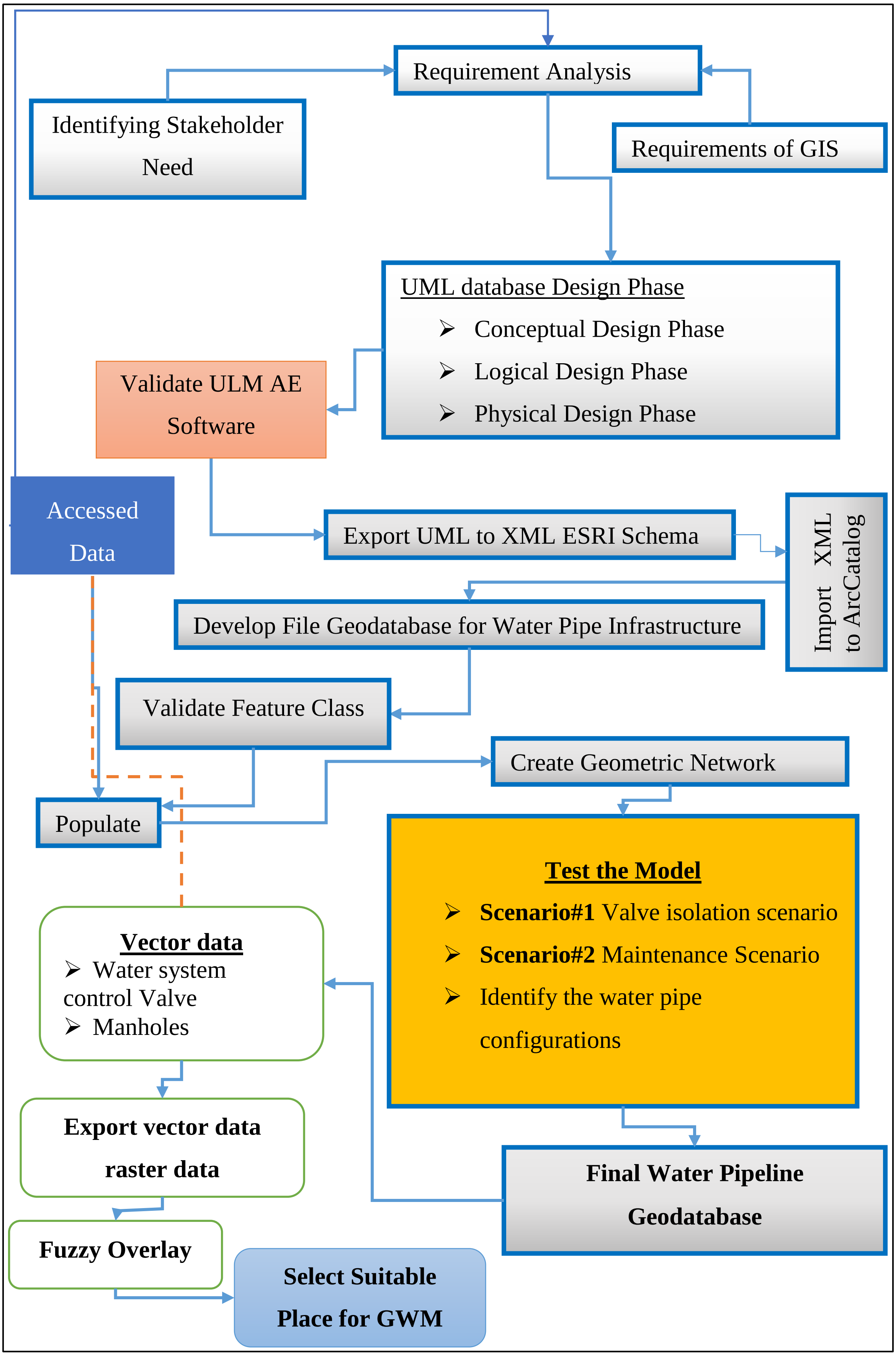


Figure 3.3 Methodological Flow Chart

CHAPTER FOUR

4. DATA ANALYSIS, RESULT AND DISCUSSION

4.1 Introduction

In order to achieve the objectives of this study as per the developed methodology, using the primary and secondary data, data analysis was made, results are obtained and discussed in detail. So, this chapter includes data analysis, result and discussion undergone to achieve the objectives of the study.

4.2 Requirement Analysis

To achieve the objective this study undergoes requirement analysis. The requirement analysis made in this study involves two folds; organization's need, and GIS needs and data requirements. The Enterprise (AWSSE) needs to manage water and water pipelines infrastructures, to identify the configuration of water pipelines and water flow direction if there is leaks, to update GIS databases with as-built and CAD data, produce standard and custom map products, integrate with other enterprise systems, manage operations activities such as; leaks, repairs, and inspections. The Enterprise needs to place the gross water meter to control illegal connection pipe and to prevent unbilled water. To secure the Gross Water Meter the Enterprise need to put where both manhole and water system control valves are there. This study selected techniques to identify requirement analysis through interview questions and observation (Appendix-A).

The other requirement analysis was for GIS to design the geodatabase model. To design, database it is the first step to identify the required parameters of spatial and non-spatial geodatabase objects. The process includes, in this study is defining the spatial reference system and identifying data required to GIS Environment.

4.2.1 Define the Spatial Reference System

In order to design geodatabase, the spatial reference systems must be defined first. The geographic reference is the spatial information including the projection or coordinate system, and datum that the agency uses for mapping display (Girma, 2019). This study adopted Ethiopian Map Authority (EMA) referencing system, which the datum chosen for best results is the Clarke 1880 modified spheroid. This study design and developed geodatabase uses UTM grid specifically zone 37 projected coordinate system spatial reference for horizontal measurements with Clarke 1880 modified datum because Adama Town locate between 36^0 and 42^0 longitude (ULGDP, 2016; Girma, 2019) (APPENDIX- B). Therefore this define the geographic reference system under physical design phase in enterprise architecture ULM. This study was set coordinate system under physical design phase in enterprise architecture software.

4.2.2 Identifying Data Required to GIS Environment

The data required for GIS to design the geodatabase model are identified on the basis of the need and requirement to the GIS environment and availability in the organization water pipelines infrastructures. This data involves water pipelines infrastructures features and they are identified on the basis of EFDR ULGDP (2016) and ESRI Data model water utilities manual infrastructures for water utilities. These data features of water utilities in the Adama Town was cross checked and validated through onsite inspection during data collection. Moreover, those features that have to be included in the model according to the ULGDP and ESRI Data model water utilities manual, but doesn't exist in the study area are also included by considering these utilities will be installed and included in the future. The water utility infrastructures data features identified are presented in Table 4.1.

Table 4.1 Water Feature Data Required for GIS

S/No	Water Feature Data
1.	Water System Control Valve
2.	Water Fitting
3.	Water Hydrant
4.	Water Lateral line
5.	Water Mainline
6.	Water Pump
7.	Water Service Connection
8.	Reservoir
9.	Individual customer water meter
10.	Manhole

4.3 Geodatabase Design Phase

In order to develop geometric network model for the water pipeline infrastructures, it needs first to develop geodatabase model that stores water network features. In this study, Geodatabase model design is done through three design phases and it involves; conceptual, logical and physical design phase. This was made on the basis of ESRI geodatabase model design. The details of these design phases are discussed in the consecutive sections.

4.3.1 Conceptual Design Phase

Conceptual design phase is the research phase of designing a geodatabase model. In this study, all the requirements for conceptual design of water pipeline infrastructure are examined and identified. It involves; classifying features based on understanding of the data required to support the organization's functions (i.e. defining geographic data entities) and deciding their spatial representation. This is done for data identified on the basis of organization and GIS needs and requirement identified in the requirement analysis.

4.3.1.1 Defining Geographic Data Entities

The geographic data entities required for GIS in designing geodatabase model are classified as feature class, which are presented in Table 4.2.

Table 4.2 Defined Geographic Data Entities for Water Feature Data's

S/N	Water Pipeline Features	Geographic Data Entity
1	System Control Valve	Feature Class
2	Water Fitting	Feature Class
3	Water Hydrant	Feature Class
4	Water Lateral Line	Feature Class
5	Water Main Line	Feature Class
6	Water Pump	Feature Class
7	Individual customer water meter	Feature Class
8	Reservoir	Feature Class

4.3.1.2 Spatial Representation of Entities

For the feature class defined in previous section, they are further broke down into point and polyline based on their spatial representation of each feature class, presented in Table 4.3.

The geographic data entities (Table 4.2) with their spatial representations (Table 4.3) are cross-checked with the ESRI water utility infrastructure manual to verify the defined geographic entity and the spatial representation and it is confirmed. Therefore, it is prepared for logical design phase in the consecutive section.

Table 4.3 Spatial Representation of Water Feature Class

S/N	Feature Class	Spatial Representation
1	System Control Valve	Point
2	Water Fitting	Point

3	Water Hydrant	Point
4	Water Lateral Line	Polyline
5	Water Main Line	Polyline
6	Water Pump	Point
7	Individual customer water meter	Point
8	Reservoir	Point

4.3.2 Logical Design Phase

Logical data model bridges the gap between conceptual and physical data model (ESRI, 2008; Girma, 2019). It involves; matching the conceptual model to ArcGIS geographic dataset, determine geometry type of discrete features and implement attribute type for objects. So, in present study this are implemented in logical design phase for the feature classes discussed in conceptual phase.

4.3.2.1 Organizing into Geodatabase Structure

For implementation in physical design phase, the feature dataset and feature classes are organized into geodatabase structure, presented in Figure 4.1.

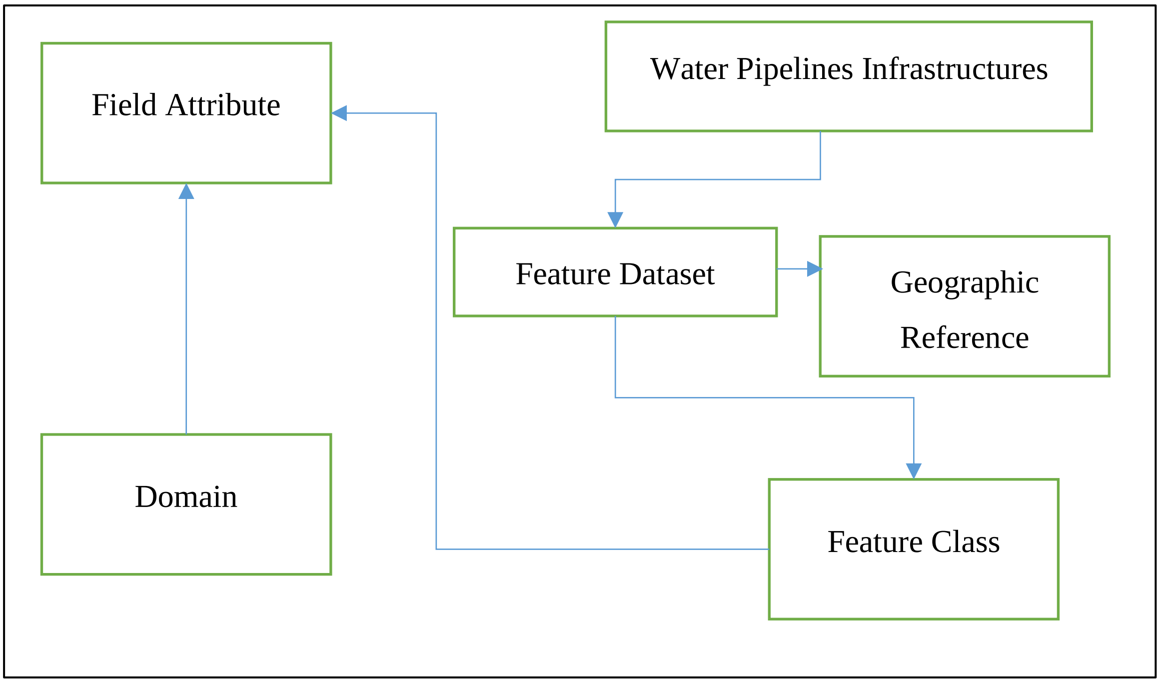


Figure 4.1 Structures of Logical Design for Water Pipelines Infrastructures

As shown in Figure 4.1, water pipelines infrastructures exists and these are included in feature datasets that store various feature classes. The advantage of having features datasets is it enables to have the same spatial reference for all feature classes. All the feature classes are included in the feature dataset and each feature classes have their own attribute with their associated domains. Therefore, the organization of the geodatabase into structure helpings during implementation in physical design phase.

4.3.2.2 Identifying Geometric Data Types and Attributes

The result of this logical design phase, which includes; attribute fields /field name/, data types, character size (length), associated domains, and field description are examined and here geometric network with other are identified. These attribute and associated domains identification was made on the basis of existing features in the study area and ESRI water utility infrastructure manual. Domains identified includes; asset manager, asset owner, water system control valve type, pipe fitting type, pipe diameter, lateral line type, water pump type, and water type. These domains are Coded value domain type. Here as an example the result for water fitting is presented in Table 4.4 and some other examples are attached as an Appendix-D in the document.

Table 4.4 Geometry Type and Attribute of Water Fitting

Field Name	**Data Type**	**Length**	**Domain**	**Description**
Shape	Geometry	-	-	Point (Default)
Facility Identifier	String	20	-	Code that identifies Water Fitting
Install Date	Date	-	-	The Date the Water fitting is installed
Fitting Type	String	50	Pip_Fitting Type	List of infrastructure Fitting Types; 90 degree, Bend, Cap, Coupling Cross, etc.
Enabled	Short	-	Enabled Domain_1	An attribute that shows the feature class is enabled in geometric network.
Active Flag	Short	-	Boolean Domain	An attribute that shows the feature class is active in geometric network.
Owned By	Short	-	Asset Owner	The owner of water fitting which includes; Private, AWSSE, Agency, other.
Managed By	Short	-	Asset Manager	The expert of the organization that manages Water fitting
Last Update Date	Date	-	-	The last date the feature is edited in the geodatabase
Last Editor	String	50	-	The person that edits the feature for the last time in the geodatabase.

Domains (Table 4.4) that associate attributes for the feature class is defined to use in attribute of the features. It offers a way to define a range of values that can be used for multiple attribute fields. Using domains helps ensure data integrity by limiting the choice of values for a particular field. The values of these attributes are known and they are defined at design stage (physical design stage), the user can select from these defined attributes during edition after population of features. For example, (Table 4.4 (fitting type)), when a user edits water fitting in the geodatabase model for water fitting type, since they are pre-determined on the basis of existing type and ESRI water pipelines infrastructures, it also used a user can simply select his fitting type when implementing the design by the drop the down list when editing. Validation for these coded value domains is accomplished by restricting field values found in dropdown lists. This means a user can only select the defined values and can't add another values to the attribute under the domain type attribute field.

4.3.3 Physical Design Phase

In physical design phase, the logical data model design is implemented into actual design of geodatabase model. ArcGIS workspace is created in Enterprise Architect UML software and it includes; Feature dataset, Domains and Spatial Reference, presented in Figure 4.2. Under feature dataset, feature classes identified in conceptual and logical phase are established and the spatial reference described in requirement analysis is defined for the dataset.

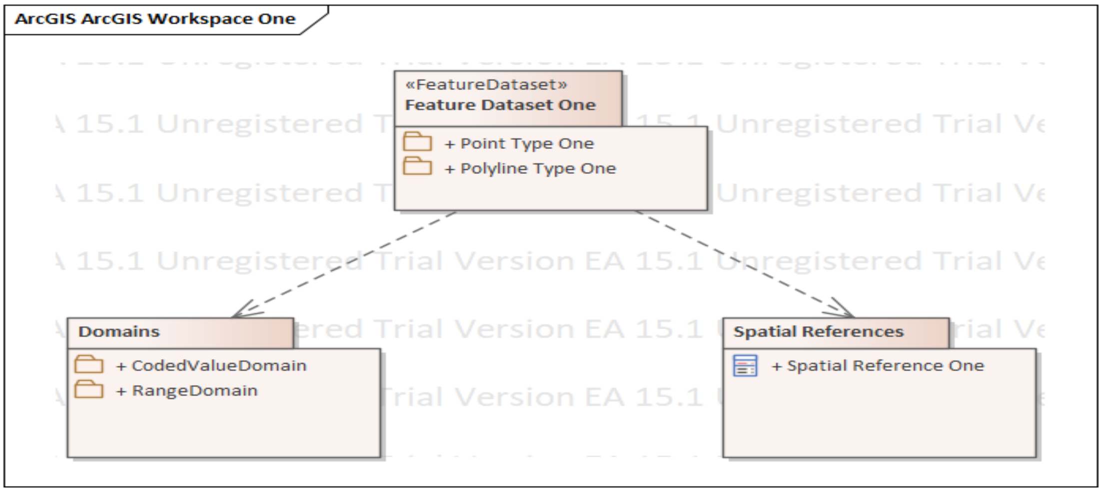


Figure 4.2 UML Physical Design Model of Water Pipeline Infrastructures

As identified under requirement analysis, conceptual and logical design phase, Figure 4.2 shows that creating ArcGIS workspace EA UML which contain feature dataset (point, polyline), domains (coded value, range) and spatial reference. Then, the identified feature class under logical design phase was entered UML with their geometric representation and their attributes. Spatial reference systems was done according to the need of stakeholders which was discussed under requirement analysis sub-type 4.2.1.

The feature class established with their corresponding attributes and domains established in EA UML are presented for water pipe fitting as a sample in Figure 4.3. Created Field Attributes with Created Domain, and for all features it is attached as an (Appedix-E).

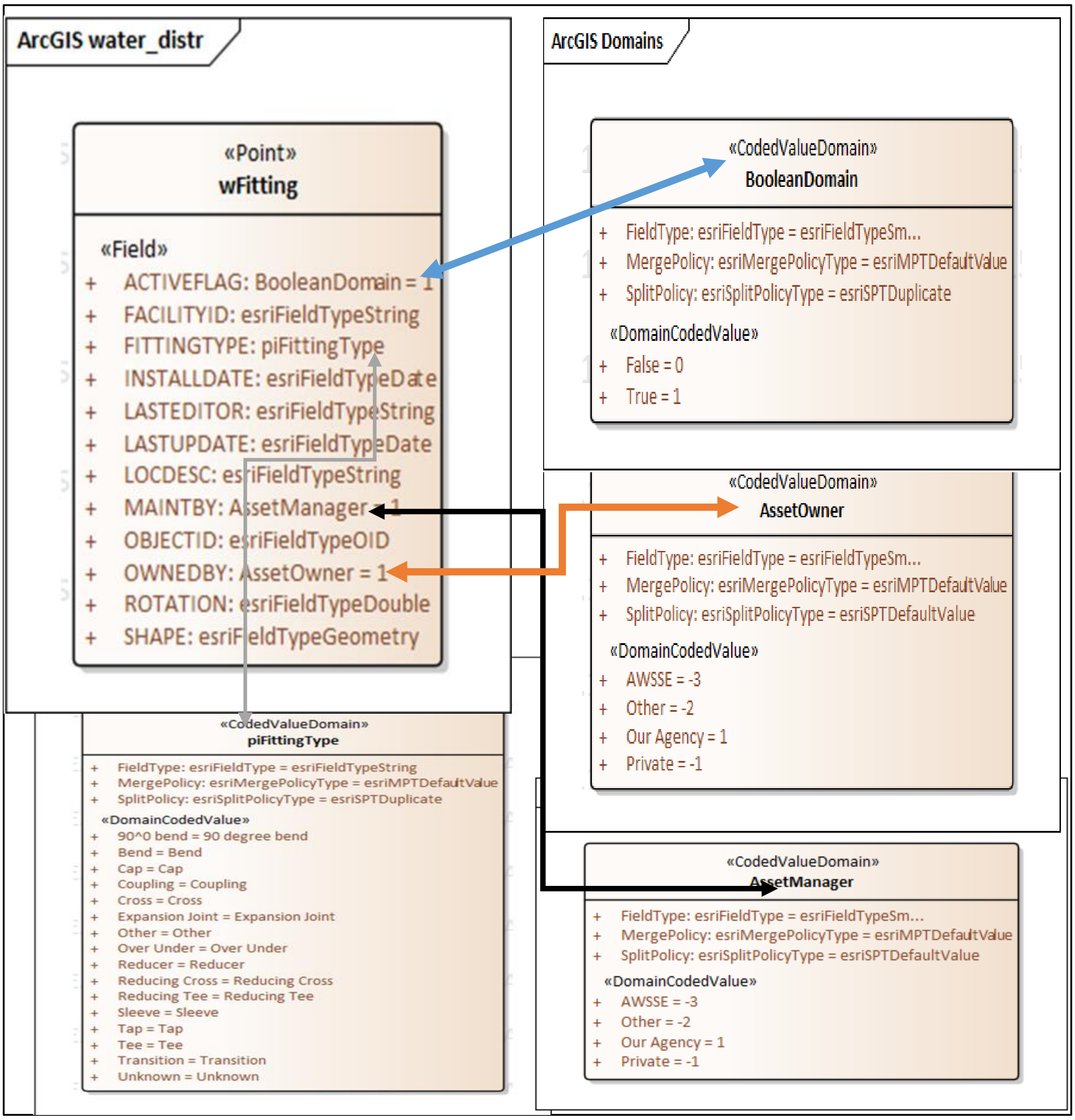


Figure 4.3 UML Designed Attributes and Domains of Water Fitting

In the above Figure 4.3 the geometric representation of water fitting is point. Positive (+) signs are public which was visible on ArcGIS attribute table. This study doesn't used signs #, - and ~ attribute which was protected, private and package respectively because the model used for public service. In EA UML water fitting attribute field 1) Active Flag was short integer field type, coded domain type which is 1 and 0, there description is true and false respectively. 2) Facility Id was string field type and the field type length is 20. 3) Fitting type was text field type, coded domain type which is 90 degree bend, bend, Cap, Coupling, Cross, Expansion Joint, Over Under, Reducer, Reducing Cross, Reducing Tee, Sleeve, Tap, Tee, Transition, Other and Unknown.

After assaying feature class geometric data type with the field attributes, length field type, and domain for their attributes in UML, it is validated to export into XML. The result of validated ArcGIS model is presented in Figure 4.4.

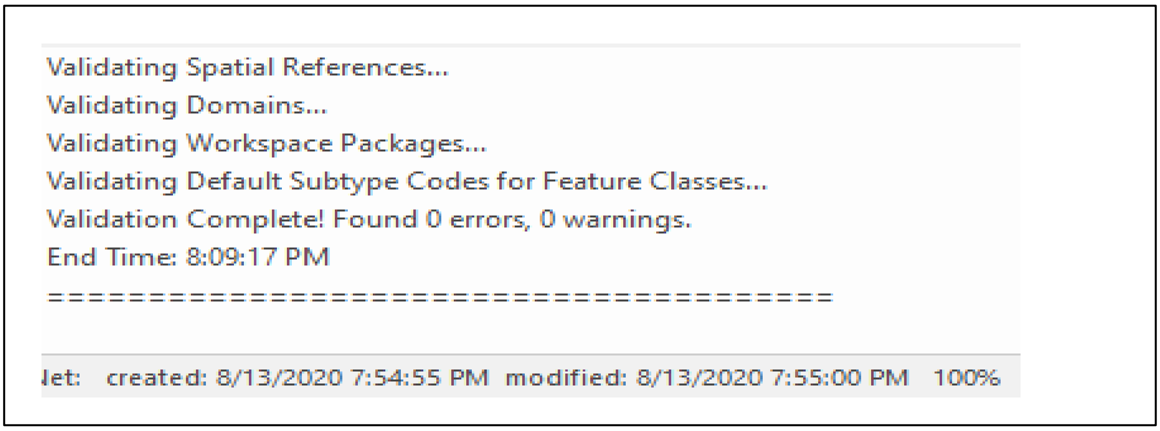


Figure 4.4 Validation Result of Designed UML physical Design

As figure shows Figure 4.4 EA validate spatial reference, domains, feature classes was completed Zero (0) errors and zero (0) warnings. The validated model was exported from UML diagram into XML scheme and XML scheme was imported into ArcCatalog and presented in Figure 4.5. The imported water feature dataset to ArcCatalog.

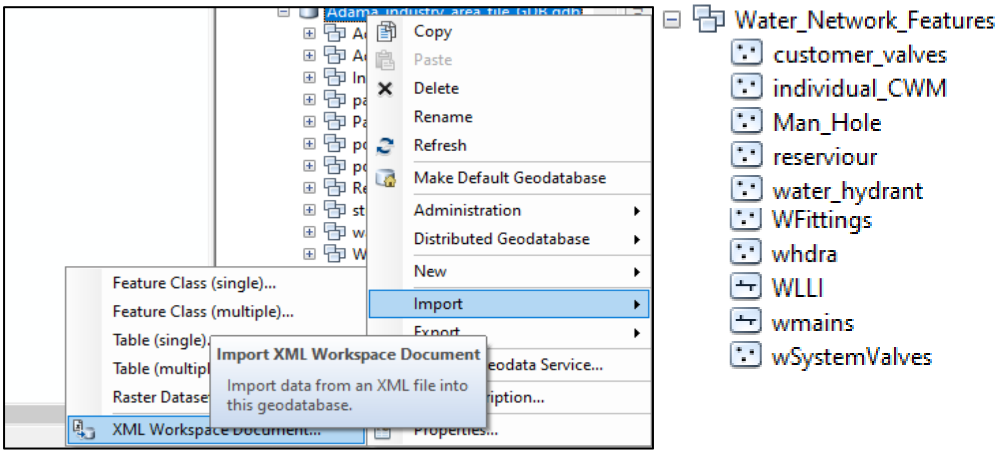


Figure 4.5 Physical Geodatabase Model in ArcCatalog of ArcGIS Environment

4.4 Populate and Implementation

File geodatabase was developed through conceptual, logical and physical phase described in previous chapter in Table 2.2. So, in order to achieve the other objectives of the study, following model geodatabase development, the model is populated by using the prototype data to test the model for the intended purpose for which it is designed. These purpose involves; valve isolation in case of leakage and identify the number of affected customers or material needs immediate and annual maintenance; when the valve is closed due to leakage in the network and configuration of pipe network. And also, build the geodatabase and test the model by performing network analysis and validate the model, it is populated as a prototype Adama Industry Area, using the primary and secondary data collected in the prototype for the Adama Town. This area is used as a prototype on the basis of required and availability of spatial and non-spatial data for testing the model. To deliver water to customers' services provided by the water system from water source to consumed the water this study populated into database model. Water network features collected and populated as prototype in geodatabase are tabulated with their quantitative detail in Table 4.5.

Table 4.5 Features Present in Selected Prototype

S/N	Feature classes	Quantity	Amount
1.	System Control Valve	Number	1
2.	Water Fitting	Number	114
3.	Water Hydrant	Number	1
4.	Water Lateral Line (523 meters from AutoCAD file)	Length in meters	7,835
5.	Water Main Line	Length in meters	3,484
6.	Water Pump	Number	1
7.	Reservoir	Number	1
8.	Individual water meter	Number	82
9.	Manhole	Number	1

In addition, the attributes and associated domains are also exist and imported to ArcGIS. Here the attribute for water fitting is presented in Figure 4.6 as asample.

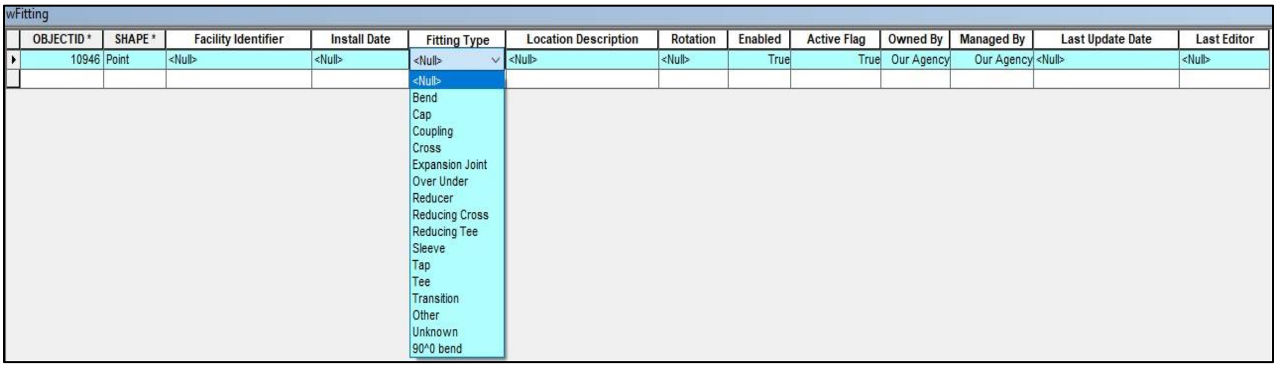


Figure 4.6 Attribute and associated domains of Water fitting in ArcGIS environment

As shown in the Figure 4.6, all the water pipe infrastructure features established in EA UML are imported to ArcCatalog geodatabase tree in ArcGIS environment. It is verified that all water network features intended to be included in the geodatabase model exists including their attributes and associated domains. The coded value domains are verified by dropdown list in the attribute table, but the option was after digitization. Therefore, this geodatabase model is prepared for implementation through prototype data population and for building geometric network.

4.5 Building Geometric Network

Geometric networks offer a way to model common networks and infrastructures found in the real world. Once a geometric network is modeled, user can benefit from performing various network analyses. Following population of the features to the geodatabase model, geometric network is created to perform network analysis on the model. Geodatabase feature classes, populated feature classes, are used as the data sources to define the geometric network. The data in the geometric network is comprised of edges (line), and junctions (point). Point features (reservoir, valve, meter, fire hydrant, water fitting) are assigned as junctions while line features (main line and lateral line) are assigned as edge. A geometric network is composed of two types of edges; simple and complex edges. The role of these feature classes in the geometric network are defined as; simple junction, complex junction, simple edge, and a complex edge. In this study water lines (main line and lateral line) are assigned as complex edge and all point features as simple junction. And, rules for how resources flow through the geometric network, i.e. connectivity rules, are also defined.

The connectivity rules can be established between two features classes, a feature class and the subtype of another feature class, or between a subtype of one feature and the subtype of another (ESRI, 2008). There are two types of connectivity rules edge-junction and edge-edge rules that can be associated to network features involved in a geometric network. The edge-junction rule specifies the valid types of junctions that may connect to an edge and the number of each type that can be connected. In this study only edge-junction connectivity rule is defined between edge (water lines) and junctions (point features). Setting the network connectivity rules is done from ArcCatalog using the connectivity property of the Geometric Network. The network connectivity rules are established to make editing the network less tedious. The network rules reduce the amount of time and error that may be introduced during an edit session.

4.5.1.1 Performing Trace Analysis on Geometric Network

The geodatabase encompasses the use of a geometric network for the water network features. The geometric network is composed of connected edges and junctions, along with connectivity rules that represent and model the water network (ESRI, 2008). A geometric network is used to represent and model the real world water network and support the use of network tracing and analysis (Zeiler, 2007). The use of a geometric network has been implemented to execute trace analysis functions available from the Utility Network Analyst toolbar. Trace task operations available in ArcMap for the water pipelines infrastructures, available through the Utility Network Analyst toolbar involves; find connected, find disconnected and path. The main objective of performing trace network analysis on the developed geometric network model was to test its efficiency in performing the analysis for the intended purpose. This test performance analysis were done by through different scenarios which includes; connected network, valve isolation due to leakage, affected customers due to valve closure, and immediate and annual maintenance.

4.5.1.2 Find Connected Trace

The find connected trace task supports the ability to check connectivity between features in the network as it allows the user to analyze features that are connected to one another. To perform this analysis, first flag is placed on point of interest in the network next find connected task is chosen and solve is applied under network analysis toolbar in ArcGIS software environment. The result of find connected trace analysis output is presented in Figure 4.7.

As the result shows (Figure 4.7), all water features in selected prototype are connected each other. This means, the water passes through all the pipes and reaches all the customers. This output result is confirmed through field observation in a way that the customers in the area have the accessibility of water supply. So, the model output result in performing find connected task shows the developed geometric model is efficient for identifying connected water pipeline networks. Additionally, find disconnected trace analysis was performed on the model and it showed that there is no disconnected feature in the network. This is confirmed from the find connected trace analysis result that all pipeline networks are connected in the prototype area.

The identification of connected pipeline infrastructures enables the enterprise in managing the networks for supplying and addressing water for all its customers through a well-connected pipe networks. Moreover, it helps in connecting pipeline networks to resilience the affected customers in the absence of water from one flow direction in the distribution line by allowing water to come from the opposite flow direction. And, the find disconnected trace task supports the ability to check for breaks in the connectivity of features in the network. For example, if a service lateral is not snapped to the edge of a main, the find disconnect trace will identify the lateral and any other feature connected to it, there is no disconnected feature.

Therefore, the find connected features trace analysis on the developed geometric network model showed that the model is efficient in identifying connected and disconnected pipeline infrastructure networks.

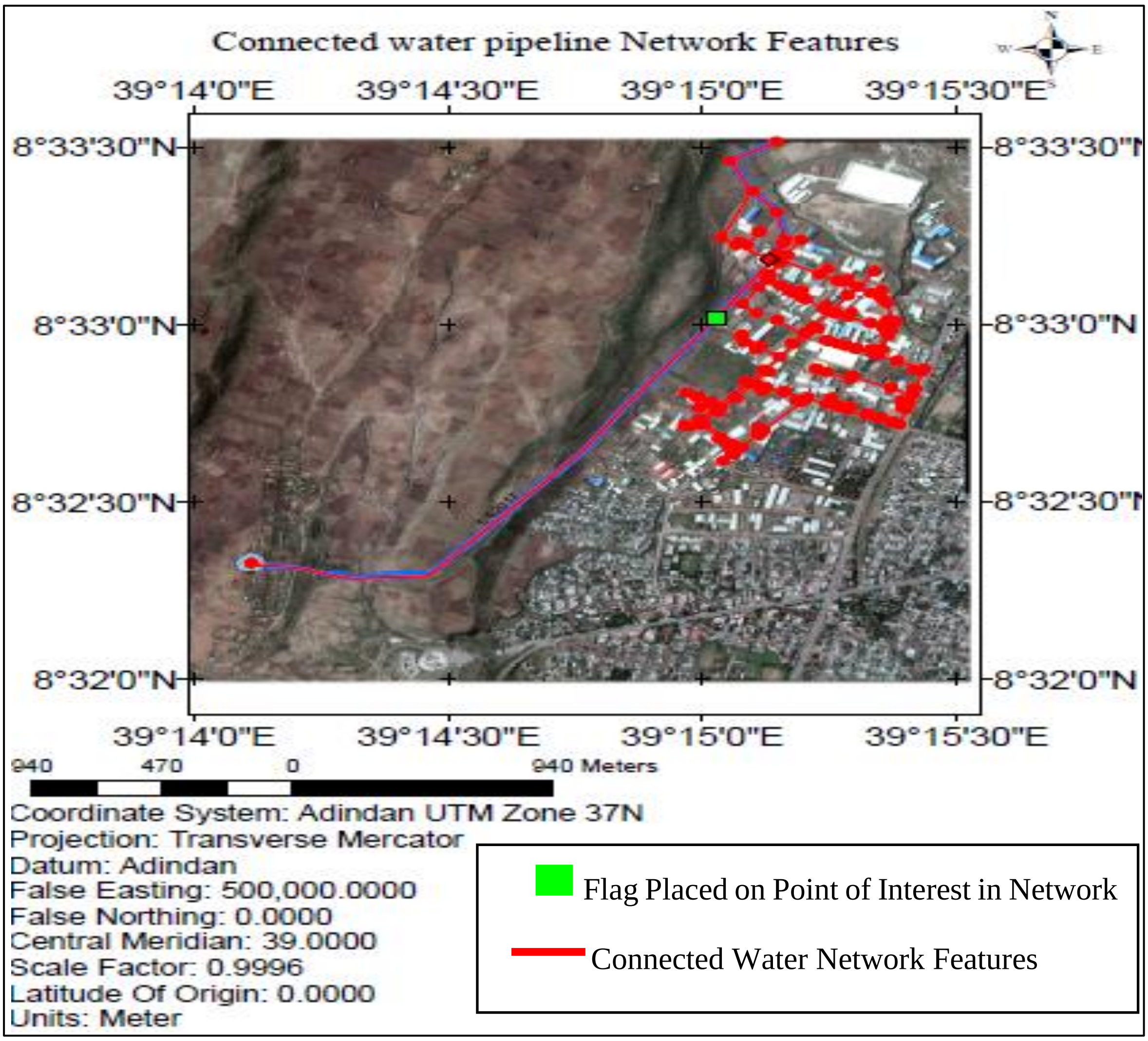


Figure 4.7. Connected Water Feature Networks

4.6 Valve Isolation and Maintenance scenarios

To place flag on reported location, the GIS Expert in the office identify place where leakage or need to be maintained, by asking unique parcel ID, query sourced unique parcel ID, select and identify around the pipe burst or maintenance planned and Figure 4.8.

As Figure 4.8 shows, customer notices a leak in front of their property and calls their utility's call center to report the issue and the expert in the office records the location of the leak

(ESRI, 2015). An example; if pipe was bursts around unique parcel ID (UPID) OR001050116005 informed from customer through phone or other. The attribute field for individual customers' water meters with their parcel ID was designed. A unique ID number was established in both attribute table and the attribute table of the block group shape-file (Tao Tang and Gregory Keyser, 2007).

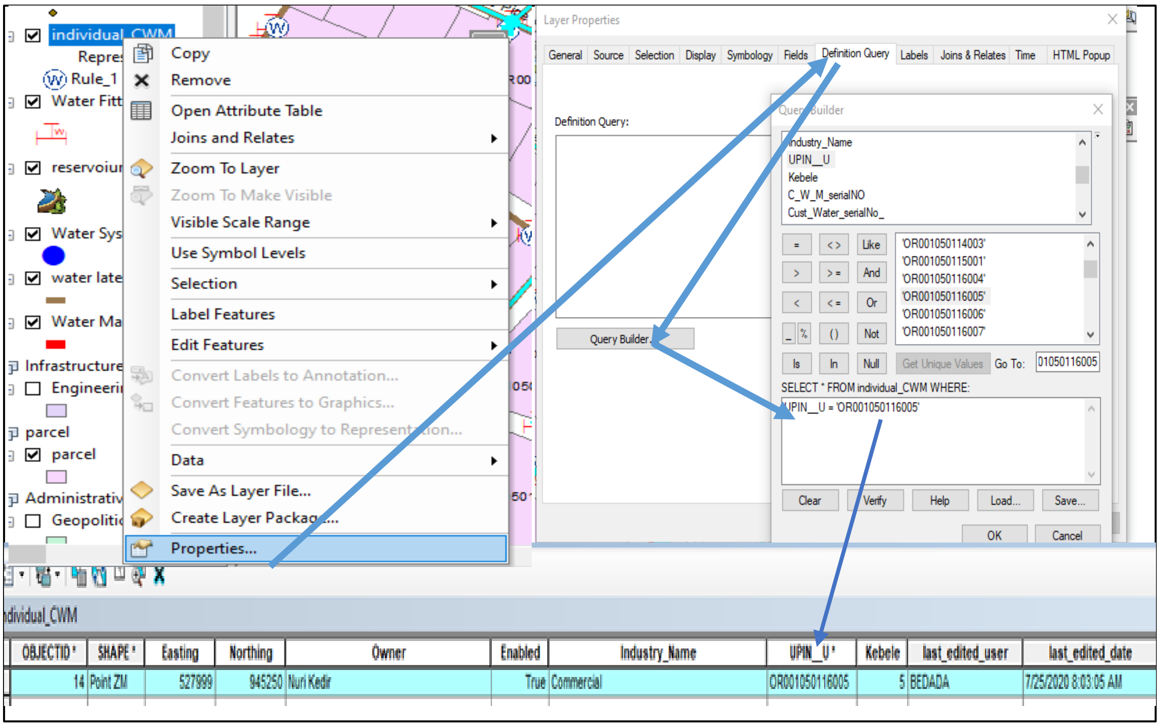


Figure 4.8. Identifying Water Leakage Area

This study easily identify the location where flag is to be placed which identifies the location of a water leak, the results can be solved and graphically displayed on-screen.

Then, next valve isolation trace analysis scenario was performed on the geometric network by adding flag on identified place to isolate valve. This analysis were performed through; 1) Place an edge flag at reported site of water leak, 2) Disable system valve layer, 3)choose the features stopping the trace 4) select the system valve only be selectable layer 5) choose find connected task 6) select solve Figure 4.9.

Accordingly, in the network if the valve is closed the water stops to flow in the network to the next pipe after the valve. This result in shortage of water to the customers that get water that passes through the closed valve. In the prototype area, the water comes from and passes only through the selected valve to be closed (Figure 4.9) to reach the customers after that valve. So, if the valve is closed these customers selected in red colour (Figure 4.10) will not get water. This shows those customers are affected due to valve closure. Additionally, there are customers that are not affected due to valve closure which are not selected in Figure 4.10. These customers are not selected when affected customers trace analysis is performed on the network due to valve closure. These non-selected customers get water before the water reaches the valve that is identified to be closed. Moreover, these find affected customer output result by the model is confirmed by field observation that it the output was correct. Also, as shown in Figure 4.10, the details of affected customers are also easily accessed. Identification of affected customers due to valve closure with their number and spatial detail enables the enterprise in decision making for management of water supply to its customers that meet the needs of the customers. Additionally, it helps to take immediate action for re-silencing these affected customers. Therefore, the output result of testing the developed geometric network model to identify affected customers due to valve closure showed that it is efficient and performed well.

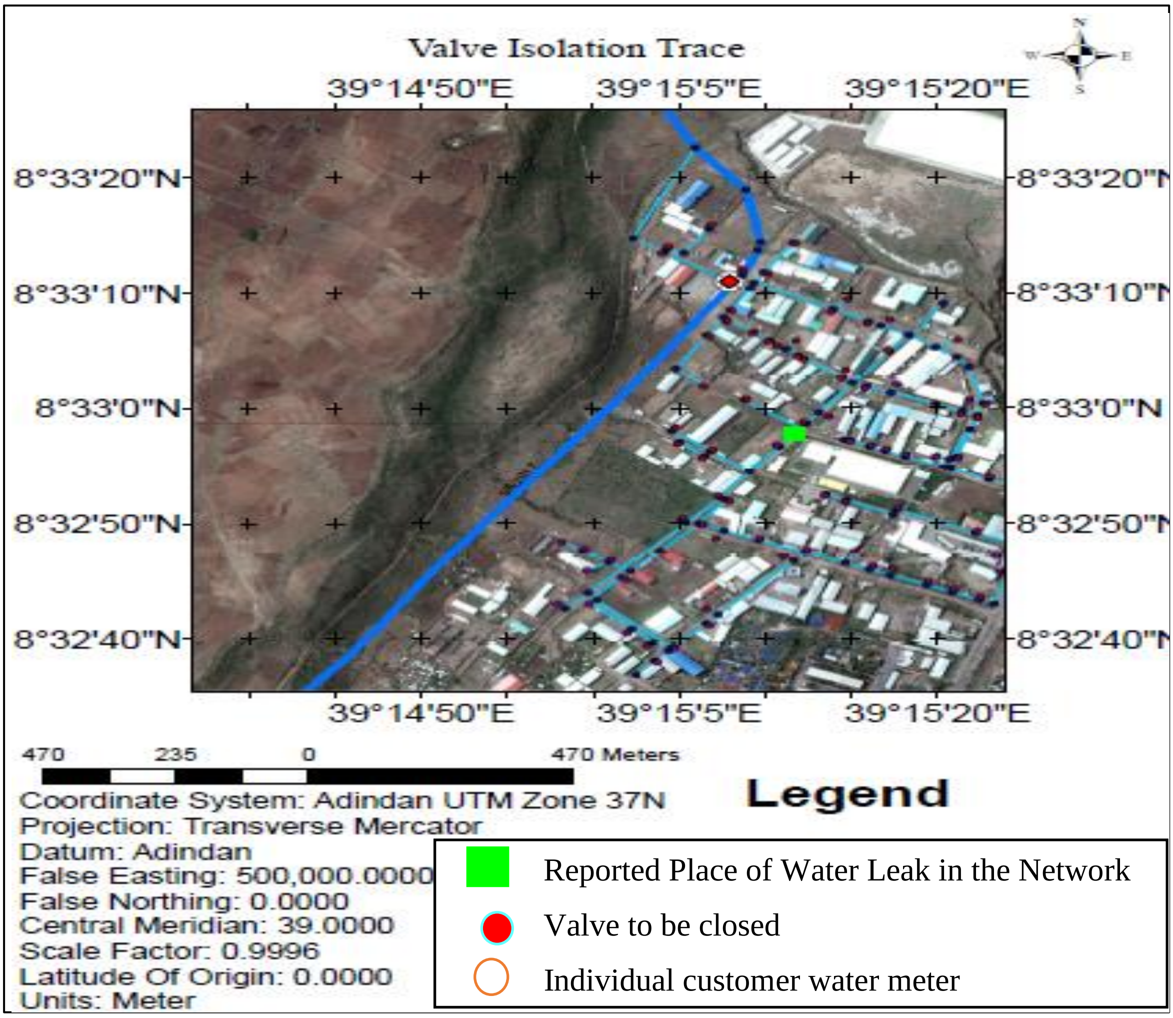


Figure 4.9 Valve Isolation for Reported Water Leak

Valve isolation tracing output result Figure 4.9 showed that the valve to be closed in the network depending on the reported water leakage position, which is marked green in Figure

4.9, is marked. And, a valve that has to be closed is selected, which is marked in red colour on Figure 4.9, in the network. This is on the basis of water flow direction in the network. This means, the water passes through a selected valve to be closed to reach the reported water leakage place. In the network there exists only the selected valve before the place reported as water leakage is happened on the basis of water flow direction.

Moreover, the result output is confirmed through field observation by identifying the existing system valve in the network that exist before the reported water leakage place based on the direction of water flow. So, the selected valve to be closed in the network based on reported water leakage by the developed geometric model was correct. This shows, the developed geometric network model is efficient and performed well in identifying a valve to be closed if the leakage or burst is happened in the network and reported to trace through trace network analysis. Additionally, the spatial location and detail of the valve to be closed is displayed digitally. Accordingly, valve isolation helps the enterprise in taking immediate action to control wastage of water in a way that it is easily selected by the trace analysis and the result is displayed digitally with spatial detail. So, any expert of the enterprise that performs trace analysis on the network can easily access the valve that have to be closed and take remedial measure immediately by closing that valve without encountering spatial detail information.

Therefore, the developed geometric network model is efficient in identifying a valve that has to be closed by network trace analysis if the location of reported water leakage is given in the network. And, it can be used for the whole Adama Town in the future.

4.6.1 Find Affected Customer

When the system valve is closed, there exist affected customers due to maintenance repair of the water main. These affected customers can be identified and located. With the system valves identified to be closed, it is now possible to locate the customers who will be affected by the maintenance repair of the water main. This is performed by trace analysis as follows; 1) select service connection to be selectable 2) choose find connected task 3) select solve and the result is presented in Figure 4.10.

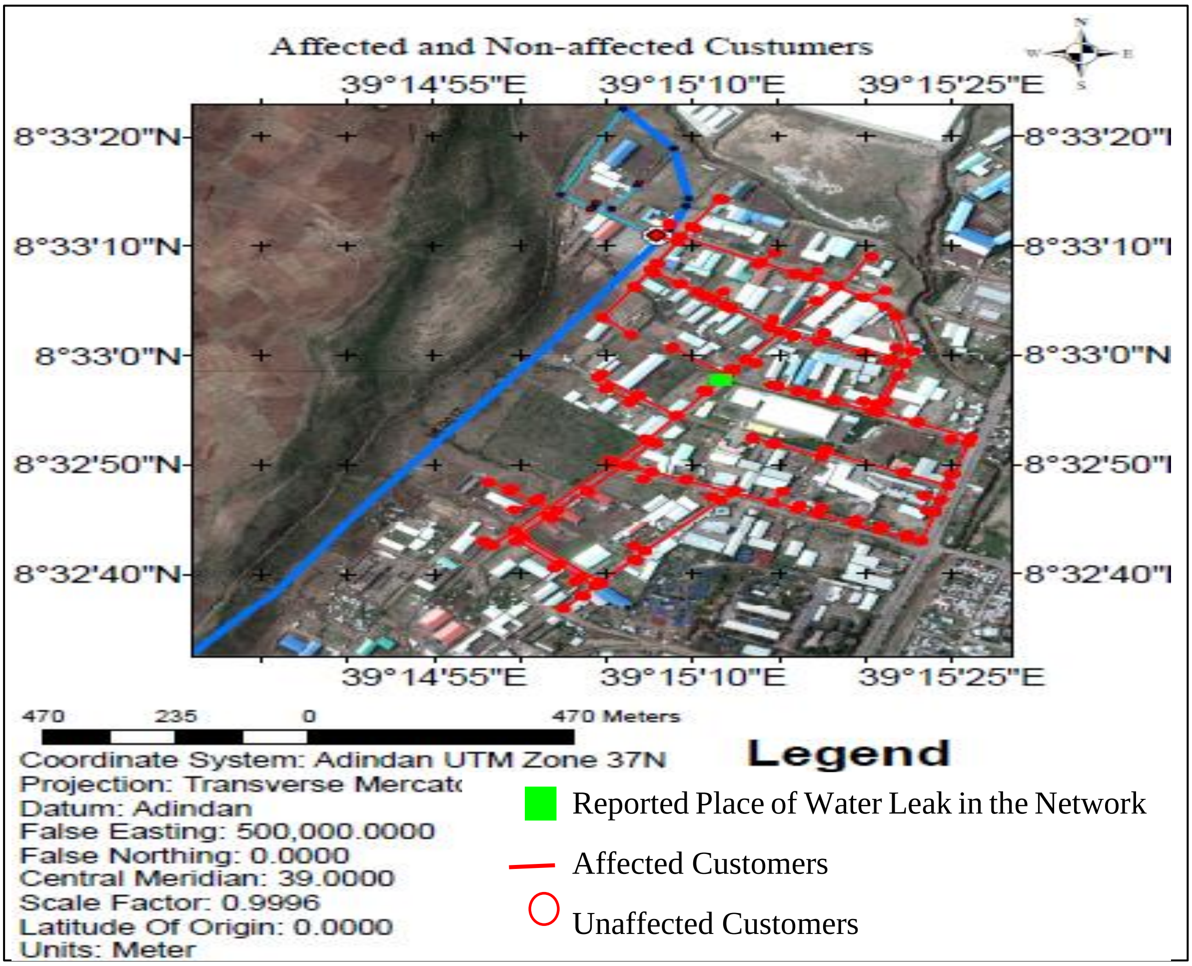


Figure 4.10 Identified Affected and Un-Affected Customers Due to Valve Closure

The result shows (Figure 4.10) on the displayed selected red line shows affected and purple line shows un-affected customers due to valve closure, the details and number of affected customers are displayed in the attribute table of individual water meter feature class, presented in Figure 4.11.

Figure 4.11 shows that, the number of affected customers with their details are also accessed in the attribute table of customer meter. This is verified through field observation based on the primary data collected, direction of water flow in the network and location of system valve the control the flow of water to those affected customers. This enables the organization to take the remedial measure to resilient the affected customer relying on the information obtained from the network analysis**.**

Table

individual_CWM

OBJECTID *	SHAPE *	Easting	Northing	Owner	Enabled	Industry_Na
7	Point ZM	527874.3933	945162.2809	SAHELE BENA	True	Commercial Institution
8	Point ZM	527885.3762	945154.3526	Abdela Musa	True	MCDDN
9	Point ZM	527952.5454	945101.9108	Hassun	True	DFMN PLC
10	Point ZM	527961.1206	945126.2948	Mulan Biscuite and Flour Factory	True	Mulan Biscuite and Flour Fact
11	Point ZM	528035.8316	945177.9883	Tesfaye Teshome	True	PLC
12	Point ZM	528043	945263	Aberu Aliyi	True	Commercial
13	Point ZM	528039	945260	Aweke Fante	True	Commercial
14	Point ZM	527999	945250	Nuri Kedir	True	Commercial
15	Point ZM	527934.0409	945279.4307	Nisha	True	Commercial
16	Point ZM	527822.671	945381.5931	Shamile Seraji	True	Commercial
17	Point ZM	527870	945461	Kiyar Rediy	True	Commercial
18	Point ZM	528217.2352	944839.3153	Adefris Kifile	True	Commercial
19	Point ZM	528209.9128	945035.4359	Lemma Jenbere	True	Commercial

1 (79 out of 82 Selected)

individual_CWM

Figure 4.11. Details of Affected Customers in Attribute Table Due To Valve Closure

Therefore, the developed geometric network is efficient and effective in network analysis to identify affected customers with their details due to valve closure cause of water leakage. Moreover, it is observed that the available water system valve on the water network is not enough to resilient the affected customers. This gives information to add additional water system valves that enables to minimize the number of affected customers when there is a water leakage and the pipe is intended to repair.

4.6.2 Immediate and Annual Maintenance Scenario

The maintenance scenarios performed on the developed geometric network model involves retrieving information for the purpose of maintenance and it involves immediate and annual. Immediate maintenance involves when the damage or burst happened on the pipe to retrieve the information of that pipe to immediate maintenance action. As discussed under section 4.6 the place where leakage occurred was reported and the pipe is known. Using identify tool in ArcGIS environment the pipe on which burst happened is selected and the output result is presented in Figure 4.12.

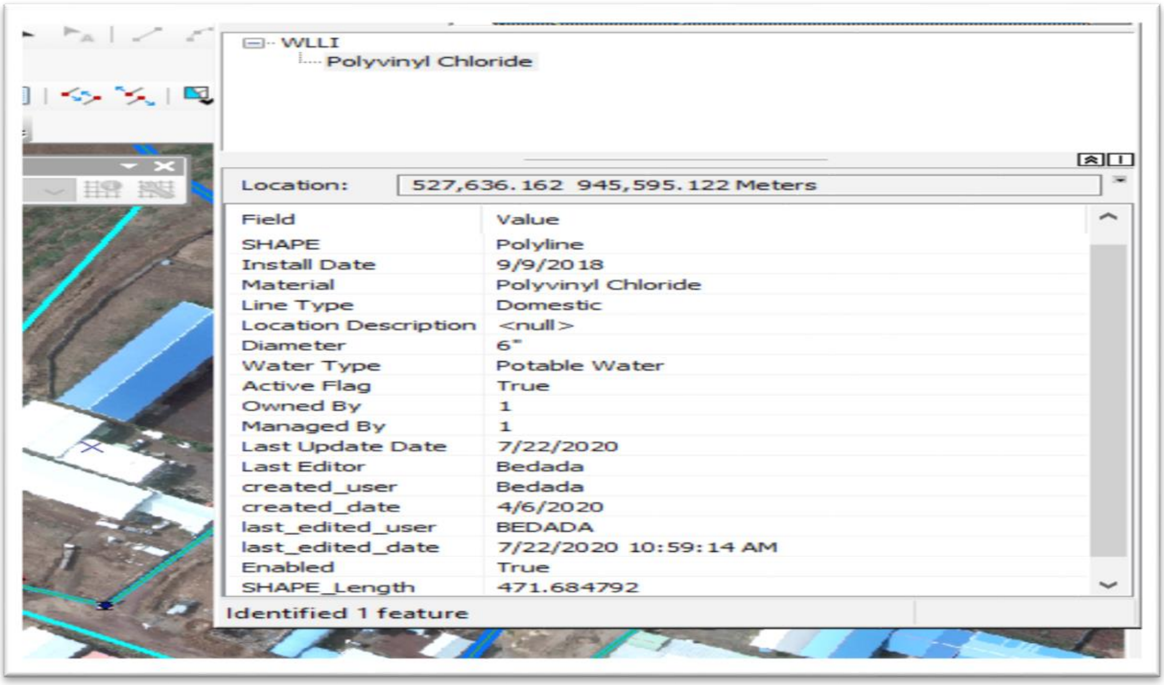


Figure 4.12 Information of Busted Pipeline

As shown in Figure 4.12, all the information of the pipe which is reported as on which burst has occurred. This information includes all the attributes of that pipe. This enables the enterprise to easily access information's such as; where, what type of material, diameter, etc. to take immediate action for maintenance. This makes the enterprise advantageous in a way that it can fulfil the needs of its customer by taking immediate maintenance action. Therefore, having the developed geometric network model in ArcGIS geo-database enables the enterprise for management of immediate maintenance of the infrastructures easily and efficiently.

The other one is annual maintenance and it involves selecting a pipeline infrastructure that needs maintenance based on its service year or lifespan. Here it is presented as a sample for water lateral line. In the attribute table of the water lateral line there exists; installation date, current date, served year and year of service. Installed date involves the date the material is installed for service. Current date involves the present date of the material every day the geodatabase is browsed and it needs to update using field calculator always. Served year is calculated as current date minus installed date in the field calculator of attribute and it involves the year that material serves starting from the installed date to the current date in that attribute. Service year is the life span of the material or the year that material is expected to serve and the value is entered from the ULGDP manual. So, to get the information of the material that needs maintenance based on service year calculate statistics is performed on the served year field under the attribute table in ArcGIS environment. The result of the output is presented in Figure 4.13.

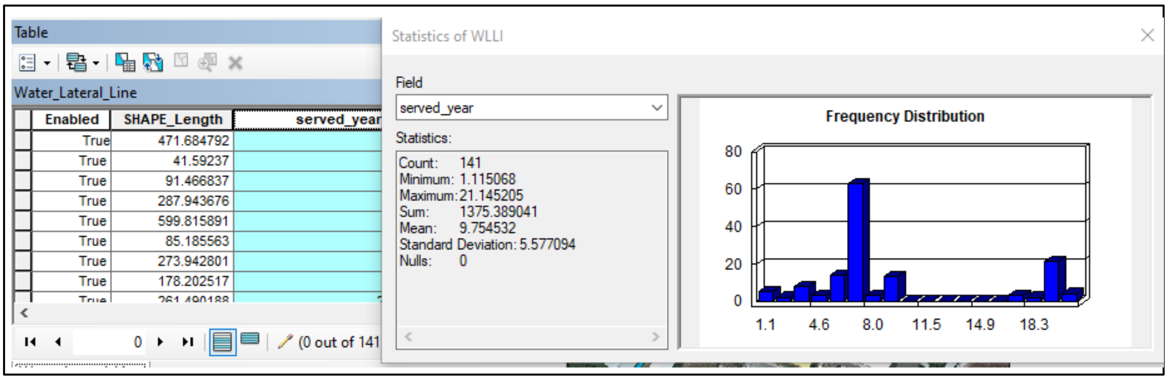


Figure 4.13 Minimum and Maximum of Served Water Pipeline

As shown in Figure 4.13, the result shows that the maximum served year of water lateral line in the prototype area is 21.145 years. According to ULGDP manual the lifespan of water pipeline is 35 years. So, in this prototype no material has reached the specified lifespan. Moreover, the aim of this study in annual maintenance scenario was to select materials which have finished their lifespan by using the served year attribute field discussed above. However, this helps the enterprise in the future to easily identify the material that needs maintenance on the basis of their lifespan which is annual maintenance.

Generally, the developed geometric network model geodatabase enables the enterprise for decision making in maintenance of the pipeline infrastructures and plan annual budgets for maintenance.

4.7 Water Pipe Network Configuration

In order to identify the pipe network configuration, trace analysis using loop is made on the geometric network, presented in Figure 4.14.

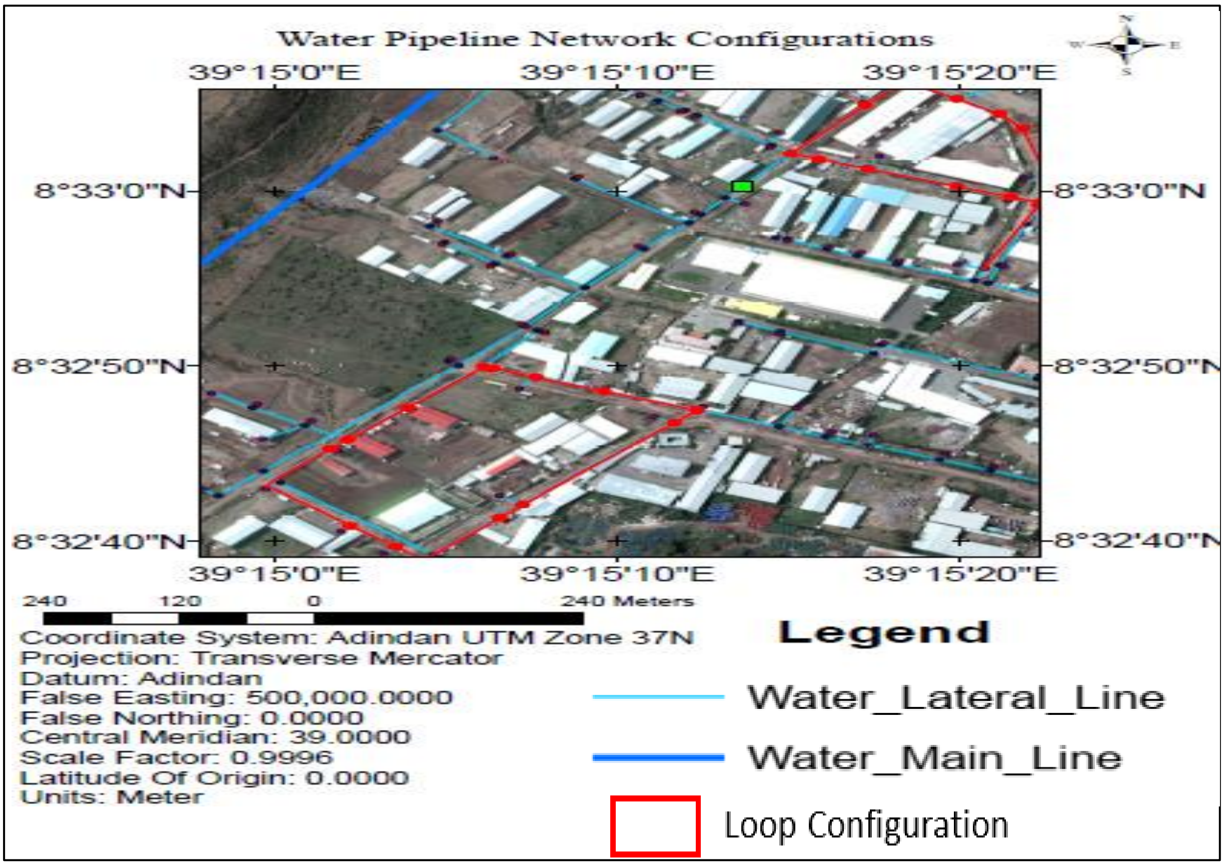


Figure 4.14 Configuration of Water Pipe Prototype Area

As the result shows (Figure 4.14) the developed model identify the configuration of water pipe infrastructure, the purple and red line shows series and loop network configurations respectively and identified water flow direction from the reservoir to users. There are two basic configurations for most water distribution systems are the series (branch) and loop (grid). That means if series network water flow in direction, but control valve for both configurations is only one gate valve. That means if there is a leakage in network almost all customers are out of service in these prototype area. The result is shows loop configuration two sites and when the configuration is series for water fitting type tee minimum valve is two and also for cross fitting type minimum valve is three. For loop configuration water can flow in every direction that means if the connection is more than two every connection needs valve to prevent water back flow when pipe maintenance or leakage. The digital map pipe networks of the various spatial (positions) features within the water pipe network.

4.8 Placement of Gross Water Meter

The Enterprise was faced illegal use of water in the Adama Town, so they need to place gross water meter in suitable place. Which measures the used water in identified water customers. Therefore the study is made interviews questions (Appendix-A) and observation to identify the need of stakeholders. The Enterprise was need to place gross water meter where there are manhole to secure it and water control valves to open and close where the supervisor need to measure the usage of water. That means the sum of customers water meter was approximately the same with the reading on gross water meter. So, the data of manhole and water control valves are collected on site because the Enterprise does have spatial location of all water pipelines infrastructures. By using ArcGIS tool the collected vector data was converted to raster data. The study was selected fuzzy overlay analysis to select suitable place for gross water meter, this was done on selected prototype Figure 4.15.

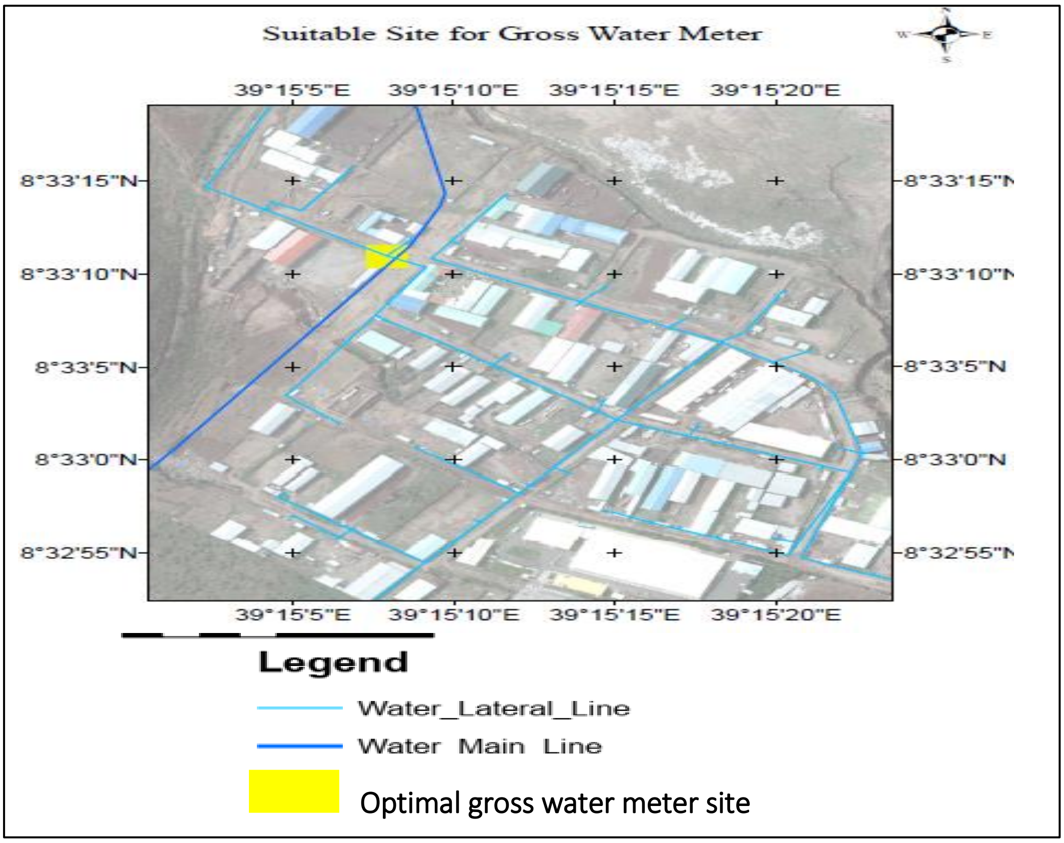


Figure 4.15 Optimal Site for Gross Water Meter

As shown in the Figure 4.15, the suitable site to place gross water meter that controls the amount of water passed through a network for a set of customers is selected. The selected site is verified on the site based on the need and requirement of the organization to place gross water meter to control illegal water use. So, the selected site by this study through fuzzy overlay full fills the organization need and it is the place as per the requirement. Therefore, the organization can place the water gross meter on the selected suitable site to control illegal water use. Because the reading on gross water meter was almost the same with individual water meters reading, so in these case almost all customers are used from one water control valve.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, GIS based geometric network model for water pipelines infrastructures is developed. The geo-database is developed through conceptual, logical and physical design phase. And, it consists of all the required water network features as per the existing features in the study area and ESRI water utility. On the developed geo-database model geometric network were built. The result of the developed geometric network consists of all water feature network with the defined connectivity rule. The result of developed geometric network model implies that, it enables to store, manage, analyse, manipulate and display data that are linked spatially and attribute data (i.e. water main type, diameter, pipe type, installation date and etc.). Also, it allows querying and retrieving information, and creating digital map for water pipe infrastructures. Moreover, it implies it can be applied for network trace analysis which helps in decision making for effective, efficient and time-saving management of pipeline infrastructures assets. Therefore, the study concludes the developed geometric network model can be used for performing network trace analysis.

The developed geometric network, through connective rule (edges are water mainline and water lateral lines whereas junctions are water hydrant, water fitting, reservoirs, water control valve systems, individual customers water meter), is tested through different network analysis scenarios such as; isolation of valves due to leakage, identifying affected customers due to valve closure and planning immediate and annual maintenance using data in selected prototype area. The results of performing trace analysis showed that the model has identified valve to be closed in the network if leakage is occurred, affected customers due to valve closure. Additionally, the output result on maintenance scenario showed the detail of pipe which needs immediate maintenance due to burst and materials that needs maintenance on the basis of their service year for annual maintenance. This implies that the developed geometric network model is efficient and appropriate for water network tracing analysis and maintenance of assets that enables to take mitigating measures. Moreover, it enables to get information (detail information) of the trace network analysis and its displays with spatial information digitally. Therefore, the study concludes the developed geometric network model can be used for the whole Adama Town in the future for proper management of water pipeline infrastructures assets.

Using the developed geometric network, water pipelines configurations are identified by network tracing analysis. The result of pipeline configuration in the prototype includes both loop and series. The result showed that the identified pipe line configurations in the prototype area by network tracing analysis were correct and confirmed through field observation. This implies that the developed geometric network model is capable of identifying the pipelines configurations. Therefore, this study concludes the developed geometric network is capable of identifying pipelines configurations of the whole Adama Town in in the future for the intended purpose by the enterprise.

Suitable gross water meter that enables to control illegal or unmetered water usage is selected. Fuzzy overlay analysis is selected in the prototype area on the basis of water network features available to place gross water meter in the area. The result showed that, the suitable site selected is appropriate to place Gross water meter that meets the need of the enterprise. It is verified that, the site selected by this fuzzy overlay full fills the requirement that the Enterprise want to control illegal water use. So, this study concludes the site selected in the prototype area is suitable for placing Gross Water Meter. Moreover, the fuzzy overlay analysis is appropriate for selecting suitable site to gross water meter for the whole Adama Town in the future.

5.2 Recommendation

- This study recommends to use the model for the City, to solve the Enterprise water pipeline infrastructures spatial and non-spatial data management system and the model used to identify the configurations pipe network systems. So, AWSSE was the direct benefit from this study and the Enterprise can update their daily activities, CAD file to geodatabase and share the up-dated geometric network geodatabase model to other sectors such as roads, electrics, drainage easily identified the spatial and non-spatial data of water pipe infrastructure to prevent damage during construction.

- The Enterprise can use the model to manage these infrastructures in efficient and effective manners which includes valve isolation to be closed during leakage or pipe burst, detail of affected customers due to valve closure which have significant role in resilience these customers. Moreover it can be used to get the detail information of these infrastructures to that needs maintenance immediately at the time of burst or annually maintenance on the of service years.

- The Enterprise can use the developed model for pipelines configuration for the intended purpose for the whole Adama Town in the future.

- The Enterprise can place Gross water meter on selected suitable site for the prototype area. Additionally, they can use fuzzy overlay to select suitable site for the whole Adama Town.

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APPENDIX- A

Interview Questions and Response to Questions

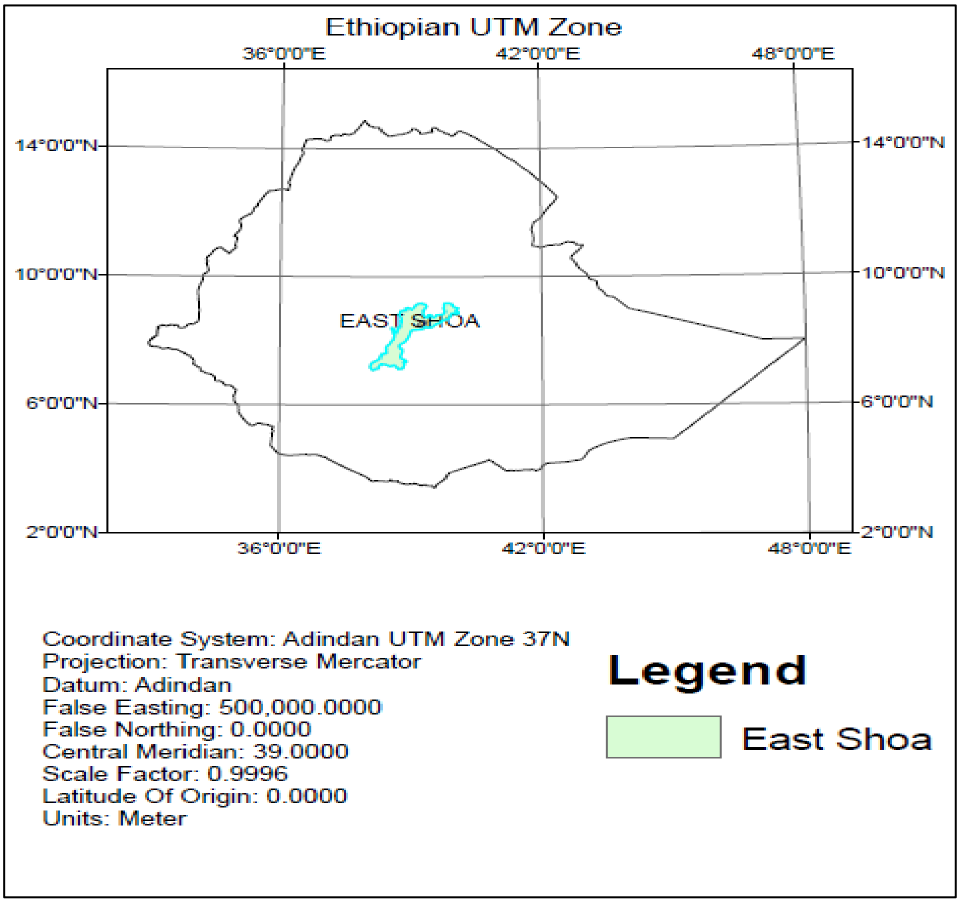
S/N	Interview Questions	Response for questions
1.	What is your name and responsibility in the enterprise?	Name: Mr. Hassein Ture, Responsibility: Team leader Interview Place: His Office Interview date and time: 23/08/2011 E.C at 3:05 local time (May 01, 2019 at 9:05 am G.C).
2.	How the Enterprise manage water pipeline infrastructure and is the Enterprise data handling Automated in geodatabase?	The enterprise handles data with hard copy, and also they use CAD for major water line. But, for distributions line (water lateral line) which distribute to the customers was depend on the person who installed before. The Enterprise was not experienced to update the daily activities in geodatabase.
3.	Does the Enterprise have the spatial location for all water pipelines infrastructures?	The enterprise doesn't have well-documented and enough spatial location that includes all assets.
4.	Does the Enterprise have the attributes for water pipelines infrastructures?	AWSSE doesn't have the attributes of feature classes in geodatabase,
5.	What are the water pipeline infrastructure data's your enterprise have installed as an asset?	Those are water pipeline materials (Cast Iron, Copper, Ductile Iron, Polyvinyl Chloride, High Density Polyethylene, etc.), hydrant, water fitting. Etc.
6.	Are the enterprise spatial and non-spatial data well documented?	No, the enterprise store data in shelf and different offices and it is verified through observation.
7.	Does your enterprise want to implement GIS for water pipe infrastructures management?	Yes!

8.	How the enterprise communicate with other sectors about spatial location of water utility asset?	It is difficult to give information about spatial location and non-spatial information water pipelines infrastructures with other sector. The enterprise is facing the problems of pipe break, when there is maintenance and constructions of the roads.
9.	Which spatial reference system does your enterprise prefer for geodatabase?	Adama Town is located at UTM zone 37, projected coordinate system. The enterprise need to adopt Ethiopian Maps Authority (EMA) reference systems.
10.	Is there any problems your enterprise facing in managing the usage of water?	Yes, the enterprise faced there is illegal use, some customers use unbilled water by connecting water pipeline before customer water meter.
11.	If your answer is yes question number 10, how your enterprise need to overcome these problem?	The enterprise need to place water meter, which measure sum up the customers used from specified line.
12.	What are the Enterprise requirements to select suitable site to place gross water meter?	The enterprise need to place in suitable place, where there is manhole box to secure the water meter and where there is water control valve to open or close water to or from the customers.

Generally, the problems of the Enterprise was identified through interview questions and observation. So, the Enterprise faced problems due to absences of geodatabase are, the spatial detail or location of all the water network pipelines are not known and they are known on the site only by the expert that installed the pipelines and the spatial detail of pipeline water network to individual customer is not known. The Enterprise is unable to control the amount of total water utilized because of non-existence of Gross Water Meter that controls total amount of water utilized by individual customers within the same distribution pipelines. There is illegal use of water by some customers by installing/connecting pipeline to their home before their own meter. Knowing installation date of infrastructures are difficult to the enterprise that implies to unable to plan immediate and annual maintain. To overcome those problems, this study was planned to develop GIS based geometric network modeling of water pipeline infrastructures of the Adama Town.

APPENDIX- B

Ethiopian UTM Zone 36, 37 and 38



APPENDIX- C

Primary Data for Individuals Water Customer Meters

S/N	Easting	Northing	Owner	Industry_Name	UPIN__U	Kebele	Cust_Water_serialNo_
1.	527758.0494	945281.6304	Mesfin Teshome	Paint and Chemical Factory	OR001050116010	5	35651970
2.	527750.5231	945256.6996	Debebe Berga	WM	OR001050121001	5	006065/CA
3.	527795	945224	Abdulfata Sani	Ceramic Manufacture	OR001050121002	5	OC16-16305.010.2
4.	527824.2943	945201.4845		Ethio-Feed PLC	OR001050121003	5	CA001256
5.	527839.3492	945190.7733		Commercial Animal Feed Manufacture	OR001050121004	5	
6.	527872.065	945202.9265	Rediet	Rediet Food Complex	OR001050116009	5	OC16-16305.10.5
7.	527874.3933	945162.2809	SAHELE BENA	Commercial Institution	OR001050121005	5	OC16-16305.1
8.	527885.3762	945154.3526	Abdela Musa	MCDDN	OR001050121006	5	OC16-16305.1.7
9.	527952.5454	945101.9108	Hassun	DFMN PLC	OR001050121007	5	OC16-16305.1.01
10.	527961.1206	945126.2948	Mulan Biscuite and Flour Factory	Mulan Biscuite and Flour Factory	OR001050116007	5	OC16-16305.1.1.1
11.	528035.8316	945177.9883	Tesfaye Teshome	PLC	OR001050116006	5	
12.	528043	945263	Aberu Aliyi	Commercial	OR001050111003	5	
13.	528039	945260	Aweke Fante	Commercial	OR001050111001	5	
14.	527999	945250	Nuri Kedir	Commercial	OR001050116005	5	
15.	527934.0409	945279.4307	Nisha	Commercial	OR001050116004	5	
16.	527822.671	945381.5931	Shamile Seraji	Commercial	OR001050112004	5	
17.	527870	945461	Kiyar Rediy	Commercial	OR001050112002	5	
18.	528217.2352	944839.3153	Adefris Kifile	Commercial	OR001050119004	5	OC16-16305.011
19.	528209.9128	945035.4359	Lemma Jenbere	Commercial	OR001050119001	5	
20.	527633.4666	945435.1751	Yusuf Mohammed	Commercial	OR001050115001	5	

21.	527717	945215	Belete Adugna	Basby Trading	OR001050121010	5	
22.	527708	945082	Genene Negash		OR001050122002	5	
23.	527784	945048	Ahmed Idris	Industry	OR001050121009	5	
24.	527885	944987	Kemal Jemal	industry	OR001050121008	5	
25.	527724	944913	Germen Amente	Industry	OR001050122003	5	
26.	527658	944972	Shukur Shifa	Industry	OR001050122002	5	
27.	527706.0328	944892.5013	Adefris Kifle	Industry	OR001050126001	5	
28.	527662.0165	944929.6608	Adefris Kifle	Industry	OR001050126001	5	
29.	527754	944776	Kalid Mohammed	Industry	OR001050125007	5	
30.	527733.2388	944790.3127	Adefris Kifle		OR001050126002	5	
31.	527646.0993	945455.2402			OR001050114003	5	
32.	527720.7232	945512.1967	Ababayo Shifera	Industry	OR001050114002	5	
33.	527776.6226	945393.5432	Mararo Food Complex	Industry	OR001050113003	5	
34.	527503.8053	944501.9505	Mohammed Yimer	Industry	OR001050130001	5	
35.	527447.396	944501.9241	Zelalem Mersha	Food complex Institution	OR001050131001	5	
36.	527656.8098	944383.8028	Hailu W/amanuel	Industry	OR001050129009	5	
37.	527837.5201	944926.3888	Girma Bedaso	Industry	OR001050122004	5	
38.	527929.344	945001.9982	Sintayehu Mulatu	Other	OR001050120001	5	
39.	527995.2581	945077.0079	Sintayehu Mulatu		OR001050120001	5	
40.	528050.8244	945086.5647	NEGADRAS GENERAL T.C	Industry	OR001050117001	5	
41.	528179.8614	945045.681	ABDUL FETA ABERARE	Industry	OR001050117001	5	
42.	528119.3431	945030.2672	BEYENE TEKA	Industry	OR001050120002	5	
43.	528165.5729	945006.9379	Oda Aksiyon PLC	industry	OR001050120003	5	
44.	528195.1598	944999.2898	Abraham Abebe	Commercial	OR001050119002	5	
45.	528161.264	944893.7516	Bekere Merga	Commercial	OR001050119003	5	OC16-16305.018

46.	527968.6664	944938.9113	Sofiya Alemayehu	Private	OR001050120001	5	OC16-16305.1.1.2
47.	528005.4918	944925.2063	Yirgalem Teka	Seraro PLC	OR001050120002	5	OC16-16305.26
48.	528033.7531	944915.1987	Sororo P.L.C	SOROROO P.L.C	OR001050120002	5	OC16-16305.1.3
49.	528068.6215	944900.5909	Akililu Bedowi	Private	OR001050120002	5	OC16-16305.10.9
50.	528120.3318	944895.4739	Binyam Bedowi				OC16-16305.10.2
51.	528275.9256	944788.8727	Dereje Buzuneh	Commercial Institution	OR001050123003		701
52.	528275.1858	944690.4115	Guna Trading House PLC	Guna Trading House PLC	OR001050123004		8068
53.	528193.1542	944696.4565	Adama DVL PLC	Adama DVL PLC			OC16-16305.014
54.	528054.1757	944757.7556	Adama Development PLC	Adama Development PLC	OR001050123001		
55.	527960.6921	944773.9517	DINA TRADING P.L.C	DINA TRADING P.L.C	OR001050125003		OC16-16305.9.1
56.	527923.2365	944790.8168	Adama Pele state PLC	Adama Pele state PLC	OR001050125002	5	
57.	527707.4627	944714.8778	Bajiba PLC	industry	OR001050125008		OC16-16305.016
58.	527670.1663	944729.9841	Anewar Seid		OR001050126002		16550
59.	527892.566	944645.9112	Yahiso Said	Governmental Institution	OR001050125006		OC16-16305.07
60.	528007.8408	944601.973	Deriba Debersha		OR001050124001		OC16-16305.006
61.	527807.9726	944676.653	Kalid Mohammed	Bedir Printing Press	OR001050125007		OC16-16305.008
62.	527713.5233	944489.4185	Jilalu Kedir	Industry	OR001050128005	5	OC16-16305.1.6
63.	527718.4429	944446.769	Ahmed Beshir	Industry	OR001050129008		OC16-16305.10.4
64.	527624.9997	944347.0022	Gezahegn Tesema	Private		5	OC16-16305.11
65.	527850.6837	944628.5563	Abebe Tefese Belayineh		OR001050128002	5	

APPENDIX-D

Logical Design Phase for Feature class

Table for Water System Valves Attributes

Attribute	Data Type	Length	Domain	Description
SHAPE	Geometry	-	-	Point (Default)
FACILITYID	Text	20	-	Code that identifies Water system valve
INSTALLDATE	Date	-	-	The Date the Water system valve is installed
ROTATION	Double			
DIAMETER	Double		piPipeDiameter	A list of pipe diameters
VALVETYPE	Text	30	piSystemValveType	List of system valves types
OWNEDBY	Short	-	Asset Owner	The owner of water system valve which includes; Private, AWWSE, Agency, other.
MAINTBY	Short	-	Asset Manager	The expert of the organization that manages Water system valve
LASTUPDATE	Date	-	-	The last date the feature is edited in the geo-database
LASTEDITOR	String	50	-	The person that edits the feature for the last time in the geodatabase.

Table for Water hydrant

Attribute	Data Type	Length	Domain	Description
OBJECTID	Object ID			
SHAPE	Geometry	-		
FACILITYID	Text	20	-	Code that identifies Water system valve
INSTALLDATE	Date	-	-	The Date the Water hydrant is installed
MANUFACTURER	Text	30	wHydrant-Manufacturer	The name of the hydrant manufacturer
LASTSERVICE	Date	-	-	Last serviced date

OWNEDBY	Short	-	Asset Owner	The owner of water system valve which includes; Private, AWWSE, Agency, other.
MAINTBY	Short	-	Asset Manager	The expert of the organization that manages Water system valve
LASTUPDATE	Date	-	-	The last date the feature is edited in the geo-database
LASTEDITOR	String	50	-	The person that edits the feature for the last time in the geodatabase.

Table for Water Mainline Attribute

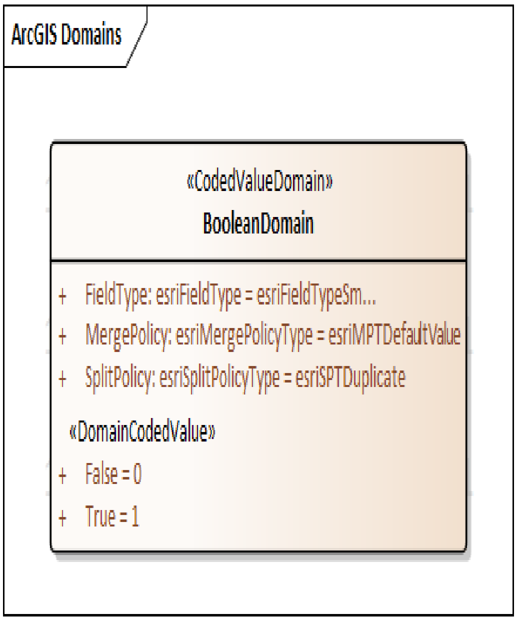
Attribute	**Data Type**	**Length**	**Domain**	**Description**
Shape	Geometry	-	-	Line
FACILITYID	Text	20	-	Code that identifies Water system valve
INSTALLDATE	Date	-	-	The Date the Water hydrant is installed
MATERIAL	Text	20	piPipeMaterial	The list of pipe materials types, Cast Iron, Copper, Cured In Place, Ductile Iron, Polyvinyl Chloride, High Density Polyethylene etc.
DIAMETER	Double	12	piPipeDiameter	A list of pipe diameters
WATERTYPE	Text	30	wWaterType	The type of water flowing through pipe, Potable Water, Raw Water, Reclaimed Water, Salt Water, Storm Runoff, Treated Water etc.
OWNEDBY	Short	-	Asset Owner	The owner of water mainline which includes; Private, AWWSE, Agency, other.
MAINTBY	Short	-	Asset Manager	The expert of the organization that manages Water mainline
LASTUPDATE	Date	-	-	The last date the feature is edited in the geo-database
LASTEDITOR	String	50	-	The person that edits the feature for the last time in the geodatabase.

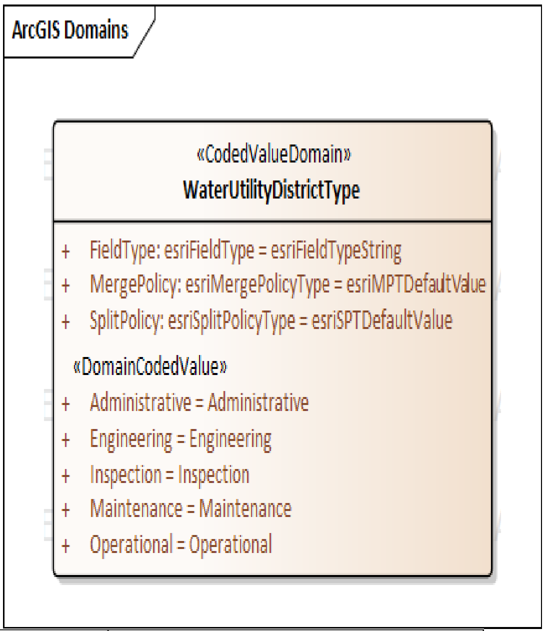
Table for Water lateral line Attribute

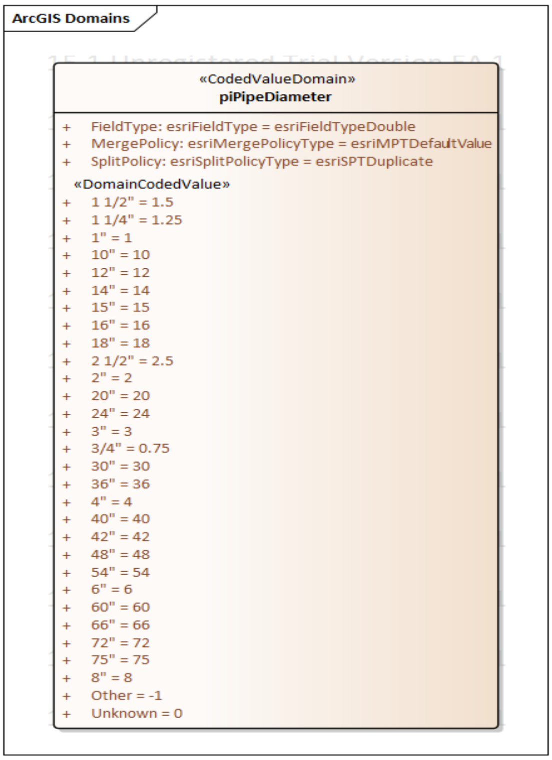
Attribute	Data Type	Length	Domain	Description
Shape	Geometry	-	-	Line
FACILITYID	Text	20	-	Code that identifies Water system valve
INSTALLDATE	Date	-	-	The Date the Water hydrant is installed
MATERIAL	Text	20	piPipeMaterial	The list of pipe materials types, Cast Iron, Copper, Cured In Place, Ductile Iron, Polyvinyl Chloride, High Density Polyethylene etc.
DIAMETER	Double	12	piPipeDiameter	A list of pipe diameters
WATERTYPE	Text	30	wWaterType	The type of water flowing through pipe, Potable Water, Raw Water, Reclaimed Water, Salt Water, Storm Runoff, Treated Water etc.
OWNEDBY	Short	-	Asset Owner	The owner of water mainline which includes; Private, AWWSE, Agency, other.
MAINTBY	Short	-	Asset Manager	The expert of the organization that manages Water lateral line
LASTUPDATE	Date	-	-	The last date the feature is edited in the geo-database
LASTEDITOR	String	50	-	The person that edits the feature for the last time in the geodatabase.

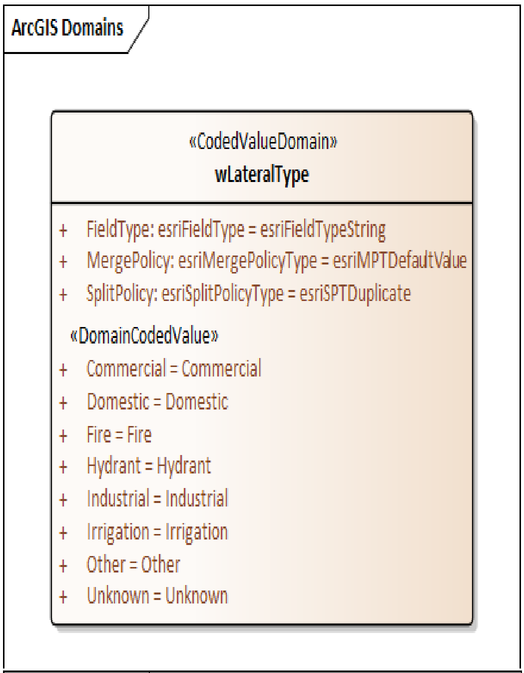
APPENDIX –E

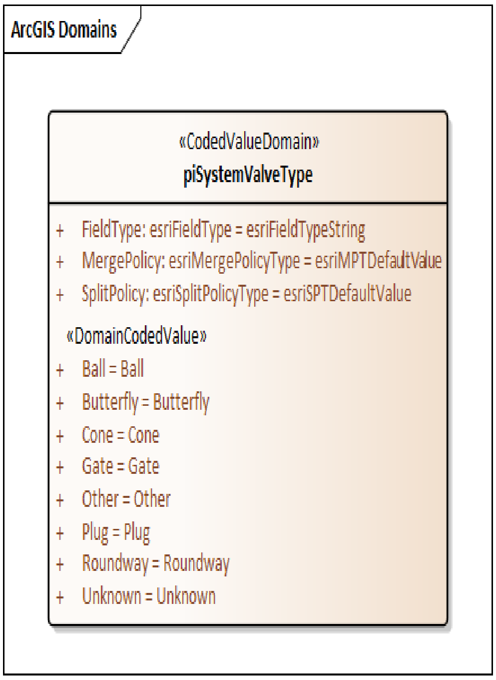
Domain for Feature Class

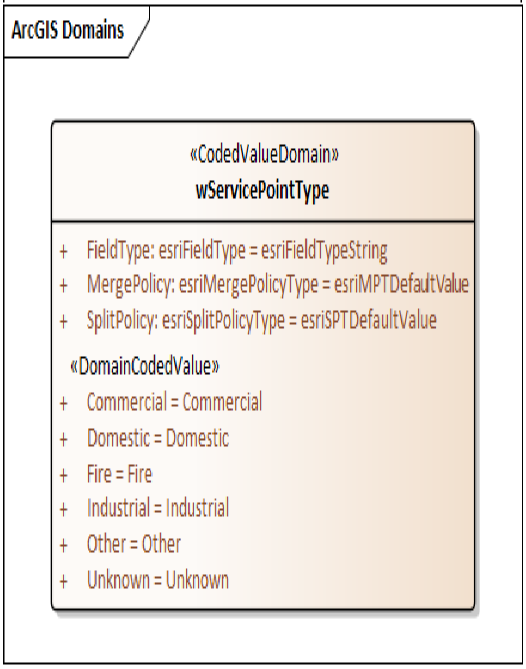







ArcGIS Domains
«CodedValueDomain»
wLateralType
+ FieldType: esriFieldType = esriFieldTypeString
+ MergePolicy: esriMergePolicyType = esriMPTDefaultValue
+ SplitPolicy: esriSplitPolicyType = esriSPTDuplicate
«DomainCodedValue»
+ Commercial = Commercial
+ Domestic = Domestic
+ Fire = Fire
+ Hydrant = Hydrant
+ Industrial = Industrial
+ Irrigation = Irrigation
+ Other = Other
+ Unknown = Unknown


ArcGIS Domains
«CodedValueDomain»
piSystemValveType
+ FieldType: esriFieldType = esriFieldTypeString
+ MergePolicy: esriMergePolicyType = esriMPTDefaultValue
+ SplitPolicy: esriSplitPolicyType = esriSPTDefaultValue
«DomainCodedValue»
+ Ball = Ball
+ Butterfly = Butterfly
+ Cone = Cone
+ Gate = Gate
+ Other = Other
+ Plug = Plug
+ Roundway = Roundway
+ Unknown = Unknown


ArcGIS Domains
«CodedValueDomain»
wServicePointType
+ FieldType: esriFieldType = esriFieldTypeString
+ MergePolicy: esriMergePolicyType = esriMPTDefaultValue
+ SplitPolicy: esriSplitPolicyType = esriSPTDefaultValue
«DomainCodedValue»
+ Commercial = Commercial
+ Domestic = Domestic
+ Fire = Fire
+ Industrial = Industrial
+ Other = Other
+ Unknown = Unknown