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WATER ENGINEERING

Presented by

Nduduzo Arnold MSIBI

MANAGEMENT OF A WATER DISTRIBUTION NETWORK BY COUPLING GIS AND HYDRAULIC MODELING: A CASE OF GHAZAOUET, ALGERIA

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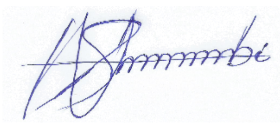
DECLARATION

I, Mr. **Nduduzo Arnold MSIBI**, hereby declare that this thesis represents my personal effort, realized to the best of my knowledge. Furthermore, I declare that all information, material, methods, and software from other works presented here, have been fully acknowledged, cited and referenced in accordance with the academic rules and ethics.



21 September 2020

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CERTIFICATION

I, the undersigned, **Dr. Chérifa ABDELBAKI**, Water Coordinator at the Pan African University Institute for Water and Energy Sciences including Climate Change (PAUWES); certify that Mr. Nduduzo Arnold MSIBI conducted his Master's Thesis research under my supervision.

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ABSTRACT

The rapid population growth, increase in unaccounted for water along with climate change serve as a major problem in both rural and urban water supply. For arid regions, this problem may be aggravated by inadequate management plans and lack of proper data collection related to the geographical location of water distribution networks. A possible solution is the utilization of a geographic information system (GIS) as a tool in decision-making process in the field of water distribution management. Coupling external hydraulic models with GIS can further enhance this management tool. The current study proposes these tools in assessing the performance of a drinking water distribution network. A methodology was developed by coupling GIS to a hydraulic model which was used to model the existing water distribution network in Ghazaouet town in the Tlemcen province, Algeria. The results obtained verified that the pressures at most junctions and majority pipes are enough to provide water to water consumers of the study area. Simulated water pressure varied significantly indicating that some sections of the network needed augmentation and may lose their hydraulic capacities. The velocity range of the water distribution network was generally between 0.1 m/s – 0.5 m/s, however parts of the network gave high velocities and very high unit head losses which exceeded 3 m/km. The approach adopted in this work showed how use of GIS effectively manage a water distribution network data and use of hydraulic models to analyze for malfunctions in the system. Consequently, water engineers and managers can better plan and budget for maintenance and predict future operating scenario.

RÉSUMÉ

La croissance rapide de la population, l'augmentation de l'eau non comptabilisée ainsi que le changement climatique constituent un problème majeur dans l'approvisionnement en eau en milieu rural et urbain. Pour les régions arides, ce problème peut être aggravé par des plans de gestion inadéquats et le manque de collecte de données appropriées liées à la localisation géographique des réseaux de distribution d'eau. Une solution possible est l'utilisation d'un système d'information géographique (SIG) comme outil de prise de décision dans le domaine de la gestion de la distribution de l'eau. Le couplage de modèles hydrauliques externes avec le SIG peut encore améliorer cet outil de gestion. La présente étude propose ces outils pour évaluer la performance d'un réseau de distribution d'eau potable. Une méthodologie a été développée en couplant le SIG à un modèle hydraulique qui a été utilisé pour modéliser le réseau de distribution d'eau existant de la ville de Ghazaouet. Les résultats obtenus ont vérifié que les pressions à presque toutes les jonctions à toutes les canalisations sont suffisamment réalisables pour fournir une eau adéquate au réseau de la zone d'étude. La pression d'eau simulée a varié considérablement, indiquant que certaines sections du réseau nécessitaient une augmentation et pourraient perdre leurs capacités hydrauliques. La plage de vitesse du réseau de distribution d'eau était généralement comprise entre 0,1 m / s et 0,5 m / s, mais certaines parties du réseau ont donné des vitesses élevées et des pertes de charge unitaires très élevées qui dépassaient 3 m / km. L'approche adoptée dans ce travail a montré comment l'utilisation du SIG gère efficacement les données d'un réseau de distribution d'eau et l'utilisation de modèles hydrauliques pour analyser les dysfonctionnements du système. Par conséquent, les ingénieurs et gestionnaires de l'eau peuvent mieux planifier et budgéter la maintenance et prédire le futur scénario d'exploitation.

DEDICATION

Bearing in mind that a journey of a thousand miles begins with one-step, with the right people, to the right direction, I would like to express my deepest gratitude and special thanks to my family and friends.

This work is dedicated to:

My Mother- Simangele Dlamini

My Brother- Danielson DosSantos

My friends

I greatly appreciate all of you for supporting and believing in me in my worst times. Your support has been my fortress and pillar of strength.

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It is my radiant sentiment to place on record my best regards, deepest sense of gratitude to Dr. Chérifa ABDELBAKI, the Water Coordinator as well as my thesis Supervisor for her warm heartedness and willingness to share knowledge. Her supportive approach resonates well with the work she does in the department. At this moment, I choose to gratefully, acknowledge her and her excellent contribution to my work.

Furthermore, my special appreciation is expressed to my mother, family, colleagues and friends, all of whom are my support structure, for their careful and precious guidance, which were extremely valuable for my academic pursuit. Lastly, special recognition goes to all PAUWES staff and Algerian Authorities and People for their sustenance and caring roles they played in helping me to adapt to the new diverse environment which led to successful accomplishment of my work.

I perceive this opportunity as a big milestone in my academic growth. I will strive to use gained skills and knowledge in the best way possible. If it were entirely my choice, I would not choose to leave out a single individual I had an encounter with in pursuit of this work, nevertheless hope to specially thank them in the near future.

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List of Acronyms and Abbreviations

ADE	Algeriene dex Eaux
CAD	Computer Aided Design
CMD	Cubic Meters per Day
DEM	Digital Elevation Model
DMA	District Metered Area
DXF	Drawing eXchange Format
ESRI	Environmental Science Research Institute
GIS	Geographic Information System
H-W	Hazen Williams Head loss Equation
IWS	Intermittent Water Supply
OBC	Open Database Connectivity
PAUWES	Pan African University Institute for Water and Energy Sciences
QGIS	Quantum Geographic Information System
SDGs	Sustainable Development Goals
TIN	Triangulated Irregular Networks
UFW	Unaccounted for Water
UNESCO	United Nations Educational, Scientific and Cultural Organization
US-EPA	United States Environment Protection Agency
WDN	Water Distribution Network

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Water scarcity has historically been more acute in arid regions especially rural areas. However, emerging trends point to worsening availability and quality in urban areas, due to changes in hydrology, climatology, increasing demand owing to population growth and most importantly mismanagement, (Romero-Lankao & Gnatz, 2016). Further to this claim, A 2006 United Nations report, entitled “Water, A shared responsibility,” concluded emphatically that: “Water insufficiency is often due to mismanagement, corruption, lack of appropriate institutions, bureaucratic inertia and a shortage of investment in both human capacity and physical infrastructure” (UNESCO, 2006). This presents the need to confront water supply systems amongst the key factors affecting sustainable supply of water for urban populations. Municipal, utilities or governments as a result are constantly struggling to reconcile water supply with growing demand due to poor physical infrastructure management.

Failure in the water supply network during operation makes it impossible to deliver water to urban dwellers, (Pietrucha-Urbanik & Studziński, 2019). This failure can be attributed to a number of factors including; ageing infrastructure, defects in materials installed, excessive pressure on the network and lack of preventative maintenance. Therefore, to deal with these problems and optimize water distribution network there is a need for data and a proactive or rather preventative maintenance system that capitalizes on big data, advanced digital tools and models. Water distribution managers can thereby employ tools such as the Geographic Information System that is capable of modeling and simulating the water supply network (Gössling et al., 2012). Moreover, the hydraulic model of the supply system developed in computer programs is now a research tool of fundamental importance used to analyze the properties and operations of a city's water-supply system (Kowalski, Kowalska, & Kwietniewski, 2015).

1.2 Problem Statement

The World Bank estimates that each year over 32 billion m^3 of treated water is lost through leakages and 16 billion m^3 lost through illegal connections from distribution network (Kingdom, Liemberger, & Marin, 2006). In Africa, many water utility companies are faced with the burden of poor management of water distribution networks. This is a nightmare for arid regions, as water supply services coverage is greatly affected due to 40% to 50% water losses in the distribution network (van den Berg, 2015). If this trend continues water stressed areas in Africa will remain troubled with water scarcity (Kingdom et al., 2006). However, dealing with half of the losses, could see water utilities increasing their coverage by a third to the growing urban population.

The Ghazaouet town hosts an important harbor on the coast for the entire north-western region of Algeria. Coastal seawaters are continuously exposed to industrial, urban, and agricultural wastes, releasing huge quantities of contaminants and trace metals, especially Zn and Cd, originating from a large industrial complex of zinc electrolysis, near the harbor of Ghazaouet (Belhadj, Aubert, & Dali Youcef, 2017). The deterioration of water quality aggravates the water scarcity problem and further adds to the staggering problem of water losses, as they account for over 30% of treated water nationally. Detection and identification of water distribution network parameters takes longer as a result contributes to an increased water loss volume. Consequently, there is lack of preventative maintenance that later on lead to poor water supply service provision and extended use of ageing infrastructure. Real-time data is often helpful in managing WDN and responding to emergencies and leakages. But unfortunately, there is shortfall in the system in place; to actively monitor, model and simulate performance, provide data and geographical information as well as report status of WDN to water utility company. According (Francisco González-Gómez, Miguel García-Rubio, 2011) the efficient management of water resources is a growing necessity especially, in an arid region as the Sahara.

1.3 Broad Objective

The principal objective of this study was to develop and apply a more effective management system for a water distribution network by coupling GIS with hydraulic modeling.

1.3.1 Specific Objectives

I. To create a GIS water distribution networks' database of descriptive and spatial operations data for the Ghazaouet water distribution network.

II. To simulate and analyze malfunctions of the Ghazaouet water distribution network using a hydraulic modelling software.

III. To develop a GIS and hydraulic modelling-based methodology to predict operating situations for improved management of a water distribution network.

1.4 Research Questions

- What is the most significant contribution of GIS and hydraulic modelling in improving management of an urban water distribution network?
- What are the existing hydraulic conditions of the Ghazaouet water distribution network?
- Why is GIS and hydraulic models recommended for management of urban water distribution networks in arid region?
- What are the main hydraulic components necessary to predict malfunctions in a water distribution network?
- What are the most effective methodologies that can be recommended for increasing water distribution network troubleshooting and management in Ghazaouet?

1.5 Justification of the Study

Water distribution network (WDN) serve as a crucial component for improved supply and adequate access to water. In light of the aspiration to achieve water for all as stated in African Water Vision 2025, the Sustainable Development Goals (SDGs) 2030 and the Africa Agenda 2063, efficient water management cannot be overemphasized. Therefore, the research studies the problems affecting water distribution in the African context. Realizing the problems, it is fundamental to collect data and create databases as well as propose a possible solution which is the utilization of a geographic information system (GIS) as a tool in decision-making process in the field of water distribution management. Furthermore, coupling external hydraulic models with GIS will be exploited to further enhance the proposed management tool. The outcomes of the research will add on to the scientific knowledge for the application of databases and software based on GIS and hydraulic modelling applications in order to access and use real-time data in the field of water supply.

1.6 Thesis Outline

Chapter 1 corresponds to this introduction.

Chapter 2 provides the foundation required to understand the water distribution network and hydraulic network modelling as well as simulation theories. This is accompanied by a literature survey highlighting issues in the existing modelling, simulation and optimization of WDNs.

Chapter 3 outlines the adopted methodologies and justifications of how the research will be carried out and where. The attention is placed on the suitability of the particular method for data collection, cleaning and analysis. Within this chapter a tool for effective water distribution network is proposed and explained in detail for application in a case study.

Chapter 4 presents and discusses the findings of this study and seeks to compare with previous theories and concepts of water distribution management. Subsequently, the chapter shall summarize the tool work flow chart for effective water distribution network, which can be applied in different case study areas.

Chapter 5 sums up the whole research work and commenting on the set objectives, how they were achieved and what can be done to improve this work in the near future and on the case study itself.

In addition to the main body of this thesis, there are several appendices that are of interest for the future reference.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter discusses the strengths, limitations, and, most importantly, the gaps identified in previous studies in water distribution network. The literature reviewed water demand and supply, hydraulic models and application of GIS as a tool in WDN management and gaps in the management strategies. Upon completion of the review, conclusions were drawn that preceded the choice for the methodology employed.

2.2 Water Supply

Water is a finite resource and one of the most vital commodities for survival of all living things on earth, (Alkali, Yadima, Usman, Ibrahim, & Lawan, 2017). It serves as a basic need with a wide range of valuable purposes that can never be substituted in domestic use, commercial, agriculture, navigation, recreation and construction amongst others. This precedes the notion of it being finite, as it varies spatially, and greatly with time and quantity on the earth. The total supplies of fresh water on earth far exceed human demand (Ortuña, 2010). About 2.8% of the total amount of water on earth is fresh water of which 0.6% is groundwater. The rest is available in the seas and oceans while a negligible amount as soil moisture. Out of the 2.2%, 2.15% is found in the form of ice sheets and glaciers while the remaining 0.05% is available as surface runoff. Anthropogenic activities, demands more efficient supply and share of the available freshwater resources, as hydrologically distributed (Lipponen & Nikiforova, 2017).

Water supply is largely dependent on demand by consumers (Bandyopadhyay, 2016). Thus, population projections are essential in determining how much water needs to be abstracted, treated and distributed for its different purposes in a given location (Berardi, Laucelli, Ugarelli, & Giustolisi, 2015). However, the greatest paradox of all times in the establishment of efficient water supply system is the capacity failure to meet the needs of the ever-growing populations. Increase in population and industrialisation is directly proportional to the rise in potable water demand (Ahmadi, Sušnik, Veerbeek, & Zevenbergen, 2020). For decision makers, it is very important to plan for effective and adequate delivery of potable water to cities. Whereas, network operators are very critical in managing and maintaining an efficient distribution system that will optimally supply water to populations with zero or less losses and malfunctions (van den Berg, 2015).

Pushing the system to unimaginable limits in order to satisfy fresh demand due to population growth results in water supply failure. Therefore, (Huang & Lee, 2019) believes that the population projections are necessary to design the best water supply system that will accommodate population growth over a 50-year period. As such, water policy makers rely on population projections to assess future demands for this much needed commodity (Sanchez et al., 2020). These projections are necessitated by the population change with time as a result of births and the arrival of migrants which add individuals to a population, whereas deaths and the departure of migrants subtract individuals from a population (Grouillet, Fabre, Ruelland, & Dezetter, 2015). In short, A water supply system has two primary requirements. Firstly, it needs to deliver adequate amounts of water to meet consumption requirements plus needed free flow requirements. Secondly, the water system needs to be reliable; the required amount of water needs to be available 24 hours a day.

2.3 Water Demand

According to (Trifunovic, 2006), the sum of water consumed plus water lost or leakages is called water demand whilst, (Scheele & Malz, 2007) argued that water can be defined as the quantity of water that the treatment plant must produce in order to meet all water needs in the community. This includes water used to fill individual tanks during consumption. Water demand is commonly expressed in cubic metres per hour (m^3/hr) or per second (m^3/sec), mega litres per day (ML/day) as well as litres per second (lps). Water demand can be expressed in various terminologies with special importance directed to average demand, specific demand or consumption and unaccounted for water (UFW). Average demand is the mean value of water demand derived from annual records. Whilst, specific water consumption is the average demand divided by the number of consumers (unit consumption per capita).

The precise and accurate forecasting of water demand is crucial when analysing the hydraulic performance of a water distribution system (Sanchez et al., 2020; Trifunovic, 2006). The population demand is key in ensuring an optimal supply of water in urban areas (Zhao, Jin, Zhou, Wang, & Pu, 2018). Water managers, take into account a lot of factors when designing water distribution systems, which is often accompanied by an unavoidable component of water demand which is water supplied free of charge (Liu, Shu, Yang, Wang, & Geng, 2018; Xiao et al., 2014; Yu, Liya, Xiaohui, & Yunzhong, 2010). In developing countries, this is the most significant consumer of water, accounting for over 50% of the total water delivery. This is a consequence of physical leakages existing in the system (Zaman, Tiwari, Gupta, & Sen, 2020).

Determination of water demand is the first step in hydraulic modelling work. The following equations are outlined by (Trifunovic, 2006), as crucial in water demand calculation.

$$\boldsymbol{Q_d = \frac{Q_{wc} \times pf_o}{(1 - {}^{l}/_{100}) f_c}} \qquad 2.1$$

Where:

Q_d,	Water demand (m^3/h)
$Q_{wc,avg}$,	Average water consumption (lcdp)
Pf_o,	Overall peak factor
l,	the leakage expressed as a percentage of the water production
f_c,	Unit conversion factor

This is a very simple equation; however, it necessarily introduces inaccuracies in the demand calculation. Nonetheless, the inaccuracy introduced by the equation adds to the safety to the design. This is as a result that the volume of leakage increases with higher consumption despite the fixed leakage percentage. Leakage level is usually constant throughout the day with a slight increase over night when the pressures in the network are generally higher (Trifunovic, 2006). Consequently, leakage is pressure dependent rather than consumption dependent.

The final water demand equation is written as:

$$\boldsymbol{Q_d = \frac{Q_{wc,avg}}{f_c} \times \left(pf_o + \frac{l}{(100 - l)}\right)} \qquad 2.2$$

Average water consumption can also be calculated, assuming there is no reliable information in the given distribution area. The approximation can be done in several ways and the equations below represents the methods that can be used.

$$Q_{wc,avg} = ncq \quad 2.3$$

$$Q_{wc,avg} = dAcq \quad 2.4$$

$$Q_{wc,avg} = Acq_a \quad 2.5$$

$$Q_{wc,avg} = n_u q_u \quad 2.6$$

Where:

n, is the number of inhabitants in the distribution area

c, is the coverage of the area, a 0 and 1 factor that converts number of inhabitants to number of consumers

q, is the specific consumption in litres per capita per day (l/c/d)

d, is the population density (number of inhabitants per unit surface area)

A, is the surface area of the distribution area

q_a, the consumption registered per unit surface area

n_u, the production capacity

q_u, the water consumption per unit product

The data for n, c, d, A, and n_u are accessible from central statistics or set by planning, local, urban, regional sectors.

2.4 Water Distribution Network

Water distribution system is a hydraulic framework consisting of aspect such as pipes, tanks reservoirs, pumps and valves, (A Saminu, Abubakar, Nasiru, 2013; Rossman, 2000). Also, water distribution system is summarised as infrastructure that consists three major components: pumps, distribution storage, and distribution piping network. Depending on topography, most of the water distribution systems require pumps to supply extra head to overcome the head loss due to friction. Storage tanks are included in the systems for emergency supply or for balancing storage to reduce energy costs. Pipes may contain flow-control devices, such as regulating or pressure-reducing valves. Water distribution network is represented by a series of links and nodes. A link has a node at each end. Nodes represent junctions, tanks and reservoirs, whereas links represent pipes. Water distribution network is maintained at positive pressure to ensure that water reaches all parts of the network, that a sufficient flow is available at every take-off point and to ensure that untreated water in the ground cannot enter the network (Ayad, Awad, & Yassin, 2016). The water is typically pressurised by pumps that lift water into storage tanks constructed at the highest local point in the network.

These systems are usually owned and maintained by local governments, such as cities, or other public entities. Water distribution networks are part of the master planning of communities, counties, and municipalities. Their planning and design require the expertise of city planners, water policy makers, water and civil engineers. Setting up this system requires an in-depth consideration of many factors, such as location, current demand, future growth, leakage, pressure, pipe size, pressure loss, firefighting flows, etc.

It is essential to supply water to the public; efficient water supply is of vital importance in designing a new water distribution network or in spanning the existing one. Also, investigating and establishing a good network ensuring sufficient head is necessary (Halagalimath, Vijaykumar, & Patil, 2016). Determination of flows and pressure head in network pipes has been of great amount and concern for those winding with designs, construction and conservation of public water distribution systems. Analysis and design of pipe networks create a relatively complex problem, especially if the network rest on range of pipes as frequently occurs in water distribution systems of large urban areas (Li, Yang, & Tan, 2019). In the vacancy of significant fluid acceleration, the behavior of a network can be determined by a continuance of even state conditions, which form a small but vital component for assessing the adequacy of a network (Ateş, 2016). Thus, an efficient water distribution network should contain pipe systems, pumping stations, storage facilities, fire hydrants, house service connections, meters, booster pumps and other appurtenances (Abubakar et. al., 2013).

2.4.1 Layout of Water Distribution Network

The distribution pipes are generally laid below the road pavements, and as such their layouts generally follow the layouts of roads. The components of a water distribution network include aspects of pipes, valves, reservoirs, tanks, junctions and pumps. Figure 2.1, below illustrates the design layout of a typical water distribution network (Rossman, 2000).

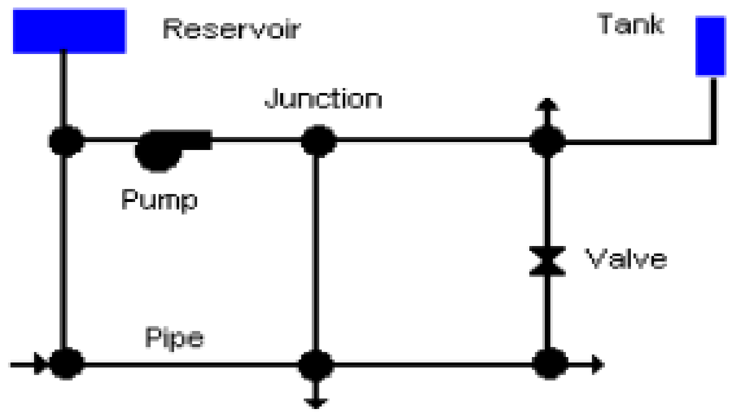

Figure 2.1: Water Distribution Network Components

Table 1.1: Summary of Water Distribution Network Components

Components	Description
PIPE	A pipe is the principal network element, viewed as a circular closed conduit for supplying water under pressure to the end users.
NODE/ JUNCTION	A connection point where pipes join together within the network.
VALVE	Pressure and flow regulator within the network.
PUMP	A hydraulic device used to increase water pressure within the system.
TANK	Used to maintain continuous water supply by storing water during low demand periods and releasing at peak demands
RESERVOIR	A storage reservoir, are used to 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

2.5 Water Distribution Systems

There are four different common distribution systems of pipe networks: grid iron, ring, radial and dead-end system. The following diagram depicts a summary of the types of water distribution network systems. This is serves as descriptive data for a water distribution network. It is very important to understand the distribution system type in order to determine the modelling approach

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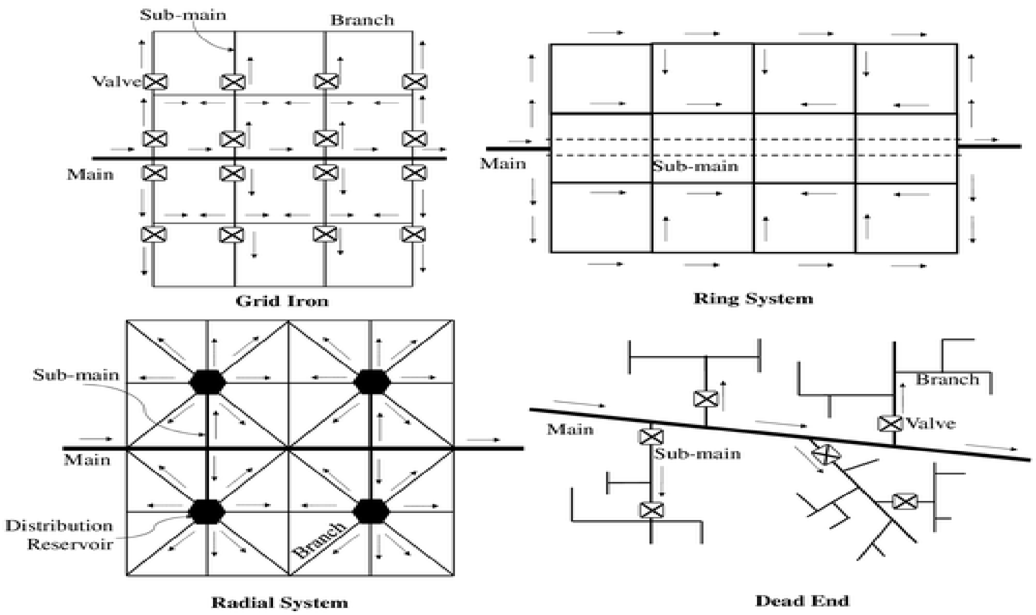


Figure 2.2: Illustration of the Different Types of Water Distribution Systems

2.5.1 Grid Iron System

Grid iron system allows water to flow continuously without stagnating through main lines, sub mains and branch lines. The interconnection of all pipelines eliminates the system dead ends. Thus, this system is also known as interlaced system or reticulation system. It is more suitable for well-planned cities. It is suitable for cities with rectangular layout, where the water mains and branches are laid in rectangles. The main advantage of this system is that the water is kept in good circulation due to the absence of dead ends. (Trifunovic, 2006). Moreover, this system has minimal head losses because of the continuous flow of water through the system. The discharge will meet the required discharge for firefighting and the system is very easy to repair by isolating areas through cutoff valves. The system has its own cons because of circulating flow from all directions, the pipes used in this system should be of large diameters and longer lengths. Determination of accurate discharge, velocity and pressure in a particular pipe is very difficult. This often presents issue in water distribution modelling as well (Wang, Deng, Won, & Cheng, 2019).

2.5.2 Ring System

Ring system, is sometimes referred to as the circular system where the main pipe line is laid peripherally to the distribution area. The supply main is placed all along the peripheral roads and sub mains branch out from the mains. Thus, this system also follows the grid iron system with the flow pattern similar in character to that of dead-end system. So, determination of the size of pipes is easy. This system gives quick service and the calculation of pipe size is easy. For a town with well-planned streets and roads, Circular system is more suitable (Yu et al., 2010).

This system provides no stagnation of water and it offers flexibility in terms of repairs as well as sparing large quantity of water for firefighting. Nevertheless, it is limited by the need of more cut-off valves and requirement of longer length and large diameter pipes.

2.5.3 Radial System

Radial system is quite opposite to the ring system. The whole area is separated into small distribution zones and an individual distribution reservoir is provided for each distribution zone. The water is pumped into the distribution reservoir kept in the middle of each zone and the supply pipes are laid radially ending towards the periphery. The system uses the elevated reservoir type that are connected radially to surrounding demand areas. A trunk main located at the center of the city is connected to all distribution reservoirs. This type of system is suitable for areas with radially designed roads (Trifunovic, 2006).

The advantages of radial system include that the water is distributed with high velocity and high pressure and thus presenting very small head losses because of quick discharge. Whereas the limitation is mainly due to high investment costs because it is characterized with a lot of individual distribution reservoirs.

2.5.4 Dead-End System

There are dead ends in the pipe system. Therefore, the water does not flow continuously and the whole pipe network is divided into several sub networks. Firstly, one main line is laid through the center of the city or area. Sub mains are laid on both sides of the main line and then sub mains divided into branch lines from which service connections are given. At every starting point of sub main line, a cut off valve is provided to regulate the flow during repair works etc. (Services, 2010). On the whole, this network diagram will look like a tree shape, so it is also called as tree system. This type of system is used mostly for the olden cities which are built in irregular manner without any planning. Nowadays, this system is not preferred. The main advantage of this system is that the determination of discharges and pressure easier due to a smaller number of valves. The disadvantage is due to many dead ends, stagnation of water occurs in the pipes (Barbeau, Gauthier, Julienne, & Carriere, 2005).

2.6 Types of Water Supply Operations

2.6.1 Continuous Supply

Continuous water supply aims to deliver water continuously to every consumer of the service area, 24 hours a day, every day of the year, through a transmission and distribution system that is continuously full and under positive pressure, (R. Rao, Naik, & Naresh, 2015). A continuous water supply system is an ideal situation for every water utility company but, presents a huge opportunity for water wastages due to unnoticeable continuous leaks and overconsumption. Nevertheless, this system provides many benefits as it reduces contamination level, because the pipes are under positive pressure and entry of contaminants into the pipes is restricted. Better health outcomes are achieved under operation of this system.

In addition, the lifespan of distribution networks is enhanced as steady pressures are reached in the pipes resulting to minimised damages. Hence, elaborate metering and effective leakage control provides a better demand management. Reduction in consumption due to change in habit from storing of water to none storing, also generates excellent consumer satisfaction which enhances willingness to pay even amongst poor consumers. Consumers can manage their time effectively; they can allocate more time for rewarding activities instead of worrying about water availability. It compensates for coping with poor quality of water services and lowers health risks. High quality of water is key to thriving cities and boosts economic development (UNESCO, 2015). It increases accessibility of water for the poor which ultimately leads to good sanitation practices and in turn works to achieve the Sustainable Development Goals (SDGs). To sum up, a continuous supply ensures that water is available 24 hours each day of the year.

2.6.2 Diurnal Pattern

A diurnal cycle is any pattern that recurs every 24 hours as a result of one full rotation of the Earth around its own axis. The diurnal water use patterns are of interest to hydraulic modelers, as these patterns are required for the design of water distribution systems.

2.6.3 Intermittent Supply

Intermittent Supply Intermittent drinking water supply (IWS) can be defined as piped water supply service that is available to consumers less than 24 hours per day seven days per week, (Nelson & Erickson, 2017). Water is supplied only during some fixed hours. It is adopted due to failure to reach sufficient pressure and sufficient quantity. This system yields very poor quality of water, since it requires greater pipe sizes due to the very high discharge through all the pipes. IWS can be caused by insufficient water resources, inadequate infrastructure, excessive water consumption by users, excessive water losses in the distribution network, or a combination of those factors (Ataoui & Ermini, 2017). An intermittent supply is inconvenient and can be costly for users, who have to adjust their water use to the supply schedule or invest in storage tanks. Unplanned urban growth and accompanying un-systematic expansion of drinking water distribution networks are also often underlying causes of IWS.

2.7 Hydraulic Modelling

Hydraulic models are efficient decision support tools for effective management of water distribution networks (WDNs) (Kara, Ethem Karadirek, Muhammetoglu, & Muhammetoglu, 2016). Water distribution modeling tools can be used by water utilities to help ensure reliable delivery of safe drinking water to the public. These modeling tools are useful for system planning, optimization of operations, contamination warning system design, contaminant detection, and disaster response (AL-Washali et al., 2020; Annan & Gooda, 2018). The ability to perform these activities depends, however, on accurate hydraulic and water quality network models and on suitable software modeling tools. These softwares depends on a series of data inputs and different hydraulic formulas in order to model WDN. One important operation in hydraulic modelling is head-loss calculation based on proven theoretical formulas. The hydraulic head loss by water flowing in a pipe due to friction with the pipe walls can be computed using one of three different formulas:

i. Hazen Williams Equation

$$\boldsymbol{h_f = \frac{10.67\,Q}{C^{1.85} d^{4.87}}^{1.85}} \qquad 2.7$$

$\boldsymbol{H_f}$**:** head loss in m

Q: flow in m^3/sec
D: internal pipe diameter in mm

ii. **Chezy-Manning Equation**

$$v = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \qquad 2.8$$

v: average velocity in m/s
R: hydraulic radius in m
S: energy slope
n: manning roughness coefficient

iii. **Darcy-Weisbach Equation**

$$h_f = \frac{flv^2}{2gd} \qquad 2.9$$

h_f - head loss in m
f: friction factor
L: length of pipe in m
V: velocity in m/s
g: acceleration due to gravity
d: diameter of pipe in mm

The Hazen-Williams (HW) formula is the most commonly used head loss formula in the US. It cannot be used for liquids other than water and was originally developed for turbulent flow only. The Darcy-Weisbach formula is the most theoretically correct. It applies over all flow regimes and to all liquids. The Chezy-Manning formula is more commonly used for open channel flow. Nonetheless, it is easier to use the HW equation compared to DW because all parameters used are readily found in literature. Furthermore, the HW presents a simple way of calculating head losses, whereas, the DW equation is a bit difficult because it involves separate calculation of friction factors.

2.7.1 Water-CAD

The importance of water distribution network modelling and analysis cannot be overemphasized. It has gained wider application amongst water utility companies around the world. This has led to development of different softwares with improved capabilities to support water supply management for utilities and engineering firms. As a result, a powerful WDN modelling software called OpenFlows WaterCAD was borne. According to Bentley, OpenFlows waterCAD is a reliable decision support tool for water infrastructure management. The software environment provides engineers with a platform to design new systems and manage existing networks effectively to reduce disruption risks and energy use (Bentley, 2014).

OpenFlows WaterCAD is a subset of OpenFlows WateGEMS. This package is very cheap to use in planning, design, and operation of water distribution systems. Therefore, it is favoured by many users for its ability to support; the supply of clean potable water without interruption, cost-effective high-quality designs and increased capacity to adequate service levels (Izinyon & Anyata, 2009).

WaterCAD is a stand-alone application, capable of working from within MicroStation, as well as to an additional integration option to run from AutoCAD. Regardless of the platform used, WaterCAD maintains a single set of modelling files for true interoperability across platforms. This application offers an unlimited undo and redo functions, merging nodes in close proximity tool, automatic element labelling, aerial views, dynamic zooming and multiple layer support in its interface and graphical editing operations (Bentley, 2014; Izinyon & Anyata, 2009).

The hydraulic modelling power of WaterCAD provides amongst many functions; steady-state simulations and extended period simulation. In addition, this software supports a wide range of data formats including; the traditional shapefiles, dfx file, spreadsheet, database and OBC connections. Also supported is oracle spatial, GIS-ID property to maintain associations between records in data source, graphical SCADA element, customer meter element, automatic demand allocation from geospatial data. Since WDN modelling requires a true representation of the network as on the real system, WaterCAD is capable of extracting elevation data from DEM, TIN and shapefiles as well as CAD drawings and surfaces (Bentley, 2014).

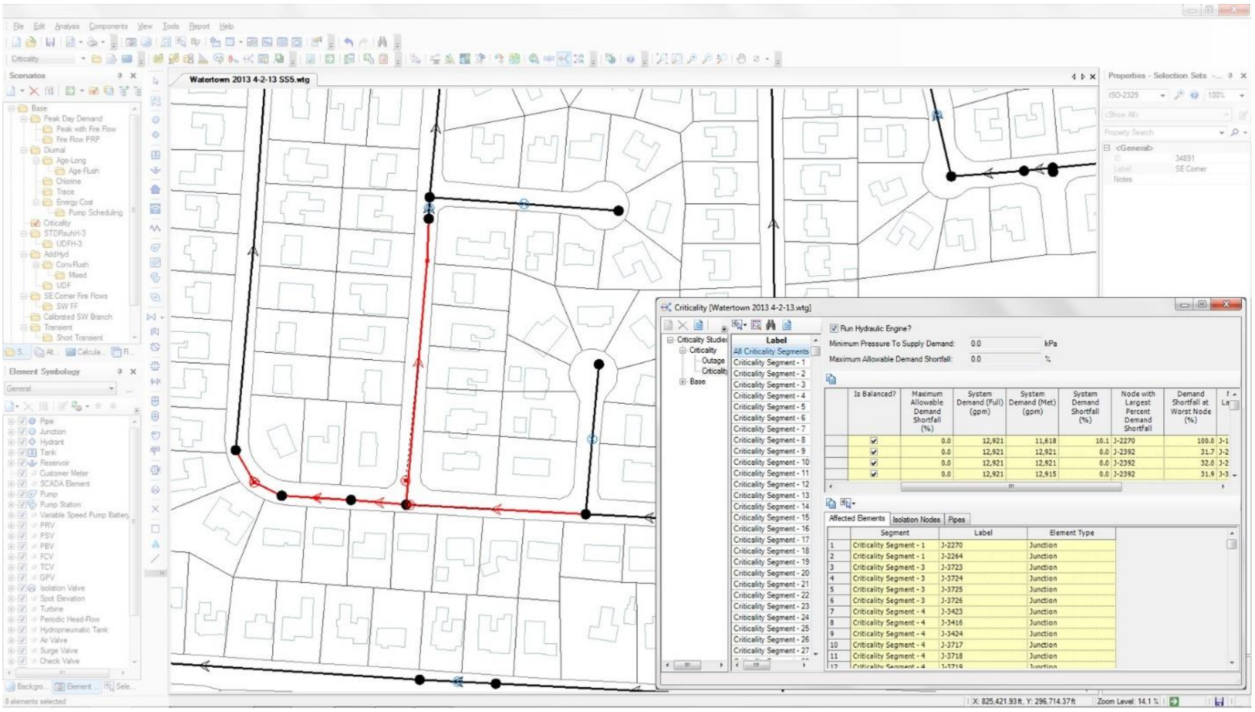


Figure 2.3:An Illustration of Schematized Water Network and its Attribute Tables on WaterCAD

2.7.2 WaterGEMS

WaterGEMS is a comprehensive and easy-to-use water distribution modelling application that can run with ArcGIS, AutoCAD and MicroStation or as a stand-alone application. This integration with different platform has made WaterGEMS more superior to OpenFlows WaterCAD. However, WaterGEMS builds on WaterCAD water distribution modelling, as a result user can easily upgrade to WateGEMS to experience an advanced modelling environment. This application is capable of pulling data from a GIS database, run various scenarios and then push data back to the GIS database.

WaterGEMS was originally developed by the Company Haestad Methods, Inc. based in Watertown, CT (USA). This company was acquired by Bentley Systems in mid-2004, acquisition from which the product began to be known commercially as Bentley WATERGEMS V8i. It is a product whose launch was given early twenty - first century and later software product WATERCAD the same software house launched in the 90s For many experts, WATERGEMS V8i more than an evolution of WATERCAD is essentially a 'super (Which is already included in WATERCAD), adds seamless integration with GIS environments and includes in a single commercial version all the advanced analysis modules which can only acquires separately in WATERCAD. In this sense, it is software whose target user is the company that operates supplies, regulators and / or important consulting projects. In terms of basic and intermediate tasks Hydraulic Modeling, WATERCAD and WaterGEMS are similar products (in fact share the same engine hydraulic calculation) and the same structure data model, so a model created in WATERCAD can be read in WATERGEMS V8i and vice versa. While WATERCAD, supports an autonomous platform (Stand Alone) and Micro Station and AutoCAD (as an addition to the product). WATERGEMS V8i adds support for ArcGIS to previous environments. In recent years the software has had a great evolution especially in features such as interoperability, ease of use, productivity tools, connection to external data; consultation processes multi-criteria, operations of spatial analysis, graphics capabilities, integration with Systems Geographic information (GIS), etc. Within the most recent developments include the following features like Data Exchange with other Information Systems, Electronic Devices and / or other management programs, Using Genetic Algorithms for automated processes hydraulic calibration, optimal design and energy optimization, Analytical Leakage Detection, Vulnerability Plans to Pollution Events, Systems integration with SCADA, Multi-parameter Quality Analysis, Network Renewal Planning, Integration with Analysis of Hydraulic Transients and Waterfall (Mehta, Yadav, Prajapati, & Waikhom, 2017).

WATERGEMS V8i is a hydraulic modelling application for water distribution systems with advanced interoperability, geospatial model building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, WATERGEMS V8i provides an easy-to-use environment for engineers to analyse, design, and optimize water distribution systems. WATERGEMS V8i is a multi-platform hydraulic and water quality modelling solution for water distribution systems with advanced interoperability, geospatial model-building, optimization, and asset management tools. From fire flow and constituent concentration analyses, to energy consumption and capital cost management, WATERGEMS V8i provides an easy-to-use environment for engineers to analyse, design, and optimize water distribution systems. WATERGEMS V8i is useful for managing the water system data, time-series hydraulic result, current and future scenarios and other core infrastructure data all within the same GIS environment (Mehta et al., 2017).

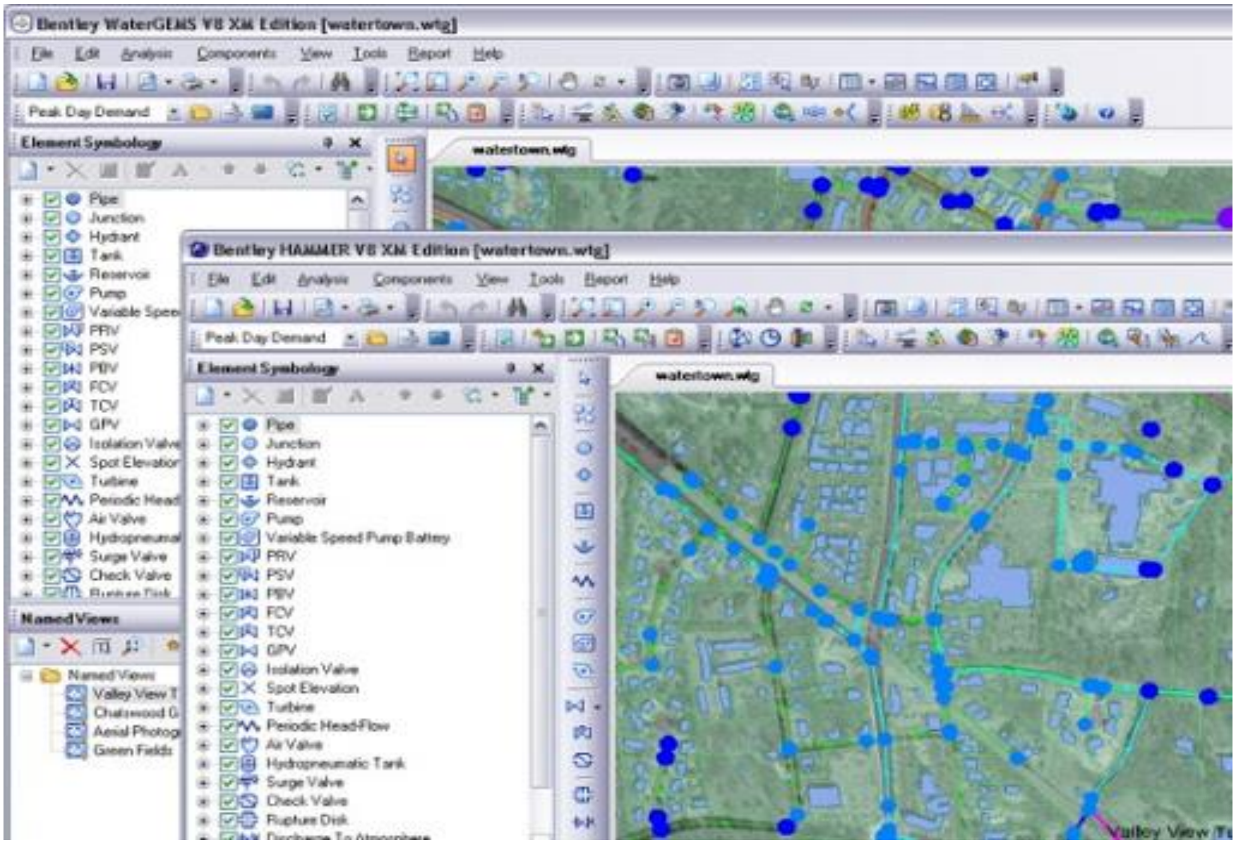


Figure 2.4: WDN Editing Operation on the Standalone Bentley WaterGEMS V8 Software

2.7.3 EPANET

The Environment Protection Agency (EPA) uses Windows-based software called EPANET to model water distribution piping systems. EPANET is a computerized simulation model which was developed by the National Risk Management Research Laboratory to help water utilities meet the growing need to better understand the movement and transformations undergone by treated water that is introduced into their distribution systems in order to meet regulatory requirements and customer expectations. EPANET performs extended period simulation of the hydraulic and water quality behavior within pressurized pipe networks (Abu-mahfouz, Hamam, Page, & Djouani, 2016). This is an open-source software available to the public. It predicts dynamic hydraulic and water quality behavior within a drinking water distribution system operating over an extended period of time. EPANET, like most water distribution system modelling software programs, performs modeling off-line, which means the engineer uses a static, stand-alone description of the water distribution system (i.e., network infrastructure model) disconnected from any real-time data (Saminu, Abubakar, Nasiru, 2013; Alkali et al., 2017).

EPANET was developed to help water utilities maintain and improve the quality of water delivered to consumers through distribution systems. It can also be used to design sampling programs, study disinfectant loss and by-product formation, and conduct consumer exposure assessments. It can assist in evaluating alternative strategies for improving water quality, such as altering source use within multi-source systems, modifying pumping and tank filling/emptying schedules to reduce water age, using booster disinfection stations at key locations to maintain target residuals, and planning cost-effective programs of targeted pipe cleaning and replacement" (Rossman, 2000).

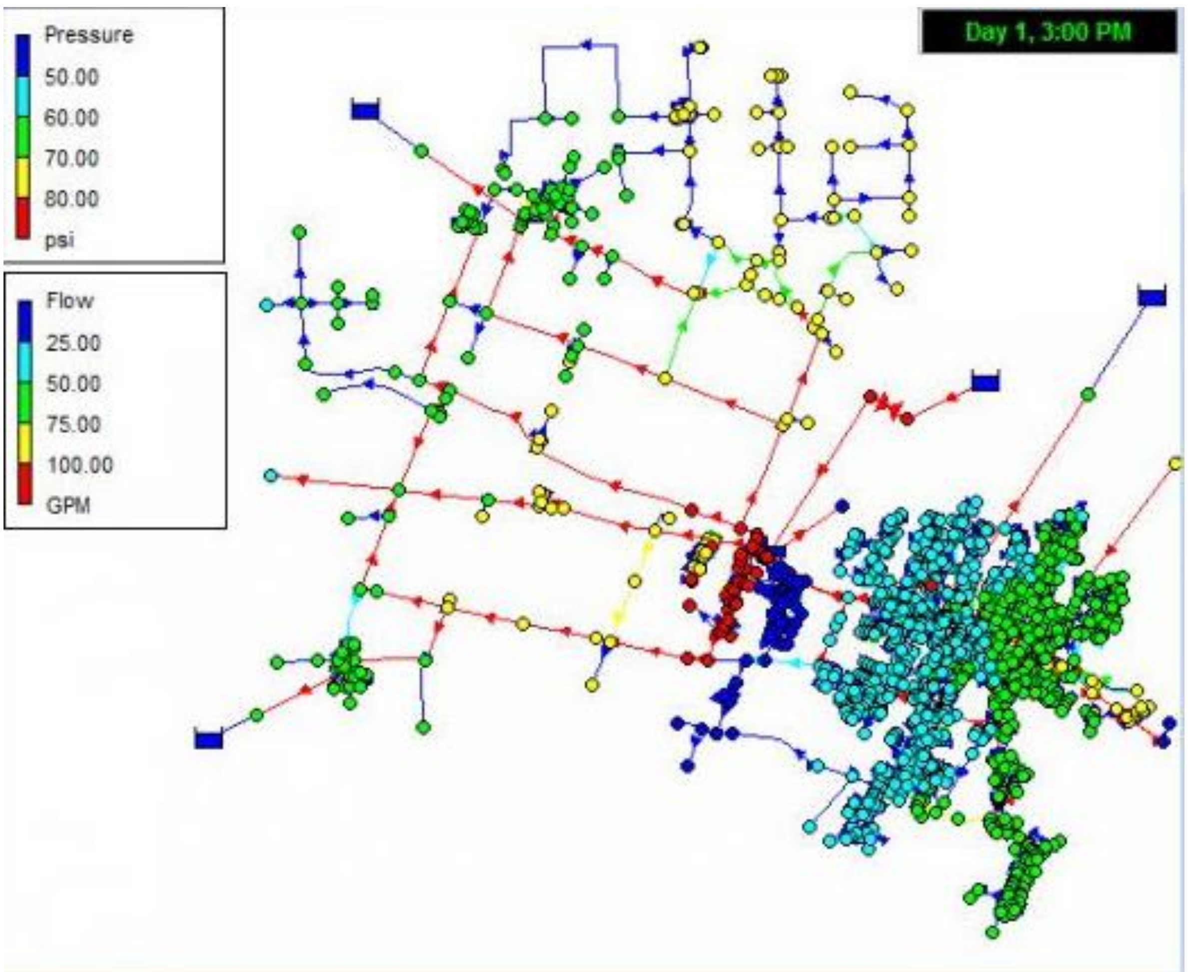


Figure 2.5: A View of the EPANET Software Displaying a WDN Model

Distribution system networks consist of pipes, nodes (pipe junctions), pumps, valves, and storage tanks or reservoirs. EPANET tracks the flow of water through each pipe, the pressure at each node, the height of the water in each tank, and the concentration of different chemicals throughout the network during a simulation period. The software provides an integrated computer environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats including color-coded network maps, data tables, time series graphs, and contour plots (Rossman, 2000).

EPANET provides an extended-period hydraulic analysis package that can handle systems varying in size, compute friction head loss using the Hazen-Williams, the Darcy Weisbach, or the Chezy-Manning head loss formula, including minor head losses for bends and fittings. It can model constant or variable speed pumps, compute pumping energy and cost, model various types of valves and storage tanks of different shapes. It can consider multiple demand categories at nodes, each with its own pattern showing variation with time variation, model pressure-dependent flow from emitters and base system operation on simple tank level or timer controls as well as on complex rule-based controls (Rossman, 2000).

2.8 Geographic Information System Application

Geographic information systems (GIS) have become essential tools in the spatial and statistical analysis of water resources for more effective management (Abdelbaki, Benchaib, Benziada, Mahmoudi, & Goosen, 2017). GIS have been characterized by many as a very powerful tool when it comes to information technologies. In definition, GIS is a system for the management, analysis, and display of geographic knowledge, which is represented using a series of information sets (Awad, Yassin, & AYAD, 2017). However, the University of Wisconsin-Madison describes GIS as: a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data. The power of GIS lies in its ability to georeferenced data. This technology is dependent on geography, which means that some portion of the data is spatial. Therefore, GIS can be used for several purposes especially problem solving and decision-making processes, not leaving behind its main feature of visualising data on a spatial environment. In GIS geospatial data is analysed to determine; feature locations and their relationships, where the most and least of some features exists, the density of features in a given space, what is happening inside an area of interest, activities nearby some feature and changes in specific area over time (A Saminu, Abubakar, Nasiru, 2013).

Realising the power of GIS application in various fields, it has also been intensively used in water supply field. In water distribution, GIS is crucial in organizing data for use in water distribution network design and analysis. Furthermore, it is used for network management; such as identifying valves to be closed in case of pipe break, service area treatment plants, and network skeletonization (Awad et al., 2017).

2.8.1 ArcGIS

ArcGIS is a comprehensive set of professional GIS applications used to solve problems, to meet a mission, to increase efficiency, to make better decisions, and to communicate, visualize, and understand an idea, a plan, a conflict, a problem, or the status of a situation (Awad et al., 2017; Hillier, 2011). ArcGIS can be used to create an integrated model for water distribution networks. In simple terms, the system contains six main procedures. Creation of digital vector maps; followed by geodatabase creation to store network data. Then, building geometric networks is needed to ensure accurate network drawing, followed by topology rules creation to ensure accurate spatial relationships. Finally, relationship classes are applied to link external model data with GIS database.

ArcGIS uses basic tools for data visualization and data inquiry handled by the ArcMap platform. One of the widely applied is the SQL attribute select tool. SQL is a standard computer language for accessing and managing databases. In ArcGIS, SQL is used to define subset of data in order to perform some operations. Furthermore, ArcGIS use thematic maps symbology are helpful in the way to visualize data associated with drawings, they are used to represent data with colours and symbols. Also, data can be labelled using the labelling tool. In WDN management the platform offers transfer attributes application or plugins. The application adjusts GIS layers to be used in hydraulic analysis models. This plugin copies attribute data from point features such as pipes to adjacent line layers (Ayad et al., 2016).

2.8.2 Quantum GIS

Quantum GIS (QGIS) is an Open Source Geographic Information System. The project was born in May of 2002 and was established as a project on Source Forge in June of the same year. A lot of effort and hard work was invested to make the GIS software (which is traditionally expensive commercial software) a viable prospect for anyone with basic access to a Personal Computer. QGIS currently runs on most Unix platforms (macOS/OS X included) and Windows. QGIS was developed using the Qt toolkit and C++. This means that QGIS feels snappy to use and has a pleasing, easy to use graphical user interface.

QGIS aims to be an easy to use GIS, providing common functions and features. The initial goal was to provide a GIS data viewer. QGIS has reached that point in its evolution and is being used by many for their daily GIS data viewing and editing needs. QGIS supports a number of rasters, vector and mesh data formats, with new support easily added using the plugin architecture.

QGIS is released under the GNU Public License (GPL) Version 2 or above. Developing QGIS under this license means that one can (if you want to) inspect and modify the source code and guarantees that you, our happy user will always have access to a GIS program that is free of cost and can be freely modified.

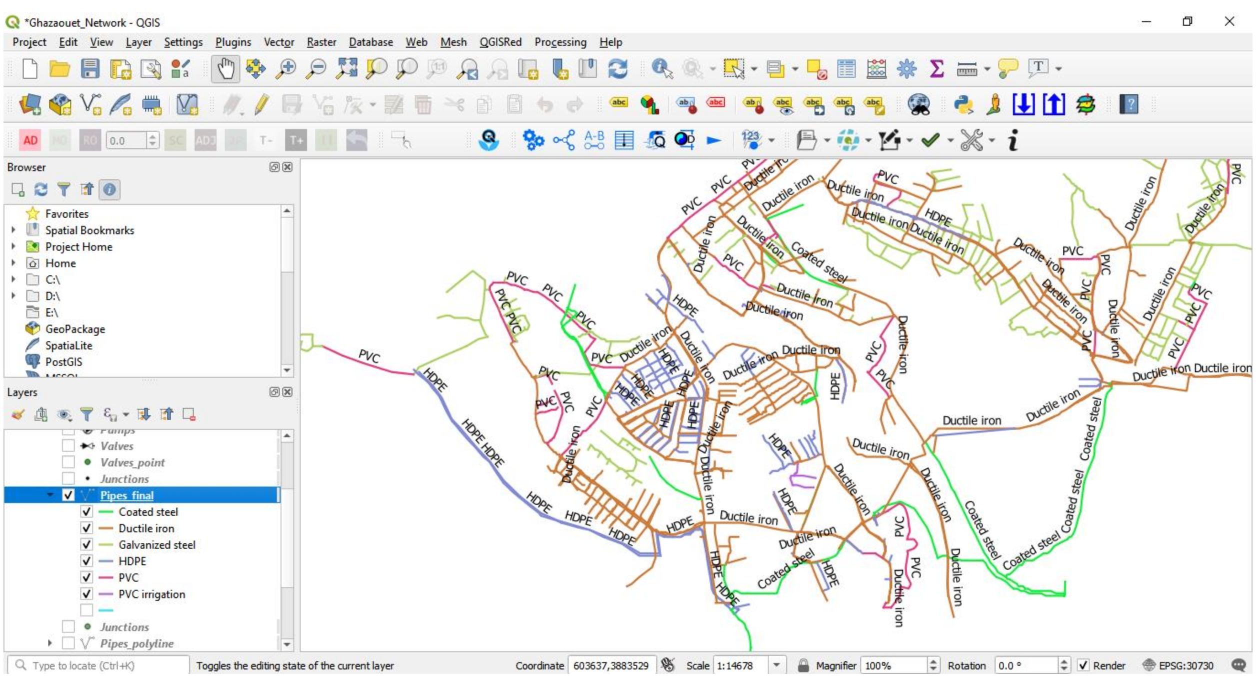


Figure 2.6: Screenshot of QGIS Display of a Color Water Distribution Network

2.8.3 MapInfo

MapInfo Pro, is a powerful computer mapping program that can handle geographical information perfectly. It allows one to display your data as points, as thematically shaded regions, as pie or bar charts, as districts, etc. Furthermore, this software allows one to perform geographic operations such as redistricting, combining and splitting objects, and buffering. In a more advanced and easy way you can also make queries against your data and access your remote data directly from MapInfo Pro. For example, MapInfo Pro can show which water reservoir is the closest to your communities. It can calculate the distances between water sources and communities. What makes it all come together is a visual display of your data on the map.

2.9 Case Studies in the African Context

h In Algeria, GIS and hydraulic modelling software EPANET was used to diagnose the Chetouane water distribution network. The study's methodology was based on network modelling which was used to analyse and simulate the Chetouane network using GIS (MapInfo 8.0) and EPANET 2.0. In this study, EPANET was chosen for the simulation of the distribution velocities and pressures. The method employed, was key in identifying network problem that were not limited to; worn out pipes, leakages and supply discontinuities (Abdelbaki et al., 2017).

The different available options in GIS allows for the acquisition of network maps and their associated characteristics (Scott, Ho, Dey, & Talluri, 2015). The establishment of GIS for the Chetouane water distribution network was inspired by the fact that it allows spatial analysis by joining layers of information stored in the database(Yu et al., 2010).

The Chetouane case study employed plugin softwares in preparing the network model before simulation. The importance of the plugins is to simplify the tedious work of organizing and joining network parameters that could have been handled manually. As a result, DFX2EPA was utilized for the conversion of GIS-EPANET files, (Abdelbaki et al., 2017). This is an open source software, that runs as a plugin on GIS. However, network elements such as tanks, pumps, and valves should be added manually to the model in EPANET. In addition, the conversion software can calculate the lengths of pipes; while other network data, such as elevations nodes, water need and pipe diameters must be modified using EPANET (Abdelbaki et al., 2017), after the converted file is loaded. After the conversion of the different layers network data, such as diameters, pipe roughness, altitudes, reservoirs and valve characteristics are added into the system. The network consumption is defined in the nodes of the water distribution network, which allocates the flow based on the needs of the population; this rate is divided according to the importance of consumption points in the network (Abdelbaki, Touaibia, Ammari, Mahmoudi, & Goosen, 2019).

The Chetouane case study revealed a methodology for improved management of a water distribution network by coupling MapInfo GIS 8.0 software with hydraulic modeling (EPANET2.0). By applying the above methodology it revealed areas of the network that were working properly and which areas needed attention (Abdelbaki et al., 2017, 2014).

2.10 Summary

It is observed in the literature that there are many topics related to the design, operation, reliability and maintenance of water distribution system. Several studies are considered the hydraulic analysis and pump scheduling performance. It was also noted that water distribution networks, does not only face hydraulic problems, but spatial data of the network is critical in managing an efficient system. This application of GIS in water distribution network is wide spread in Europe and the West as well as other developed countries, with developing countries still lagging behind. However, the case studies in the African context reveals that there is a great potential to employ GIS based network management and hydraulic modelling at the same time. Studies reveal that most of the water is wasted in leakages in the pipelines. EPANET and WATERCAD software coupled with GIS can be applied to solve water distribution system related problems. A methodology can be developed that can take advantage of useful plugins and supporting software to simplify the network modelling task. The present study shall improve on methodologies presented on literature.

CHAPTER 3: METHODOLOGY

3.1 Study Area

Ghazaouet is a town and commune located 37° 25′ 19″ north, 122° 05′ 06″ west in Tlemcen Province in north-western Algeria (Belhadj et al., 2017). According to the 2008 census it has a population of 33774 people. Ghazaouet is a commune or town located in a hilly area with ground elevations ranging between 0 to 216 m. Figure 3.1.A shows the map of Algeria and Tlemcen province where the Ghazaouet town is located.

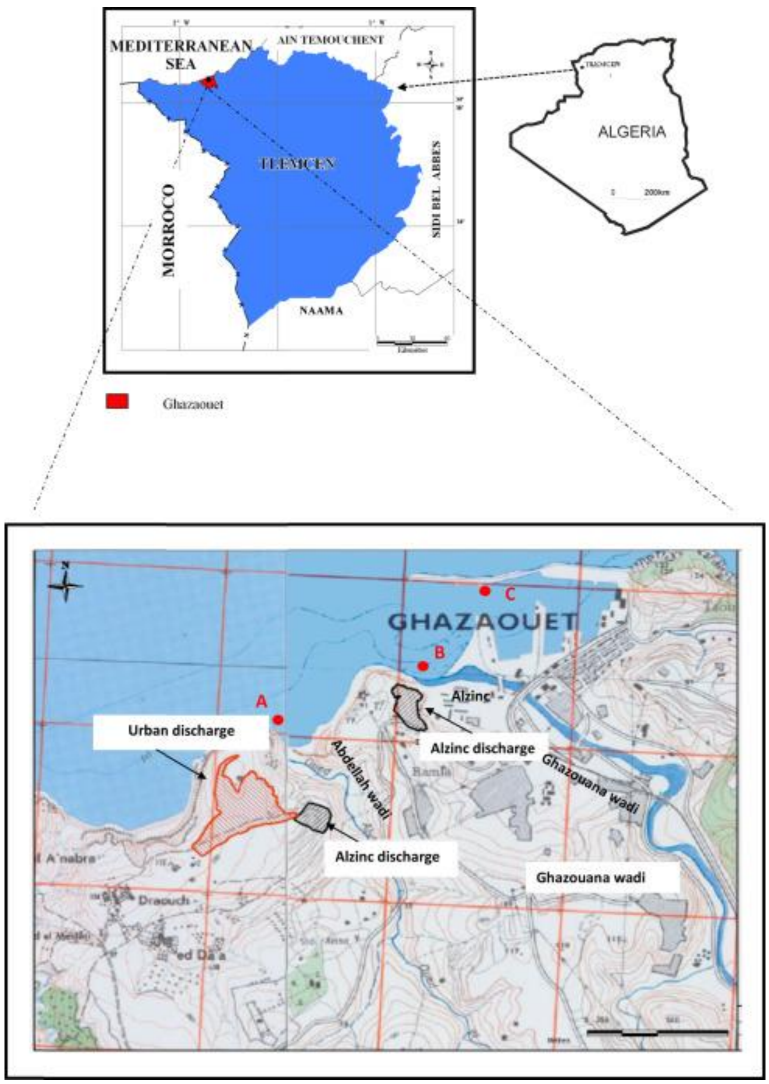


Figure 3.1: Case Study Area – Ghazaouet Map

The Ghazaouet water distribution network is combined layout system with particular variations from branched, serial and looped system at different areas of the commune. The company responsible for water supply in the town is called the Algerian Water Authority (Algeriene des Eaux, ADE).

3.2 Study Design

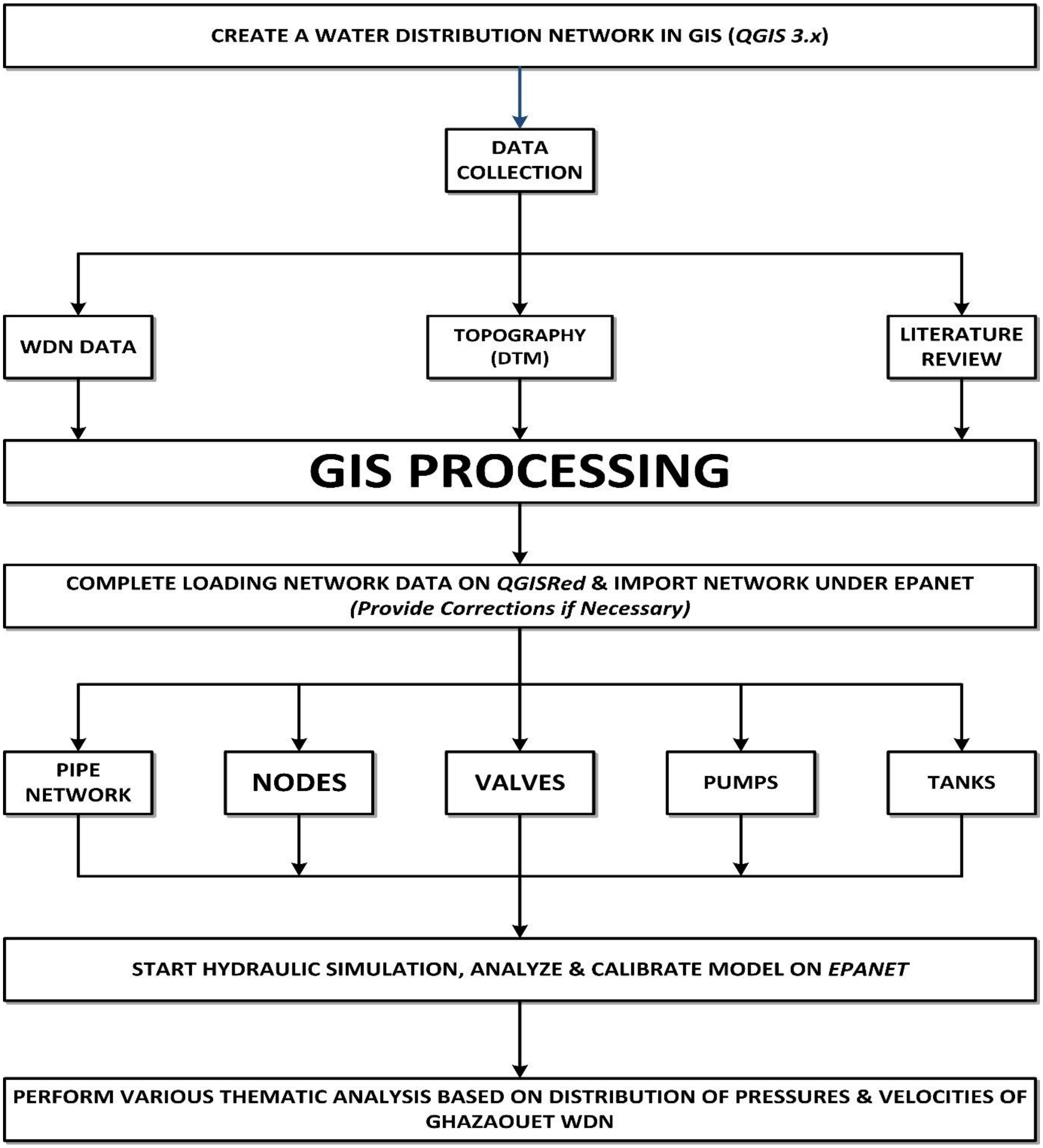


Figure 3.2: Research Design and Work Flow Chart

3.3 Data Collection

The required data will include: the population data of the different wards in Ghazaouet, general layout map of the city stratified into wards forming loops for the network, existing water distribution layout map if any, coordinates of valves, pumps and tanks and other distribution system components, elevations of water distribution nodal points and direct sample head counts of the various sectors to determine the water demand at each node in the distribution network.

3.4 General Input Data

General layout of the network will be taken from the maps available in the Algerien Water Authourity. The specific data to look for are: topography - ground elevations in the area of the system; some specific natural barriers. Type of the system - distribution scheme: gravity, pumping, combined; location and role of each system component. Population - distribution and estimated growth of the city.

3.5 Water Demand Estimation

Demand categories present in the system: domestic, industry, and agriculture. Average consumption, patterns of variation: daily, weekly and seasonal peak factors. Water demand will be estimated by equation 2.2 and 2.3.

3.5.1 Determination of Nodal Base Demand

One of the required data inputs on EPANET for hydraulic modelling is nodal demands. The determination of nodal demands shall be computed based on two assumptions. The study will assume that: there is an even distribution of consumers and that the border between supply areas of two nodes connected by a pipe is at the half of their distance (D. R. M. Rao, Ahmed, Ellamraj, & Reddy, 2016; Trifunovic, 2006). Therefore, total length generating from one node to other nodes will be determined. Half of above length is taken as representative length for that node. Demand for each node will be calculated by multiplying as representative length and demand per meter length. Demand per meter length is calculated:

$$q = \frac{Q_d}{\sum L} \qquad 3.1$$

Where: q, is the nodal demand

Q_d, is the total demand of the distribution area

L, is the total network length

A comprehensive formula for demand allocation was detailed by (Trifunovic, 2006). Hence the relationship is established for each loop formed by the total number of pipes (m) as a unit consumption per meter.

$$q_i = \frac{Q_1}{\sum_{j=1}^{m} L_{j,l}} \qquad 3.2$$

Where: Q_1 is the average demand within loop l

L_1 is the length of pipe j forming the loop.

Each pipe supplies consumers withing the loop by flow equal to:

$$Q_{i,j} = q_1 \times L_{j,l} \qquad 3.3$$

And node I, connecting two pipes of loop l, will have the average consumption

$$Q_{i,j} = \frac{Q_{j,i} + Q_{j+1,i}}{2} \qquad 3.4$$

Finally, one pipe often belongs to two neighbouring loops. This means that one node may supply the consumers from several loops. The final nodal consumption is determined after the above calculation has been completed for all loops in the system.

$$Q_i = \sum_{i=1}^{n} Q_{i,l} \qquad 3.5$$

Where n, demotes the number of loops supplied by node i.

3.6 Geographical Data

The study requires bulk data sets for use in geographical information system software such as Quantum GIS. The data was collected through field surveys using a Geographical Position System (GPS) where the coordinates for water distribution network were recorded in a checklist and later entered in to a Microsoft Excel Sheet for organisation and formatting. Google Earth was also be employed to collect coordinates data. The field data was used to calibrate and validate data obtained through Google Earth.

Administrative boundaries, layout maps of the city, Digital Elevation Model (DEM) data was obtained from the CGIAR-CSI Geo-Portal and the Ghazaouet water utility company. The data was downloaded in compatible .tif, .hdr, .tfw and .kml formats from the internet. In addition, the layout map for water distribution network was sourced from water utility company in Ghazaouet.

3.7 Water Network Parameters

A water distribution network (WDN) comprises of the following components; pipes, nodes, valves, pumps, and tanks. In terms of the distribution hydraulic concepts, there are basic equations that govern the flow in the system. These equations are conservation of mass, energy conservation equation (Bernoulli's principle) and the head loss equation (Hazen-Williams pipe head loss equation). The network parameters used include: pipe lengths, pipe diameters, roughness coefficients (Hazen-Williams), nodes numbers, and nodal elevations.

For this study, Hazen-Williams (H-W) formula was considered and the reason for the choice is explained in Table 3.2 and the flow units are as Cubic Metres Day. The map of Ghazaouet was created from shapefile data obtained from the Humanitarian Data Exchange (HDx) platform handled by the Office for the Coordination of Humanitarian Affairs. Hydraulic software EPANET using the H-W equation was used for simulating the given Ghazaouet WDN.

Table 2.1: Selection of Suitable Head Loss Equation

	Parameters for formula selection	**Darcy-Weisbach**	**Hazen-Williams**	**Manning's Equation**
1.	Fluids	*All fluids	*Only water	*Only water
2.	Friction factor 'f' or Roughness coefficient 'c'	Tedious to obtain 'f'	*Easy to obtain 'c'	Easy to obtain 'n'
3.	Flow type	*Any flow	*Smooth flow	Rough flow
4.	Open or Closed	*Closed pipes	*Closed pipes	Open channels
5.	Selection for formula for this study	Not Applicable	Applicable	Not Applicable

The hydraulic head loss by water flowing in a pipe due to friction with the pipe walls was computed using the Hazen-Williams formula. It cannot be used for liquids other than water and was originally developed for turbulent flow only. The H-W is much easier to use compared to the Darcy Weisbech equation.

The Hazen- William Formula:

$$H_f = \frac{10.44 * L * Q^{1.852}}{C^{1.852} * D^{4.866}} \qquad 3.8$$

Where:

Q = Discharge; (m^3/hr)

C = Hazen William Coefficient;

D = Diameter; (mm)

L = Length of the pipe; (m)

H_f = Head Loss (m)

The roughness coefficient is an expression of the resistance to flow of a surface such as the bed or bank of a stream. Since this research will use the Hazen-Williams equation, the pipe roughness coefficients below will be considered for different pipe materials.

Table 3.2: Hazen-Williams pipe roughness coefficients. Source: (A Saminu, Abubakar, Nasiru, 2013)

No.	Type of material	Roughness coefficient
1.	Vitrified Clay	110
2.	Galvanized Iron	120
3.	Concrete (Lined)	130
4.	Cast Iron	140
5.	Fiber/ PVC	150

Each formula uses a different pipe roughness coefficient that must be determined empirically. Therefore, it is very important to note that a pipe's roughness coefficient can change considerably with age. Hence the table below as proposed shows the pipe material types versus their roughness coefficients when age is taken into account.

Table 3.3: Hazen-Williams Pipe Roughness Coefficients for Different Material and their Age. Source: (Rossman, 2000)

Pipe type	Age	Hazen-Williams roughness coefficient
Coated steel	New	140
Cast iron (CI)	New	130- 140
Ductile iron (DI)	New	130
Galvanized steel	New	130-140
High density poly ethylene (HDPE)	New	140-150
Polyvinyl chloride (PVC)	New	140-150

3.8 Model Data Organization

The data required to build the model is in GIS shapefile format. These shapefiles were created and cleaned in GIS and imported to EPANET as an input file for hydraulic modelling. The shapefiles contained information about the WDN and maintained databases that stored the attribute tables. The network parameters included the pipe catalogue shapefile which was arranged and detailed as: GIS ID, name, class, material, length, internal diameter, pipe roughness, X and Y coordinates of junction. Valves were tabulated as: GIS ID, name, elevation, type of valve, X and Y coordinates of valve, diameter; Pumps (GIS ID, elevation, X and Y coordinates of pump, diameter, pump curve, on and off levels) and Reservoir specifications (GIS ID, elevation, capacity, reservoir levels). These network datasets were imported to EPANET for hydraulic calculation. The built model was checked for connectivity in order to identify and detect orphaned elements from pipes and nodes on the EPANET model. Furthermore, the elements were counted on EPANET in order to give a summary of pipes, junctions, valves and reservoirs and tanks. In addition, the total length of the pipe network model was estimated.

The data was organized in tables in order to create and maintain a spatial and non-spatial database for the case study area. This activity was handled by the powerful Microsoft excel spreadsheet in comma delimited or comma separated values (.csv format) and Microsoft access tables. Spatial data also exists in shapefiles. The descriptive data was added to QGIS 3.10 with case study base maps. QGIS is essential in handling the spatial data of the network and overlay operations, extracting elevations and visualizing the network on top of base maps.

QGIS was employed alongside other plugins and supporting programs like DXF2EPA software that converts shapefiles to an EPANET ready input file. However, the program, comes with a lot of limitations as it imports the basic attributes leaving out the specific and essential attributes needed for EPANET simulation. These elements are tanks, valves and pumps as the softwares exports junctions and pipes. Pipe diameters, nodal elevation data and material and demand data are added manually to EPANET.

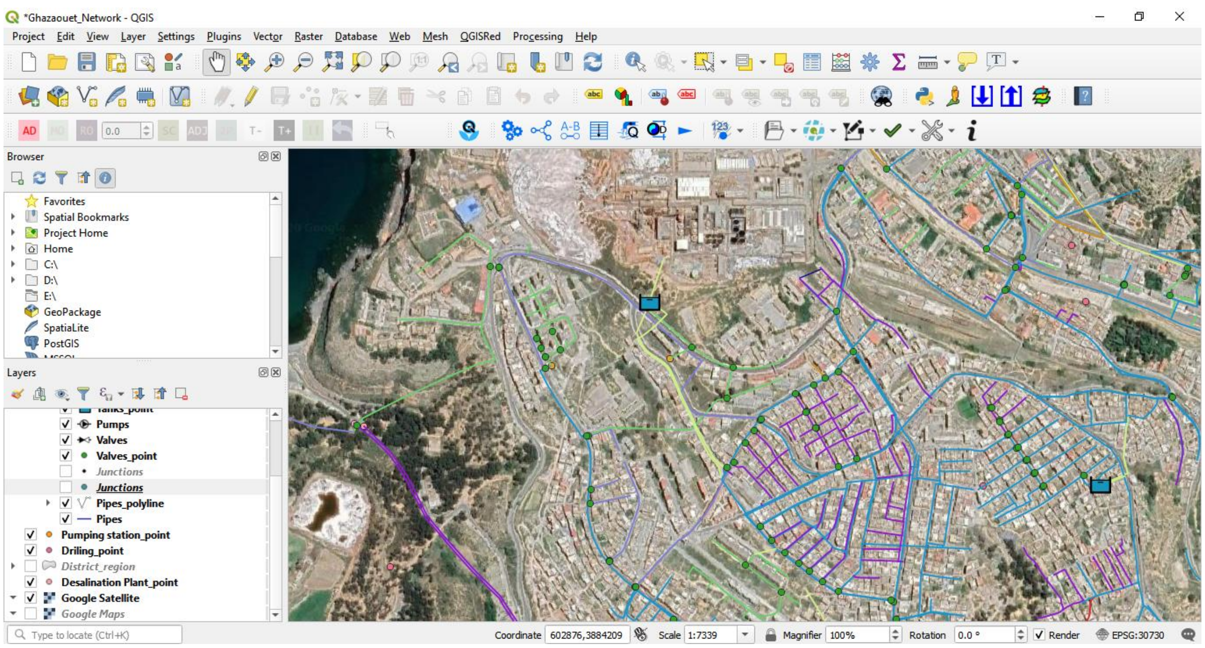


Figure 3.3: QGIS Display of the Ghazaouet Network over a Google Satellite Backdrop Map

The water distribution model data was organized in tables with columns showing the contained attribute details. Typical the GIS attribute table provides information in the form: ID, Material; diameter; status; length.

3.9 Geographic Information System Choice

The collected data was analysed in QGIS version 3.10.0 Coruna. QGIS is a free and open source software that is user friendly yet can handle big data and complex inputs. Preliminary GIS analysis was conducted for preparing data to be imported to EPANET. The operations included WDN map

digitizing, georeferencing, DEM analysis or topographical map for elevation map generation and attribute table formulation. It was used to analyse and model the water distribution network.
The DFX2EPA extension was used alongside QGIS containing a series of avenue scripts to create hydraulic model data files in order to import GIS files to EPANET input files. This extension comes with an associated map file in an EPANET 'inp' file format that was used to build the network model. The shapefiles used to create model datafiles were pipe map (pipe data), a root map (provides demand information), junctions, tanks, valves and an elevation polygon map (provides nodal elevation data). Overlay analysis were performed to visualize a more detailed water distribution network with all the network components.

3.10 Hydraulic Modeling Software: EPANET

EPANET was used for both hydraulic calculation and simulation of the continuous supply mode with suitable assumptions. The EPANET software was adopted because it is for general public and educational use as well as it is freely available on-line (Rossman, 2000). The model uses several basic equations; however, the Hazen-Williams formula was used for hydraulic pipe head loss calculation by water flowing in a pipe due to friction with pipe walls.

EPANET has the capacity to analyze virtually unlimited number of pipes and tanks. The program became a popular tool in analyzing complex and simple water distribution networks in both the developed and developing countries of the world (Ramana, Sudheer, & Rajasekhar, 2015). EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network. EPANET was designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis. In this paper it was used to carry out the hydraulic analysis of the distribution network of the study area. Import EPANET files plugin and DFX2EPA software were employed together with QGIS to prepare EPANET input files of the model and simulate the flows in water distribution network. Baseline or model data with respect to pipe age information was collected from Ghazaouet. Considering the pipe age, suitable roughness for worst case scenario adopted from literature were assigned.

3.11 Topographic Analysis

The extraction of elevation data which above sea-level was extracted both from GIS and directly from google earth. The results were compared and mean values taken to assign elevation values for demand nodes and tanks as this is a required input for EPANET. The data used was a downloaded digital elevation model DEM from A 12m resolution site called Zonums website with elevation source from the United States Geological Survey (USGS) Seamless elevation data sets hosted at USGS/EROS. The elevation values returned default to the best-available (highest resolution) data source available at the specified point was used to extract a finer resolution elevation data. From this data each junction was assigned a Z value and added manually to EPANET as plugins loses such data during conversion to EPANET.

3.12 Coupling GIS and Hydraulic Model

The importance of GIS in water distribution network cannot be over emphasized. GIS presents a powerful engine for handling descriptive data of the water supply systems. The data management capabilities of GIS were exploited by this research in order to manage and establish the Ghazaouet water distribution network. The GIS software utilized assisted in ensuring understanding of the spatial data of the network and further viewing of different components of the distribution network. QGIS an open source software as used for this work provided a backdrop google earth live map which showed the exact location of the network. Data concerning the network was edited on the attribute tables and further imported to EPANET for hydraulic modelling.

The GIS to EPANET conversion was done by QGISRed and DFX2EPA plugins. This provided a CAD drawing of only nodes and links. Unfortunately, the converted EPANET input file loses a lot of data which needs to be entered on EPANET manually. Network data such as node elevations, pipe demands, and pipe diameters, base demands, dimeters, and roughness coefficients were added manually into EPANET. In addition, some nodes are left vulnerable and a reconnection and deletion of some nodes was performed in preparing the network for analysis. The conversion program can calculate pipe lengths. Another step is to add network components such as; valves, pumps and tanks.

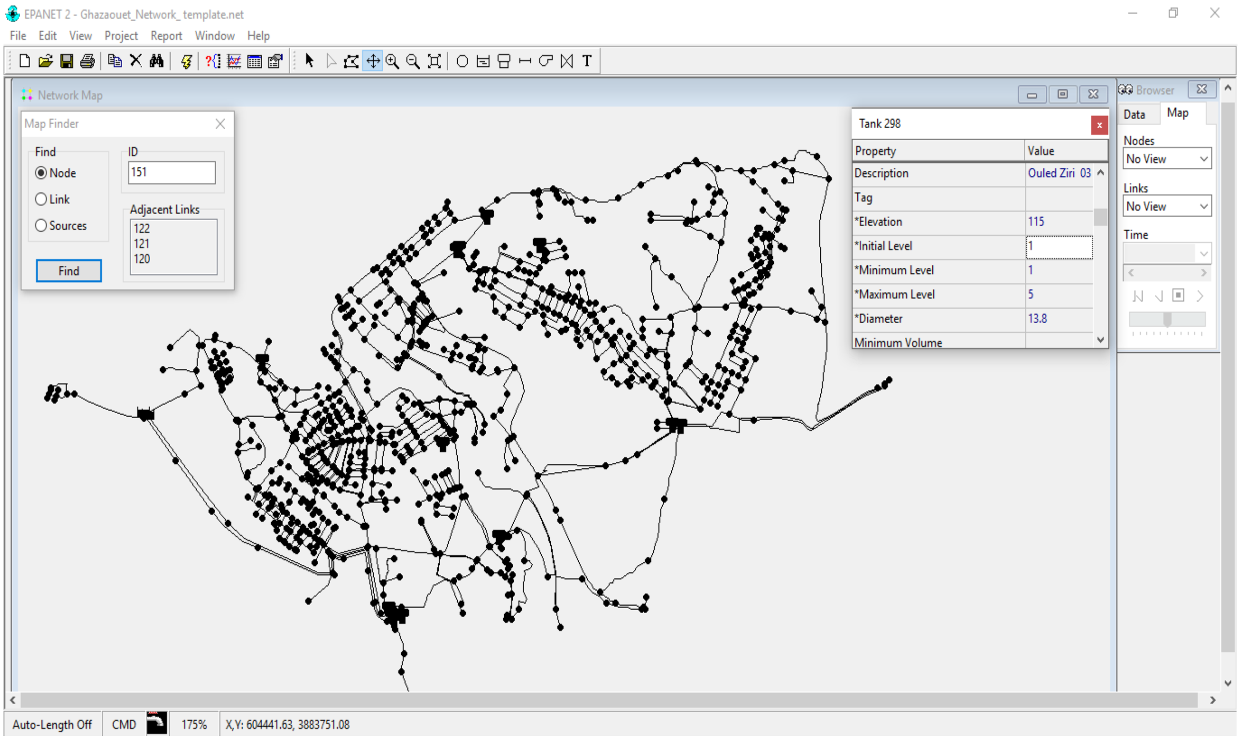


Figure 3.4: EPANET Display of the Ghazaouet Network

The EPANET program also allowed viewing of the network map options according to legend. The map provides color codes of different parameters to be viewed.

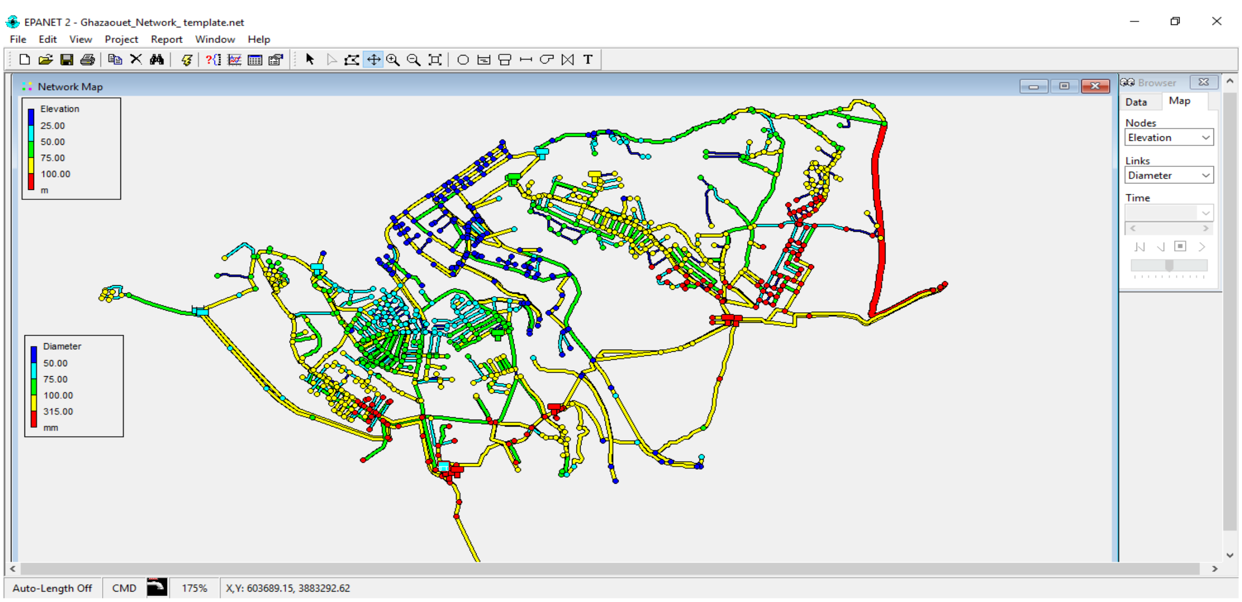


Figure 3.5: Colour Coded View of the Ghazaouet Pipe Diameters and Nodal Elevations

3.13 Summary

This research work was guided by the methods and tools discussed and explained on this section. The application of the methods explained were informed by the literature review and previous work done on the area of water supply and distribution management. Realising the availability of different approaches, for purposes of this work the methods were selected based on ease of use, availability for academic purposes and reliability to yield reproducible results.

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter presents a synthesis of information produced in this research as per the set objectives of the whole study. The case study area on this work presented several challenges in trying to fulfil the purpose of the research. This chapter references this work to proven theories and concepts in order to draw conclusion in scientific terms as well as establishing grounds of the validity and reliability of this work.

4.1 Ghazaouet Water Distribution Network Description

The research was based on a water distribution network of a small town in Algeria called Ghazaouet in the Tlemcen province. The water distribution network has 13 water distribution zones which covers about 70% of the total area of the commune of Ghazaouet. The system is characterized by 848 pipes with a diameter range of 20 millimetres to 315 millimetres, 13 storage tanks with a total capacity of 10770 cubic metres. Furthermore, there were 1221 junctions, 189 valves and 4 pumping stations. The source of the whole water distribution system is the desalination plant sourcing its water from the nearby Mediterranean Sea. The water treatment plant produces about 8,300m^3/day on average according to the ADE. Of the total water produced the network yields less than 50% making the losses to account to approximately 50% of the total water produced.

The tanks which are crucial for the water distribution network as they balance storage and ensuring constant supply of water to the town. The data obtain was put in tables and converted to shapefile point layers in QGIS and further manually entered to EPANET.

Table 4.1: Showing Storage Tanks for the Ghazaouet City

Id	Name	Capacity (m^3)	Type	X-Coordinates	Y-Coordinates	Elevation (m)
1	Ouled Ziri 01	3000	CSE	603967	3882762	116.5
2	Ouled Ziri 02	3000	CSE	603990	3882735	114.8
3	Ouled Ziri 03	750	CSE	603956	3882788	116.5
4	Ouled Ziri 04	220	CSE	604034	3882753	112.7
5	Haout Ammer	750	CSE	604261	3883611	72.3
6	Sidi Amar	200	CSE	605566	3883692	115.1

7	Ouled Ziri	250	CSE	604567	3883143	107.5
8	Metanof	200	CSE	603265	3884014	47.8
9	Centre Ville	600	CSE	604335	3884548	71.1
10	Centre Ville	600	CSE	604352	3884557	73.2
11	Sidi Amar	750	CSE	605529	3883698	114.2
12	Chateau d'eau	300	Elevated	604490	3884724	45.2
13	Chateau d'eau	150	Elevated	604796	3884579	88.7
	Total storage	**10770**				

4.2 Thematic Analysis

QGIS has a very powerful function in visualizing every feature layer according to attributes. The options are presented under the properties menu and you label features based on attribute and characterize the network under symbology. This gives the option of partitioning the information according to themes. QGIS also provides users with structured query language (SQL) algebraic function to select feature based on their attributes.

Figure 4.1: Color Coded and Symbology According to Pipe Material of the Ghazaouet Network

An illustration was made depicting network parameters such as categorizing the network in various attributes such as material, diameter, etc in order to show interactive thematic maps. The figure below shows the selection of pipes according to their pipe material throughout the water distribution network of Ghazaouet.

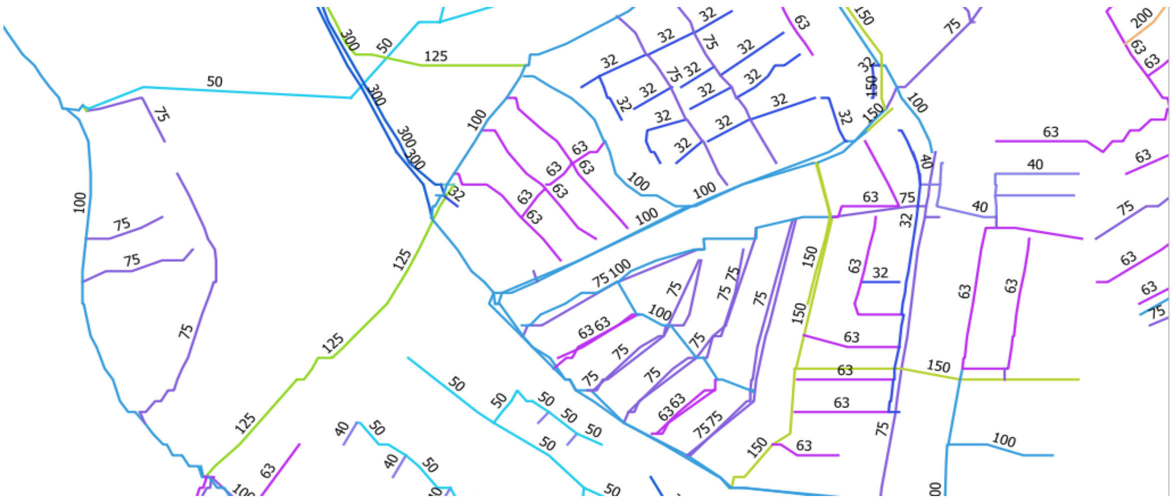


Figure 4.2: Categorization of Pipe Diameters of Ghazaouet Network

The WDN data was also categorized according to pipe diameters as shown by figure 4.2. The pipe sizes range from 33mm to 315mm. This shows some of the pipes that are under sized as it is recommended to have pipes for bulk water supply starting from 50 or 80mm in diameter. According to (Trifunovic, 2006), all pipes less than 80mm have a very low significant input into the hydraulic model and the simulation of the results. As a results skeletonization of the network very handy in weeding out service connection pipes with smaller diameters and work with main trunks and distribution mains.

The choice of pipe material is largely dependent on budgetary costs, nature of ground, pressure, ease of making connections and flexibility to repair (Karamouz, Moridi, & Nazif, 2010; Trifunovic, 2006). The Ghazaouet network consists of 6 different types of pipe construction materials with different roughness coefficients which vary greatly with age of the pipe. The materials used are: 67 Coated steel pipes contributing 8%, 89 Polyvnyl Chloride (PVC) accounting for 12%, 113 High Density Polyethene standing at 13%, and 273 Galvanized steel pipes which is 32% as well as 300 Ductile iron pipes taking the lion's share of 35% of the total network pipes.

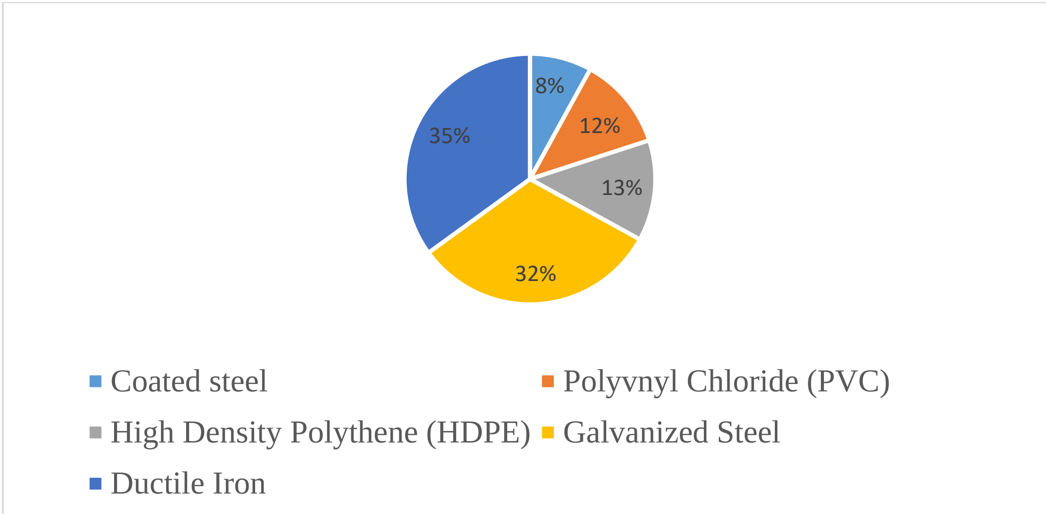


Figure 4.3: Pipe Material used in the Ghazaouet Water Distribution Network

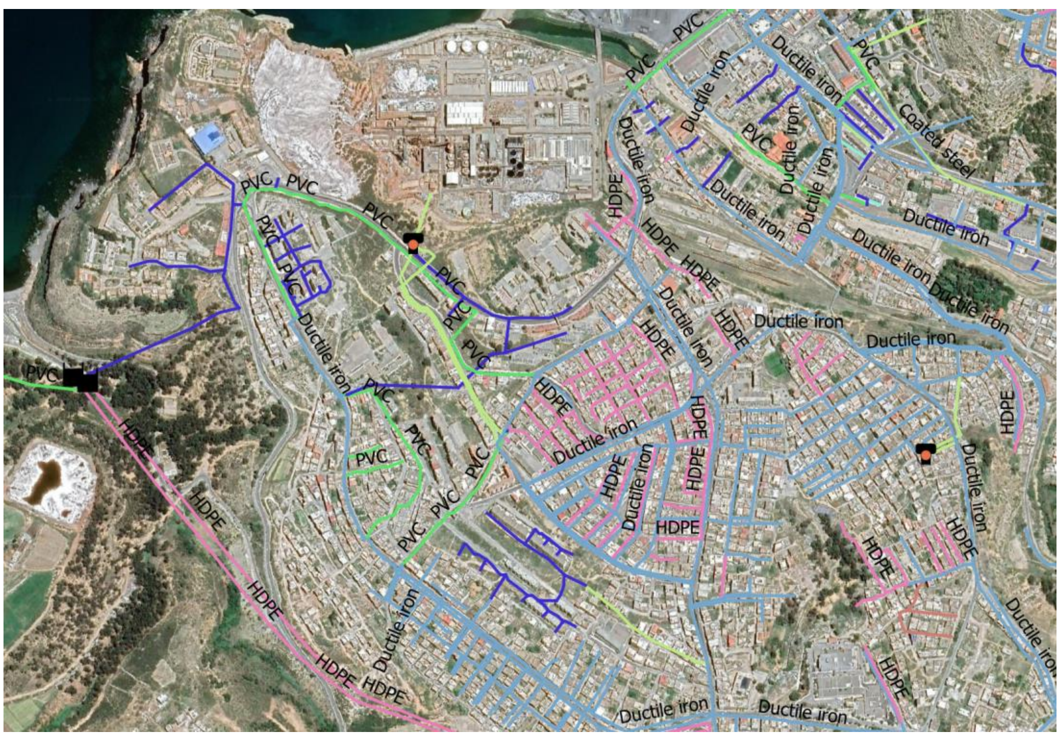


Figure 4.4: Water Distribution Network Layout Map with a Backdrop Satellite Image

4.3 Presentation of Simulation Results

This is presentation of hydraulic simulation of the Ghazaouet network from the EPANET software. The simulation was performed for a continuous water supply whilst observing the diurnal pattern nature of supply. The diurnal pattern is represented as a demand multiplier in EPANET serves as one of the most important aspects of continuous water supply.

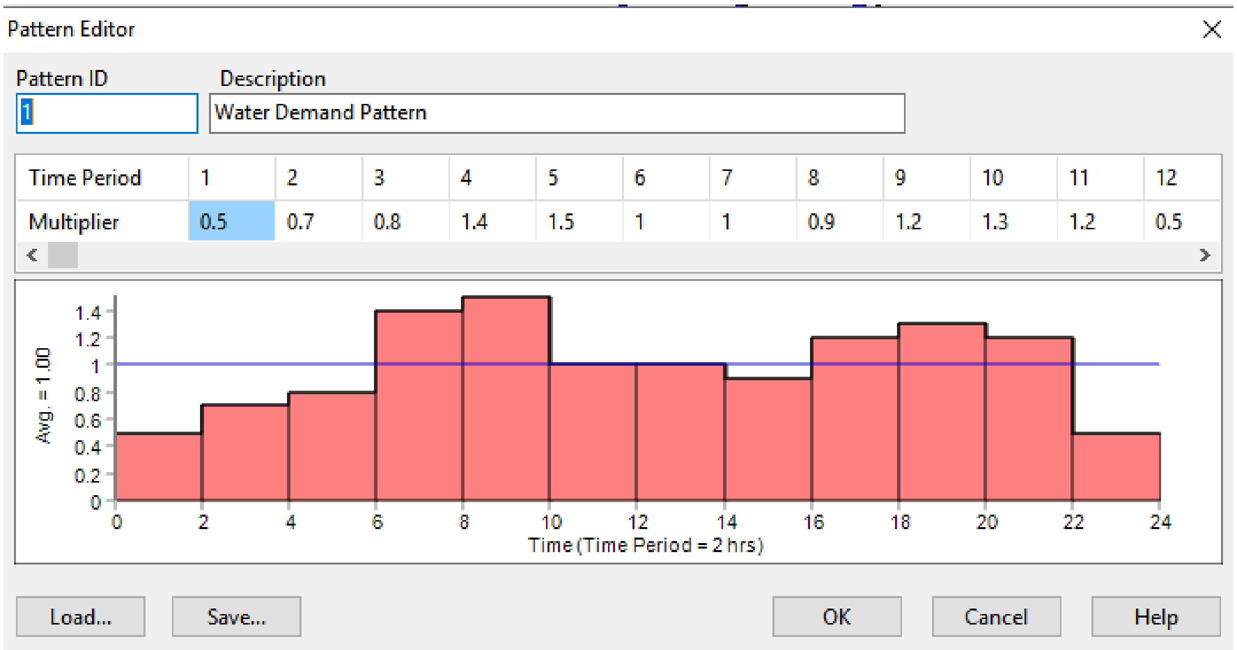


Figure 4.5: The Water Demand Pattern for the Ghazaouet Water Distribution Network

The demand pattern presented in the figure above was formulated based on random consumption pattern for the different uses of water for specific hours throughout a 24 hour day. As a result a set of multiplier for the Ghazaouet case study were established for the diurnal analysis. Nonetheless, the whole network could barely run on EPANET so a skeletonized network was created representing the trunk mains, transmission mains and demand nodes for distribution lines. This helped to weed out the majority of the pipes with diameters less than 80mm which according to (Trifunovic, 2006), they have little significant contribution to the simulation results. A 72hr extended period simulation was performed on EPANET for the Ghazaouet network and it presented the following results and showed areas of malfunction within the system such as parts of the network with negative pressures, very low velocities, excessive pressure and velocities.

4.4 Pipe Report

The Fig. 4.6 below was extracted from the EPANET network analysis. It shows a map of pressure at nodes and pipe velocities during a peak hour at 0900hrs.

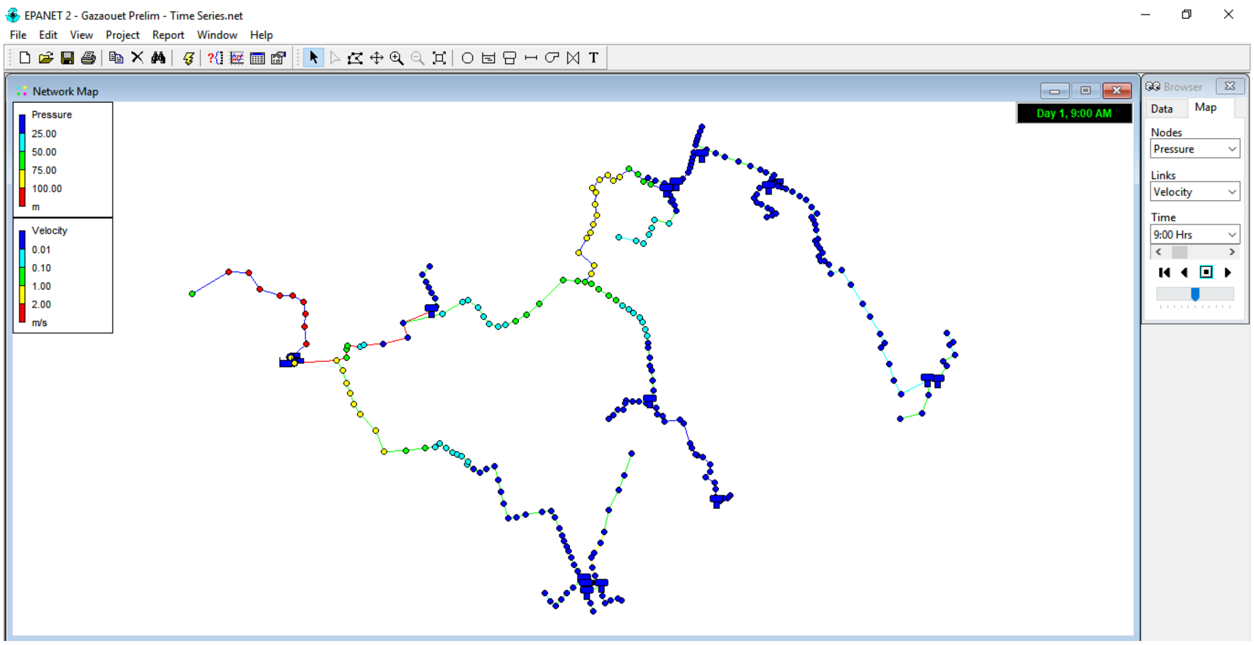


Figure 4.6: Ghazaouet Network Results, Pressure at Nodes and Pipe Velocity at 0900hrs

The pipe report showed that there were a couple of links with very low velocities, recorded below 0.5 m/s. The analysis of the velocity distribution indicated that upto 25% of the network is vulnerable to sediment deposition due to very low velocities. This is 70 out of 279 links which had a velocity lower than 0.5 m/s. This is considered as a malfunction in the operation of a water distribution network and may result in water quality deterioration due to sediment deposistion (Abdelbaki et al., 2017; R. Rao et al., 2015; Trifunovic, 2006). A total of 157 pipes out of the 279 links accounting for 56% presented velocity between 0.5 m/s and 1.5 m/s, which is a recommended range for water distribution network. However, the remaining 19% of the network which is 52 pipes out of 279 links had a velocity greater than 1.5 m/s which is often unacceptable.

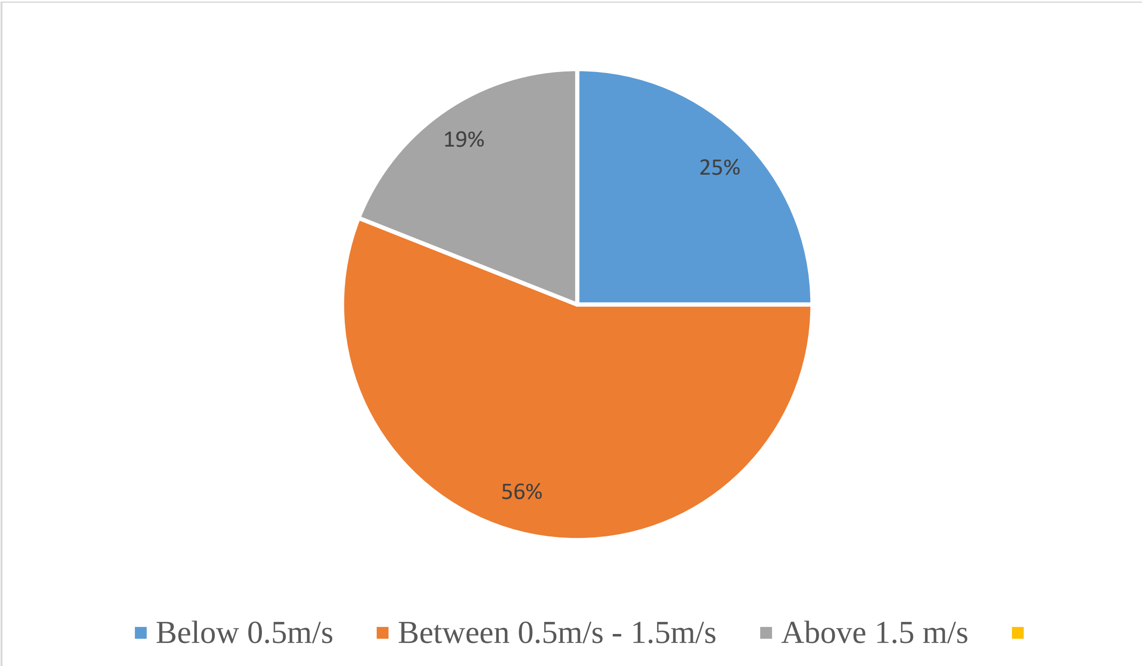


Figure 4.7: Velocity Distribution in the Ghazaouet WDN

The results showed velocity that exceeds 3 m/s around the reservoir pumping station section of the network. For the parts where a pump was installed the velocity was very high and above, 1.5 m/s yet low for most gravity flow sections. Due to gravity flow the head loss in the pipe also automatically decreases and varies greatly as pumps are used. The system may be faced with erosion due to the high internal velocities.

The unit headloss was also considered for the Ghazaouet water distribution network. The results in Fig. 4.8 showed that 12 out of the 279 pipes (i.e 4%) presented headlosses below 1m/km. The typical unit headloss were recommended to be between the range of 1m/km to 3m/km. Thus, 51% of the water distribution network which is 143 out of 279 pipes had unit headloss between 1m/km – 3m/km, suggesting that the network was operating optimally for this part of the network. However, 124 out of 279 pipes which is 44% had a headloss of more than 3m/km. According to (Annan & Gooda, 2018) unit headlosses over 5m/km begin to be too big within a network. Unit headlosses over 8m/km especially above 10m/km are too high and unacceptable to the system yet, (Mohapatra, Kamble, Sargaonkar, Labhasetwar, & Watpade, 2012) presented a unit headloss of 28.29m/km. The work concluded that optimally 4m/km headloss is acceptable but anything above that is unacceptable.

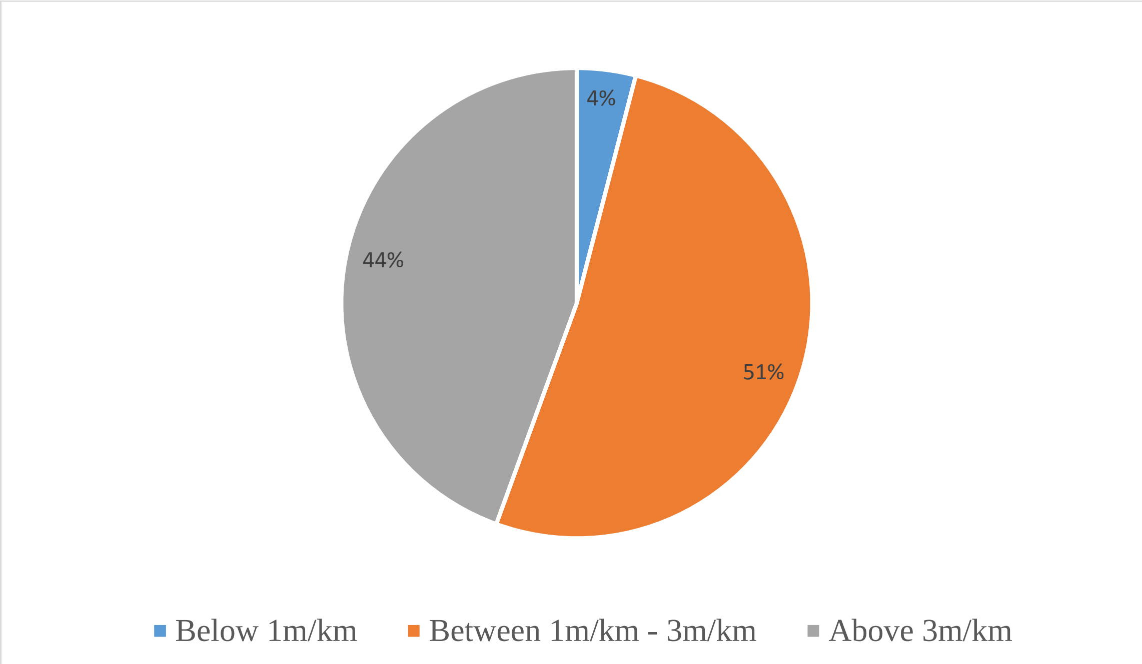


Figure 4.8: Unit Head Loss Distribution with the Ghazaouet WDN

4.5 Junction Report

The junction report from the EPANET analysis for the Ghazaouet network detailed mainly pressure distribution. Based on the analysis, about 41% (Fig 4.9) of the network which 116 junctions out of 284 junctions presented pressure lower than 10m. Furthermore, 70 out of the 116 junctions had negative pressure. The results suggest that the network might be having broken pipes resulting to leakages in the system (Abdelbaki et al., 2017). This problem if not managed the network may fail to deliver water to target consumers, thus preventative maintenance is necessary for this network. The optimal water distribution pressures were proposed to be within the range 10m of water to 70m (Trifunovic, 2006). Approximately 49% of the network is operating within recommended pressure limits. This is 140 of the 284 junctions had pressure between 10m to 70m of water. This portion of the network is assumed to be functioning well and capable of delivering water to consumers without fail based on assumptions given by (Abdelbaki et al., 2019; Sayyed, Gupta, & Tanyimboh, 2014).

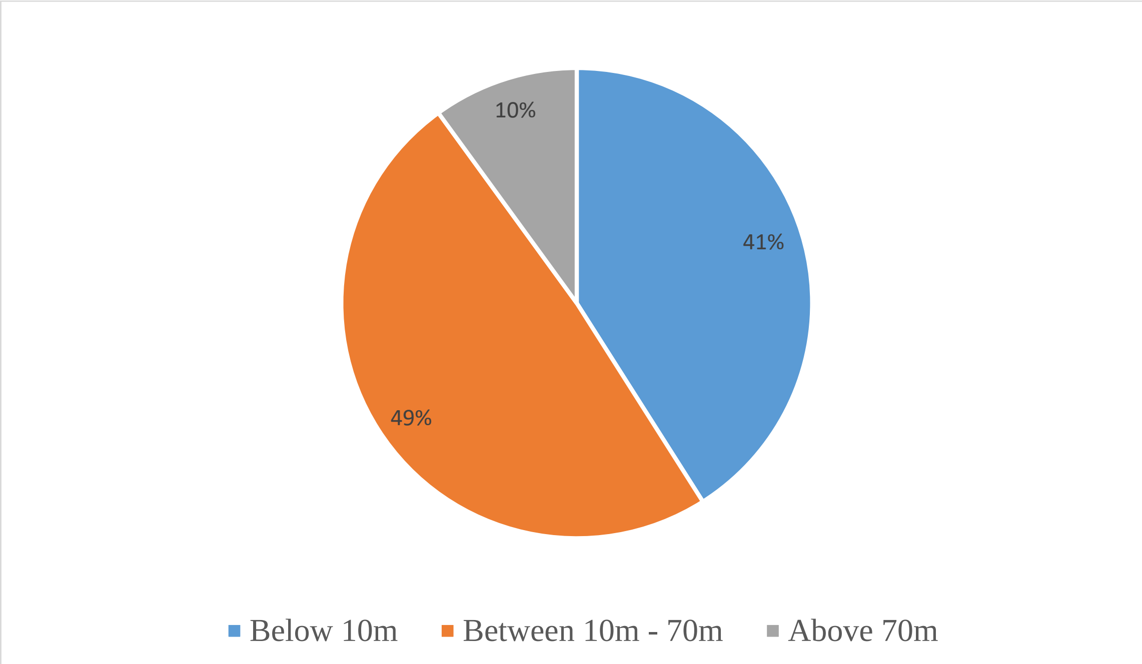


Figure 4.9: Pressure Distribution in the Junctions of the Ghazaouet WDN

Moreover, it was found that 28 of the 284 junctions have pressure greater than 70m. This implies that more than 10% of the network nodes may have serious leakage problems due to high pressure causing pipe bursts. A study conducted by (Abdelbaki et al., 2017) in a small town in Tlemcen Algeria presented 39% of the demand nodes with pressure great than 70m. A conclusion was made that water losses in Algerian water supply systems is rampant, which is the same issue with the Ghazaouet city. Other systemic problems as provided by the ADE include; poor quality of valves, corrosion problems and deteriorated meters which result in very poor management of the water distribution network.

Table 4.2: Number of recorded leak cases in the year 2020

MONTH IN 2020	RECORDED LEAKS
JANUARY	41
FEBRUARY	26
MARCH	37
APRIL	49
MAY	35

JUNE	49
JULY	38
AUGUST	44
SEPTEMBER	51
OCTOBER	35
NOVEMBER	44

Fig. 4.10 and Fig 4.11 compares the pressure distribution values between the peak hour and during minimum consumption within the city. Pressure differences are typically less than 5m/day attributed to tank level changes and changes in pumping station flows and rate of withdrawal within the network. The minimum pressure difference was noticeable because of the recorded negative pressures in the network otherwise any other difference lower than 5m/day is not noticeable.

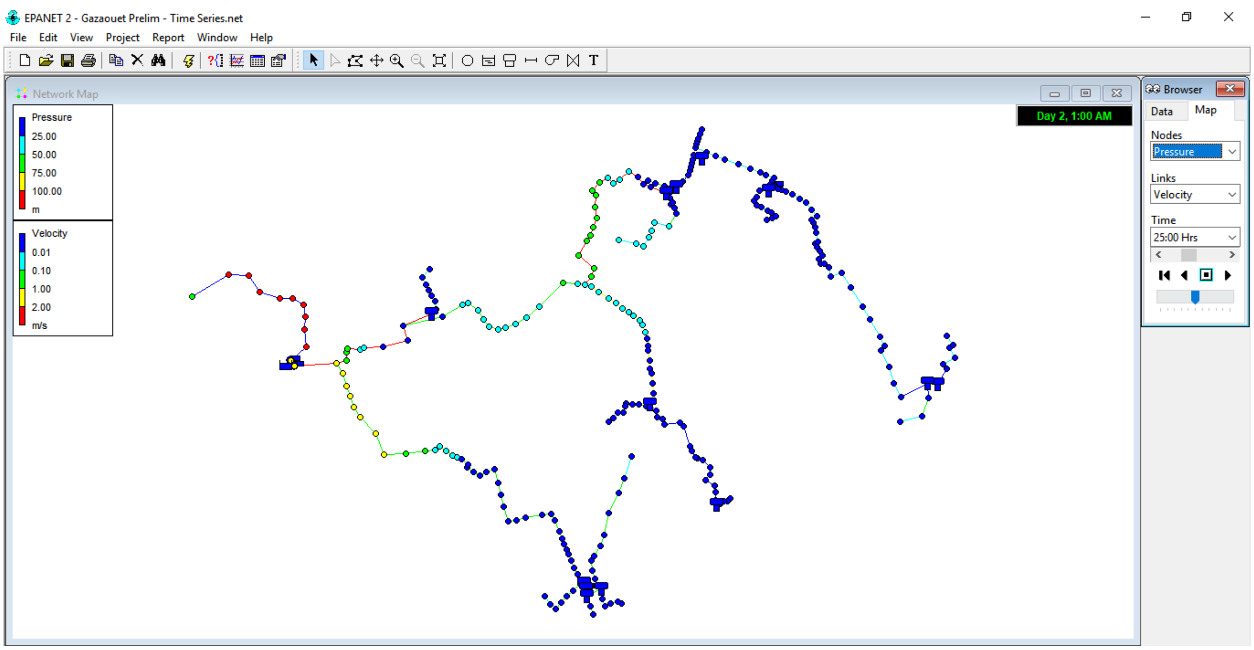


Figure 4.10: Nodal Pressure Distribution at 0100hrs

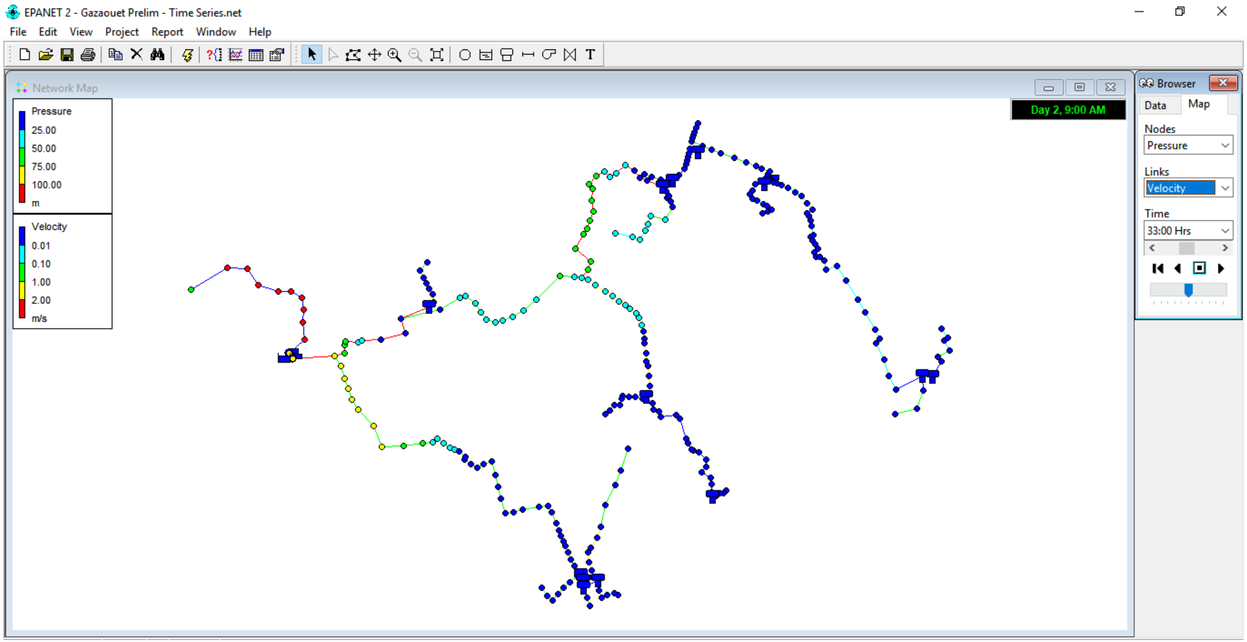


Figure 4.11: Nodal Pressure Distribution at 0900hrs

4.6 Discussion of Simulation Results

The pipes should be designed in such a way that they should be able to cope with diurnal patterns including withstanding peak flows (Mehta et al., 2017). Ghazaouet town had 6 different types of pipes and all these in their differences had to achieve a range of velocities. The recommended velocity in closed pipes as assumed to be always flowing fully is 0.5m/s to 1.5m/s (Abdelbaki et al., 2017; D. R. M. Rao et al., 2016; R. Rao et al., 2015; Trifunovic, 2006). Low velocities that is below 0.5m/s are unacceptable or at least should not be encouraged. These are capable of deteriorating water quality due to sediment deposition that may lead to corrosion and scouring. The low velocities were mainly recorded during minimum consumption hours around midnight when not so many consumers are active except for industries. During peak hours velocities were within range and some above recommended 1.5m/s.

Recommended flow pressures for the Ghazaouet WDN were between 10m to 70m. However, some nodes gave negative pressure that were caused by pump malfunction and a series of broken pipes. During peak hours pressure distribution sometimes could even reach negative for some areas with bigger head. This coupling of GIS and hydraulic modelling gives an idea of where the negative and low pressures are experienced in the system and attention can be easily directed to fixing the problems of the water distribution network. The main challenge experience during model building was encountered in system data collection as the was insufficient data of actual recorded pressures to use at specific points to calibrate the water distribution network. As a result, theoretically assumptions were used to allocate optimum pressures for water distribution networks.

Theoretically the network was initially designed appropriately observing the hydraulic principles in terms of pressure management. The system showed an economic design approach which was the combination of pumping and gravity systems. However, for purposes of this research a lot of data gaps were identified, which narrowed the research into making several assumptions which might not be exactly existing on the ground. These include location of pumps and the pump designs and specification installed to meet the demand of the population. This provided challenges in maintaining sufficient pressure in the model. The lack of sufficient data to validate the model and the different demand areas presented systematic challenges provided the amount of time that was available for the research and the lack of field work to collect real time data. However, pressure and flow values recorded at strategic locations of the WDN were used for model calibration by trial and error method. On overall the results from the simulation suggests that the system is partial functional and may also have deficiencies in delivering water to consumers. Some sections of the network proved to have had leakages and some very old pipelines that were affecting the pressure and flow conditions within the system.

4.7 The Proposed Methodology for Effective Water Distribution Network

The main aim of managing a water distribution network is to satisfy the water demand of the connected area and reduce losses as much as possible. However, due to the conventional definition of water demand (sum of all water supplied to consumers plus leakages) water managers and engineers have an urge to efficiently and effectively manage a water distribution network to satisfy their customers and eliminate non-revenue water. As a result, this research was seeking to simplify this process and employ already best available technologies to monitor, maintain and manage their systems. Despite the challenges faced in conducting this research in terms of acquisitioning data and coming up with a scientific report, a milestone was reached by using the existing water distribution network from the Algerian town of Ghazaouet in order to develop a resultant methodology that can be applied in a different case study or distribution area and still achieve desired results. Coupling GIS and hydraulic modelling makes it easy for network managers and engineers to monitor their systems from a click of a mouse in an office. This brings crucial information to the fingertips of engineers without leaving their office and enhances planning for future demand scenarios in a given area. Henceforth, the research managed to develop this methodology and hereby presents it as a finding for effective management of water distribution network by coupling GIS and hydraulic modelling.

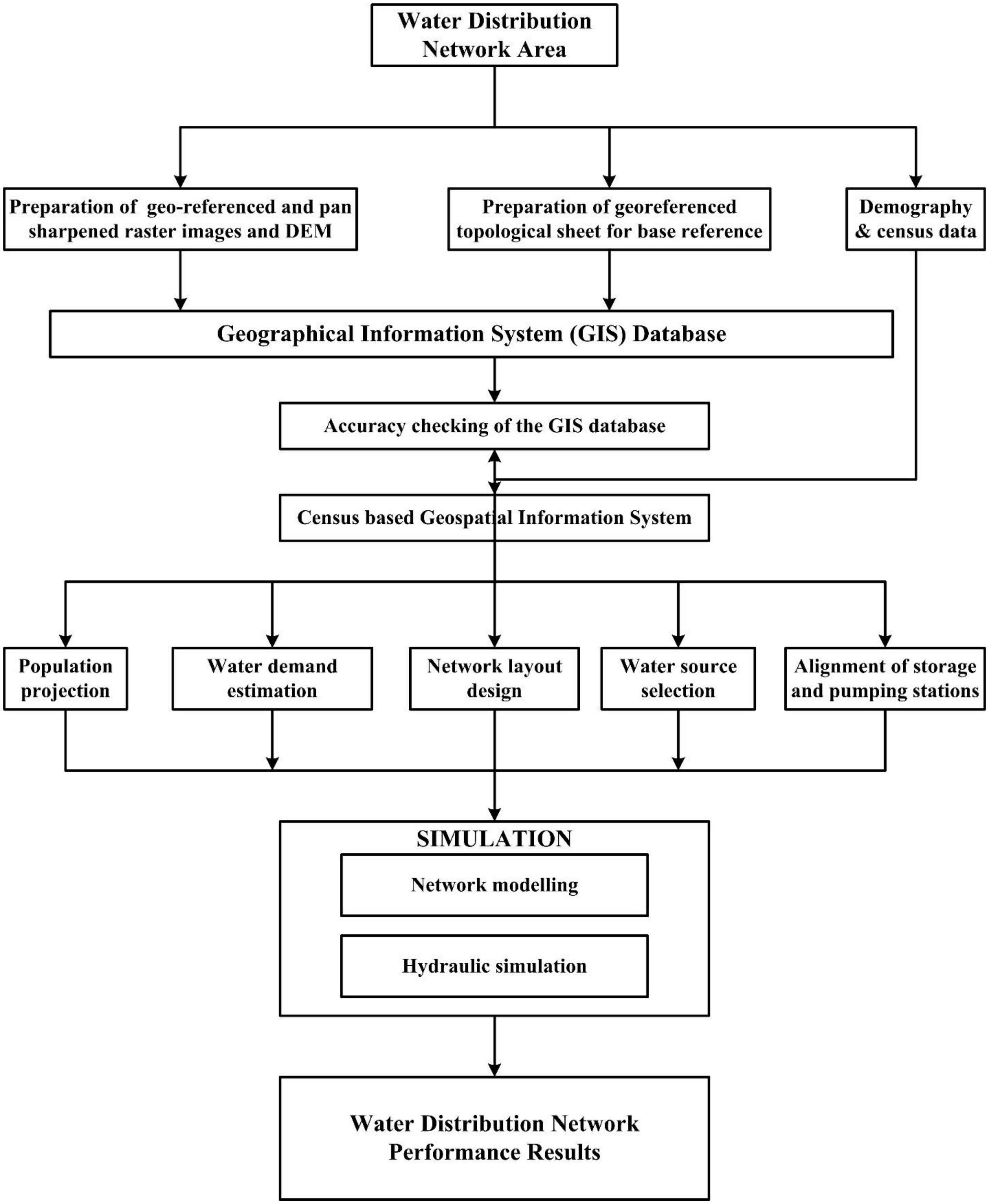


Figure 4.12: An Illustration of the Proposed Water Distribution Network Management Methodology Using GIS and Hydraulic Models

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main focus of this research was to manage a water distribution over a geographic information system with all its attributes both spatial and non-spatial data of the network. Additionally, the aim was to analyze the network in order to identify malfunctions and deficiencies in the operation of the WDN. It was found that GIS application serves as a very powerful platform in managing water distribution network, as it eliminates unnecessary ground work when all data is consistently fed into the GIS system whenever and/ or wherever there are changes made to the network. This method was found to be very economic, time saving and efficient in the design of new networks and management of existing ones. At the end, building the model for analysis served with a lot of challenges for existing network, as over reliance was put on the data retrieved remotely.

However, the hydraulic simulation results, showed that resulting pressures, at most junctions and the flows with their velocities at most pipes were adequate enough to successfully deliver water to the distribution area. Furthermore, the following instances were observed from the water distribution network which introduced immense difficulties in this research work as well as situations that can cause future inadequate supply of water to the distribution area:

1. It was observed that the distribution network is characterized by a lot of pipes with very small diameters as about 50% of the pipes are less than 80 mm and some directly connected to tanks.
2. It was also noted that some tanks were located at very low-lying elevations and supplying water to higher elevations without any data on pumping stations connected adjacent to the tanks.
3. The direction of flows and pipe connections of the network were assumed as datasets did not provide clearer information on supply mains from the tanks.
4. The distribution network presents too many tanks clustered in the same location instead of an even distribution of these storage tanks as the system is largely dependent on gravity supply system.

To sum up the study has shown the application of GIS (QGIS 3.10) and hydraulic modelling software EPANET 2.0 in the effective management of a water distribution network, the case of

Ghazaouet, Tlemcen, Algeria. The tool would be key in identifying areas of malfunctions, good performance of the system as well as providing a good database for recording the history of the network and further use the data to predict future scenarios.

5.2 Recommendations

It is recommended that the above listed observations be carefully considered and rectified in any case possible. However, considering that the system currently satisfies the demand of Ghazaouet, for good practice more field work needs to be done in order to update the data or information regarding the operation of the distribution system. Therefore, more research can be done to validate the preliminary findings of this work and serves as continuation to improve the tool developed as well as the hydraulic model built for the distribution network.

REFERENCES

A Saminu, Abubakar, Nasiru, L. S. (2013). Design of NDA Water Distribution Network Using EPANET. *International Journal of Emerging Science and Engineering*, (9), 5–9.

Abdelbaki, C., Benchaib, M. M., Benziada, S., Mahmoudi, H., & Goosen, M. (2017). Management of a water distribution network by coupling GIS and hydraulic modeling: a case study of Chetouane in Algeria. *Applied Water Science*, *7*(3), 1561–1567. https://doi.org/10.1007/s13201-016-0416-1

Abdelbaki, C., Touaibia, B., Ammari, A., Mahmoudi, H., & Goosen, M. (2019). *Contribution of GIS and Hydraulic Modeling to the Management of Water Distribution Network*. https://doi.org/10.1007/978-3-030-04750-4

Abdelbaki, C., Touaibia, B., Mahmoudi, H., Djelloul Smir, S. M., Allal, M. A., & Goosen, M. (2014). Efficiency and performance of a drinking water supply network for an urban cluster at Tlemcen Algeria. *Desalination and Water Treatment*, *52*(10–12), 2165–2173. https://doi.org/10.1080/19443994.2013.870497

Abu-mahfouz, A. M., Hamam, Y., Page, P. R., & Djouani, K. (2016). Real-time dynamic hydraulic model for potable water loss reduction. *Procedia Engineering*, *154*, 99–106. https://doi.org/10.1016/j.proeng.2016.07.426

Ahmadi, M. S., Sušnik, J., Veerbeek, W., & Zevenbergen, C. (2020). Towards a global day zero? Assessment of current and future water supply and demand in 12 rapidly developing megacities. *Sustainable Cities and Society*, *61*(July 2019). https://doi.org/10.1016/j.scs.2020.102295

AL-Washali, T., Sharma, S., Lupoja, R., AL-Nozaily, F., Haidera, M., & Kennedy, M. (2020). Assessment of water losses in distribution networks: Methods, applications, uncertainties, and implications in intermittent supply. *Resources, Conservation and Recycling*, *152*(September 2019), 104515. https://doi.org/10.1016/j.resconrec.2019.104515

Alkali, A. N., Yadima, S. G., Usman, B., Ibrahim, U. A., & Lawan, A. G. (2017). DESIGN OF A WATER SUPPLY DISTRIBUTION NETWORK USING EPANET 2.0: A CASE STUDY OF MAIDUGURI ZONE 3, NIGERIA A. N. Alkali, S. G. Yadima, B. Usman, U. A. Ibrahim and A. G. Lawan (Department of Civil and Water Resources Engineering, University of Maiduguri, Ni. *Arid Zone Journal of Engineering, Technology and Environment*, *13*(3), 347–355.

Annan, M., & Gooda, E. A. (2018). Effect of minor losses during steady flow in transmission pipelines – Case study ‘‘ water transmission system upgrade in Northern Saudi Arabia ”. *Alexandria Engineering Journal*, *57*(4), 4299–4305. https://doi.org/10.1016/j.aej.2018.12.002

Ataoui, R., & Ermini, R. (2017). Risk assessment of water distribution service. *Procedia Engineering*, *186*, 514–521. https://doi.org/10.1016/j.proeng.2017.03.264

Ateş, S. (2016). Author ’ s Accepted Manuscript. *Flow Measurement and Instrumentation*. https://doi.org/10.1016/j.flowmeasinst.2016.12.002

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

Ayad, A., Awad, H., & Yassin, A. (2016). Integrated approach for the optimal design of pipeline networks. *Alexandria Engineering Journal*. https://doi.org/10.1016/j.aej.2016.10.008

Bandyopadhyay, S. (2016). Sustainable Access to Treated Drinking Water in Rural India. *Rural Water Systems for Multiple Uses and Livelihood Security*, 203–227. https://doi.org/10.1016/B978-0-12-804132-1.00009-3

Barbeau, B., Gauthier, V., Julienne, K., & Carriere, A. (2005). *Dead-end flushing of a distribution system : Short and long-term effects on water quality Dead-end flushing of a distribution system : Short and long-term effects on water quality*. (June). https://doi.org/10.2166/aqua.2005.0035

Belhadj, H., Aubert, D., & Dali Youcef, N. (2017). Geochemistry of major and trace elements in sediments of Ghazaouet Bay (western Algeria): An assessment of metal pollution. *Comptes Rendus - Geoscience*, *349*(8), 412–421. https://doi.org/10.1016/j.crte.2017.09.013

Bentley. (2014). *Manual Watercad V8 Manual Watercad V8* (Vol. 8, pp. 8–9). Vol. 8, pp. 8–9. Retrieved from https://www.inas.ro/en/bentley-watercad

Berardi, L., Laucelli, D., Ugarelli, R., & Giustolisi, O. (2015). Hydraulic system modelling : background leakage model calibration in Oppegård municipality. *Procedia Engineering*, *119*, 633–642. https://doi.org/10.1016/j.proeng.2015.08.916

Francisco González-Gómez, Miguel A. García-Rubio, J. G. (2011). Water Policy and Management in Spain - Google Books.

Gössling, S., Peeters, P., Hall, C. M., Ceron, J. P., Dubois, G., Lehmann, L. V., & Scott, D. (2012). Tourism and water use: Supply, demand, and security. An international review. *Tourism Management*, *33*(1), 1–15. https://doi.org/10.1016/j.tourman.2011.03.015

Grouillet, B., Fabre, J., Ruelland, D., & Dezetter, A. (2015). Historical reconstruction and 2050 projections of water demand under anthropogenic and climate changes in two contrasted Mediterranean catchments. *Journal of Hydrology*, *522*, 684–696. https://doi.org/10.1016/j.jhydrol.2015.01.029

Halagalimath, S. S., Vijaykumar, H., & Patil, N. S. (2016). *Hydraulic modeling of water supply network using EPANET*. 1022–1027.

Hillier, A. (2011). Manual for working with ArcGIS 10. *University of Pennsylvania*, (January), 83. Retrieved from http://works.bepress.com/amy_hillier/24

Huang, Y. C., & Lee, C. M. (2019). Designing an optimal water supply portfolio for Taiwan under the impact of climate change: Case study of the Penghu area. *Journal of Hydrology*, *573*(May 2018), 235–245. https://doi.org/10.1016/j.jhydrol.2019.03.007

Izinyon, O. C., & Anyata, B. U. (2009). Water distribution network modelling of a small community using watercad simulator. *Global Journal of Engineering Research*, *10*(1), 35–47.

Kara, S., Ethem Karadirek, I., Muhammetoglu, A., & Muhammetoglu, H. (2016). Hydraulic Modeling of a Water Distribution Network in a Tourism Area with Highly Varying Characteristics. *Procedia Engineering*, *162*, 521–529. https://doi.org/10.1016/j.proeng.2016.11.096

Kingdom, B., Liemberger, R., & Marin, P. (2006). *The challenge of reducing non-revenue water (NRW) in developing countries - how the private sector can help : a look at performance-based service contracting*. 1–52.

Kowalski, D., Kowalska, B., & Kwietniewski, M. (2015). Monitoring of water distribution system effectiveness using fractal geometry. *Bulletin of the Polish Academy of Sciences: Technical Sciences*, *63*(1), 155–161. https://doi.org/10.1515/bpasts-2015-0017

Li, T., Yang, S., & Tan, M. (2019). Simulation and optimization of water supply and demand balance in Shenzhen: A system dynamics approach. *Journal of Cleaner Production*, *207*, 882–893. https://doi.org/10.1016/j.jclepro.2018.10.052

Lipponen, A., & Nikiforova, N. (2017). *Wastewater: The Untapped Resource. Paris, UNESCO*. Retrieved from www.unwater.org

Liu, X., Shu, S., Yang, K., Wang, T., & Geng, B. (2018). Intelligent Management of Secondary Water Supply Systems in Downtown Shanghai. *Procedia Computer Science*, *154*, 206–209. https://doi.org/10.1016/j.procs.2019.06.031

Mehta, D., Yadav, V., Prajapati, K., & Waikhom, S. (2017). *DESIGN OF OPTIMAL WATER DISTRIBUTION SYSTEMS USING WATERGEMS : A CASE STUDY OF SURAT CITY DESIGN OF OPTIMAL WATER DISTRIBUTION SYSTEMS USING WATERGEMS : A CASE STUDY OF SURAT CITY*. (December).

Mohapatra, S., Kamble, S., Sargaonkar, A., Labhasetwar, P. K., & Watpade, S. R. (2012). Efficiency study of a pilot water distribution system using EPANET and ArcGIS10. *Conference CSIR-NEERI*, (June 2014).

Nelson, K., & Erickson, J. (2017). *Intermittent supply in the context of efforts to improve piped drinking water supply in Latin America and the Caribbean: Lessons from a case study in Arraijan, Panama*. (January), 31.

Ortuña, F. G. (2010). Water Management in Coastal Areas: the Experience of Catalonia. In *Chalaenges in Water Resource Management*.

Pietrucha-Urbanik, K., & Studziński, A. (2019). Qualitative analysis of the failure risk of water pipes in terms of water supply safety. *Engineering Failure Analysis*, *95*(September 2018), 1–2. https://doi.org/10.1016/j.engfailanal.2018.09.008

Ramana, G. V., Sudheer, C. V. S. S., & Rajasekhar, B. (2015). Network analysis of water distribution system in rural areas using EPANET. *Procedia Engineering*, *119*, 496–505. https://doi.org/10.1016/j.proeng.2015.08.875

Rao, D. R. M., Ahmed, Z., Ellamraj, D. Y., & Reddy, D. D. R. M. (2016). EPAnet Demand Calculation Methods and Implications. *International Journal of Scientific Engineering and Research (IJSER)*, *4*(11), 73–76.

Rao, R., Naik, M. G., & Naresh, A. (2015). Simulation of Continuous Water Supply Distribution System : A Case Study Part of Hyderabad Metropolitan City. *20th International Conference on Hydraulics, Water Resources and River Engineering*, (December), 17–19.

Romero-Lankao, P., & Gnatz, D. M. (2016). Conceptualizing urban water security in an urbanizing world. *Current Opinion in Environmental Sustainability*, *21*, 45–51. https://doi.org/10.1016/j.cosust.2016.11.002

Rossman, L. A. (2000). EPANET 2 Users Manual EPA/600/R-00/57. *Water Supply and Water Resources Division, U.S. Agency, Environmental Protection*, (September).

Sanchez, G. M., Terando, A., Smith, J. W., García, A. M., Wagner, C. R., & Meentemeyer, R. K. (2020). Forecasting water demand across a rapidly urbanizing region. *The Science of the Total Environment*, *730*, 139050. https://doi.org/10.1016/j.scitotenv.2020.139050

Sayyed, M. A. H. A., Gupta, R., & Tanyimboh, T. T. (2014). Modelling Pressure Deficient Water Distribution Networks in EPANET. *Procedia Engineering*, *89*, 626–631. https://doi.org/10.1016/j.proeng.2014.11.487

Scheele, U., & Malz, S. (2007). *WATER USES AND HUMAN IMPACTS ON THE WATER BUDGET 2 2.2 Water demand and water use in the domestic and industrial sectors – An overview*. 95–99. Retrieved from http://www.klima-warnsignale.uni-hamburg.de/wp-content/uploads/2016/01/scheele_malz.pdf

Scott, J., Ho, W., Dey, P. K., & Talluri, S. (2015). A decision support system for supplier selection and order allocation in stochastic, multi-stakeholder and multi-criteria environments. *International Journal of Production Economics*, *166*, 226–237. https://doi.org/10.1016/j.ijpe.2014.11.008

Services, E. (2010). *WATER DISTRIBUTION SYSTEM*. (June).
Trifunovic, N. (2006). Introduction to Urban Water Distribution. *Introduction to Urban Water Distribution*. https://doi.org/10.1201/9780203964699
UNESCO. (2006). a Shared Responsibility. In *The United Nations Educational, Scientific and Cultural Organization (UNESCO)* (Vol. 265). https://doi.org/10.1016/S0140-6736(55)90351-2
UNESCO. (2015). Water for a sustainable world. In *The United Nations world water development report*.
van den Berg, C. (2015). Drivers of non-revenue water: A cross-national analysis. *Utilities Policy*, *36*, 71–78. https://doi.org/10.1016/j.jup.2015.07.005
Wang, M., Deng, Y., Won, J., & Cheng, J. C. P. (2019). Automation in Construction An integrated underground utility management and decision support based on BIM and GIS. *Automation in Construction*, *107*(November 2018), 102931. https://doi.org/10.1016/j.autcon.2019.102931
Xiao, C., Li, B., He, G., Sun, J., Ping, J., & Wang, R. (2014). *Fire Flow Capacity Analysis Based on Hydraulic Network Model*. *89*, 386–394. https://doi.org/10.1016/j.proeng.2014.11.203
Yu, T., Liya, M., Xiaohui, L., & Yunzhong, J. (2010). Construction of water supply pipe network based on GIS and EPANET model in Fangcun District of Guangzhou. *2010 2nd IITA International Conference on Geoscience and Remote Sensing, IITA-GRS 2010*, *2*, 268–271. https://doi.org/10.1109/IITA-GRS.2010.5604123
Zaman, D., Tiwari, M. K., Gupta, A. K., & Sen, D. (2020). A review of leakage detection strategies for pressurised pipeline in steady-state. *Engineering Failure Analysis*, *109*, 104264. https://doi.org/10.1016/j.engfailanal.2019.104264
Zhao, X., Jin, F., Zhou, L., Wang, Q., & Pu, X. (2018). Construction of Sag-Wide Merged 3D Seismic Data Platform. *Re-Exploration Programs for Petroleum-Rich Sags in Rift Basins*, (3), 17–48. https://doi.org/10.1016/b978-0-12-816153-1.00002-x

APPENDICES

Appendix A : Thesis Work Plan: Gantt Chart

ID	Task Name	Start	Finish	Duration
1	Proposal Development	2019-12-02	2020-01-31	45d
2	Supervisor Confirmation	2020-02-03	2020-02-06	4d
3	Budget Proposal Defence	2020-02-18	2020-02-18	1d
4	MSc. Proposal and Budget Approval	2020-03-18	2020-03-18	1d
5	Review of MSc.Thesis Proposal	2020-02-18	2020-07-03	99d
6	Submission of Mid-term report	2020-05-29	2020-05-29	1d
7	Change of Case Study due to COVID-19 Lockdown Restrictions	2020-06-22	2020-06-22	1d
8	Data Collection (Remotely)	2020-06-22	2020-07-03	10d
9	Data organization, database creation and Input	2020-06-22	2020-07-08	13d
10	Analysis of Results	2020-06-22	2020-07-30	29d
11	Final MSc. Compilation	2020-06-22	2020-07-31	30d
12	MSc. Thesis Report Submission	2020-07-31	2020-07-31	1d
13	Review Final Report	2020-07-30	2020-08-31	23d
14	MSc. Thesis Presentation	2020-09-01	2020-09-01	1d
15	MSc. Thesis Final Submission	2020-09-04	2020-09-04	1d

Appendix B : Water Demand Estimation

Commercial Average Daily Demand= 16.80 m^3/ha/day

Light Industrial Average daily demand= 22.50m^3/ha/day

Wet industrial Average daily demand= 33.60m^3/ha/day

Unaccounted for water (UFW) = 30% of the total Water production

Residential Water Demand

Known information:

Specific water consumption =180 litres per person per day (L/C/D),

Population= 33774 people

In the absence of water demand data, we use the Good Rich Formula for peak water demand estimation.

Average water consumption

$Q_{wc,avg} = ncq$

$Q_{wc,avg} = 33774 \times 180lcd \times 0.001m^3 \div 24hr$

$Q_{wc,avg} = 6079.32\ m^3/day$

$\boldsymbol{Q_{wc,avg} = 253.31\, m^3\, /hr}$

Water production estimation (Q_{wp})

$$Q_{wp} = \frac{Q_{wc,avg}}{(1 - \frac{l}{100})}$$

$$Q_{wp} = \frac{6079.32\, m^3/day}{(1 - \frac{30}{100})}$$

$$\boldsymbol{Q_{wp} = 8684.74\, m^3/day}$$

Water demand estimation

$$Q_d = \frac{Q_{wc,avg}}{f_c} \times (pf_o + \frac{l}{(100 - l)})$$

$$Q_d = \frac{6079.32}{1} \times (1.8 + \frac{30}{(100 - 30)})$$

$$Q_d = 6079.32 \times 2.23$$

$$\boldsymbol{Q_d = 13548.20 \frac{m^3}{day}}$$

$$Q_d = 13548.20 \frac{m^3}{day} \div \frac{24hr}{day}$$

$$\boldsymbol{Q_d = 564.51 \frac{m^3}{hr}}$$

Average Daily Demand (ADD) in *m^3*

$ADD = Population\ (P) \times Per\ Capita\ (Litres\ per\ person\ per\ day) \times 0.001m^3$

$ADD = 33774 \times 180\ (Litres\ per\ person\ per\ day) \times 0.001m^3$

$ADD = 6079320 \times 0.001m^3$

$\underline{\boldsymbol{ADD = 6079.32\, m^3/day}}$

Maximum Daily Demand (MAD) in *m^3*

$MAD = 1.8 \times Population\ (P) \times Per\ Capita\ (Litres\ per\ person\ per\ day) \times 0.001m^3$

$MAD = 1.8 \times 33774 \times 180\ (Litres\ per\ person\ per\ day) \times 0.001m^3$

$MAD = 1.8 \times 6079320 \times 0.001m^3$

$\underline{\boldsymbol{MAD = 10942.20\, m^3/day}}$

Average Hourly Demand (AHD) in *m^3*

$AHD = Population\ (P) \times Per\ Capita \times 0.001m^3 \div [\frac{24h}{day}]$

$AHD = 33774 \times 180 \times 0.001m^3 \div 24hr$

$AHD = 6079320 \times 0.001m^3 \div 24$

$\underline{\boldsymbol{AHD = 253.305\ m^3/hr}}$

Maximum Hourly Demand (MHD) in *m*^{3}

$MHD = 1.5 \times Average\ hourly\ demand$

$MHD = 1.5 \times AHD$

$MHD = 1.5 \times 253.305m^3/hr$

$\underline{\boldsymbol{MHD = 379.96\ m^3/hr}}$

Appendix C: Calculation of Tank Diameters

Known values are highlighted in grey. The tanks are all cylindrical in orientation and the value of ***h*= *5m*** for all tanks except IDs.

ID	Name	Capacity (m^3)	X	Y	Elevation (m)	Installation Date
1	Ouled Ziri 01	3000	603967	3882762	116.5	
2	Ouled Ziri 02	3000	603990	3882735	114.8	
3	Ouled Ziri 03	750	603956	3882788	116.5	
4	Ouled Ziri 04	220	604034	3882753	112.7	
5	Haout Ammer	750	604261	3883611	72.3	
6	Sidi Amar	200	605566	3883692	115.1	1968
7	Ouled Ziri	250	604567	3883143	107.5	
8	Metanof	200	603265	3884014	47.8	
9	Centre Ville	600	604335	3884548	71.1	1958
10	Centre Ville	600	604352	3884557	73.2	1958
11	Sidi Amar	750	605529	3883698	114.2	1975
12	Chateau d'eau	300	604490	3884724	45.2	
13	Chateau d'eau	150	604796	3884579	88.7	
	Total Storage	10770				

$$\boldsymbol{Volume\ of\ a\ Cylinder, V = \pi r^2 h}$$

i. Ouled Ziri 01

$3000 = 5\pi r^2$

$$\sqrt{r^2} = \sqrt{\frac{3000}{5\pi}}$$

$$2r = 2 \times \sqrt{\frac{3000}{5\pi}}$$

$$\underline{\boldsymbol{Diameter\ (d) = 27.64}}$$

ii. Ouled Ziri 02

$$3000 = 5\pi r^2$$

$$\sqrt{r^2} = \sqrt{\frac{3000}{5\pi}}$$

$$2r = 2 \times \sqrt{\frac{3000}{5\pi}}$$

$$\underline{\boldsymbol{Diameter\ (d) = 27.64m}}$$

iii. Ouled Ziri 03

$$750 = 5\pi r^2$$

$$\sqrt{r^2} = \sqrt{\frac{750}{5\pi}}$$

$$2r = 2 \times \sqrt{\frac{750}{5\pi}}$$

$$\underline{\boldsymbol{Diameter\ (d) = 13.82\ m}}$$

iv. Ouled Ziri 04

$$220 = 5\pi r^2$$

$$\sqrt{r^2} = \sqrt{\frac{220}{5\pi}}$$

$$2r = 2 \times \sqrt{\frac{220}{5\pi}}$$

$\underline{\boldsymbol{Diameter\ (d) = 7.48\ m}}$

v. **Haout Ammer**

$$750 = 5\pi r^2$$

$$\sqrt{r^2} = \sqrt{\frac{750}{5\pi}}$$

$$2r = 2 \times \sqrt{\frac{750}{5\pi}}$$

$\underline{\boldsymbol{Diameter\ (d) = 13.82\ m}}$

vi. **Sidi Amar 01**

$$200 = 5\pi r^2$$

$$\sqrt{r^2} = \sqrt{\frac{200}{5\pi}}$$

$$2r = 2 \times \sqrt{\frac{200}{5\pi}}$$

$\underline{\boldsymbol{Diameter\ (d) = 7.14\ m}}$

vii. **Ouled Ziri**

$$250 = 5\pi r^2$$

$$\sqrt{r^2} = \sqrt{\frac{250}{5\pi}}$$

$$2r = 2 \times \sqrt{\frac{250}{5\pi}}$$

$\underline{\boldsymbol{Diameter\ (d) = 7.98\ m}}$

viii. **Metanof**

$$200 = 5\pi r^2$$

$$\sqrt{r^2} = \sqrt{\frac{200}{5\pi}}$$

$$2r = 2 \times \sqrt{\frac{200}{5\pi}}$$

$\underline{\boldsymbol{Diameter\ (d) = 7.14\ m}}$

ix. Centre Ville 01

$600 = 5\pi r^2$

$\sqrt{r^2} = \sqrt{\frac{600}{5\pi}}$

$2r = 2 \times \sqrt{\frac{600}{5\pi}}$

$\underline{\boldsymbol{Diameter\ (d) = 12.36\ m}}$

x. Centre Ville 02

$600 = 5\pi r^2$

$\sqrt{r^2} = \sqrt{\frac{600}{5\pi}}$

$2r = 2 \times \sqrt{\frac{600}{5\pi}}$

$\underline{\boldsymbol{Diameter\ (d) = 12.36\ m}}$

xi. Sidi Amar

$750 = 5\pi r^2$

$\sqrt{r^2} = \sqrt{\frac{750}{5\pi}}$

$2r = 2 \times \sqrt{\frac{750}{5\pi}}$

$\underline{\boldsymbol{Diameter\ (d) = 13.82\ m}}$

xii. Chateau d'eau 01

$300 = 5\pi r^2$

$\sqrt{r^2} = \sqrt{\frac{300}{5\pi}}$

$2r = 2 \times \sqrt{\frac{300}{5\pi}}$

$\underline{\boldsymbol{Diameter\ (d) = 8.74\ m}}$

xiii. Chateau d'eau 02

$150 = 5\pi r^2$

$\sqrt{r^2} = \sqrt{\frac{150}{5\pi}}$

$2r = 2 \times \sqrt{\frac{150}{5\pi}}$

$\underline{\boldsymbol{Diameter\ (d) = 6.18\ m}}$

Appendix D: Flight Costs

Mémo Voyage Billet Electronique

Reference du dossier: **LUJV7B** Check My Trip

Issue date: **12 FÉVRIER 20** Bagages
Compagnie Emettrice: **QATAR AIRWAYS**
Numéro de billet: **157-2498920352**

Passager	**Msibi Nduduzo Arnold (ADT)**	Agence	**NOUBA TRAVEL** **5 BD ZIGHOUD YOUCEF** **CONSTANTINE** **CONSTANTINE**
		Téléphone	**213 31 87 22 22**
		IATA	**03211865**
		Agent	**1111**

Itinéraire

De	A	Vol	Classe	Date	Départ	Arrivée	Résa (1)	NVAV (2)	NVAP (3)	Fin d'enregistrement	Bagages (4)	Siège
Tuesday 18 February 2020												
ALGIERS Terminal I	**DOHA**	QR1380	T	18Feb	**15:45**	**23:25**	Ok		30Nov		45K	21K
Opéré par		QATAR AIRWAYS				**Base Tarif**			TLDZP1ZX			
Equipment		Boeing 787-8				**Commercialisé par**			QATAR AIRWAYS			
Flight Meal		Meal							**Durée**		05:40 (Non Stop)	
Wednesday 19 February 2020												
DOHA	**JOHANNESBURG** Terminal A	QR1363	T	19Feb	**02:10**	**10:05**	Ok		30Nov		45K	27K
Opéré par		QATAR AIRWAYS				**Base Tarif**			TLDZP1ZX			
Equipment		Airbus Industrie A350-900				**Commercialisé par**			QATAR AIRWAYS			
Flight Meal		Meal							**Durée**		08:55 (Non Stop)	
Thursday 13 August 2020												
JOHANNESBURG Terminal A	**DOHA**	QR1364	T	13Aug	**13:45**	**23:35**	Ok	21Feb			45K	27A
Opéré par		QATAR AIRWAYS				**Base Tarif**			TLDZP1ZX			
Equipment		Airbus Industrie A350-900				**Commercialisé par**			QATAR AIRWAYS			
Flight Meal		Meal							**Durée**		08:50 (Non Stop)	
Friday 14 August 2020												
DOHA	**ALGIERS** Terminal I	QR1379	T	14Aug	**07:35**	**12:20**	Ok	21Feb			45K	25K
Opéré par		QATAR AIRWAYS				**Base Tarif**			TLDZP1ZX			
Equipment		Airbus Industrie A350-900				**Commercialisé par**			QATAR AIRWAYS			
Flight Meal		Meal							**Durée**		06:45 (Non Stop)	

(1) Ok = confirmé (2)NVAV= Non valide avant (3)NVAP= Non valide après(4) Chaque passager est autorisé à enregistrer en soute un poids ou un nombre de bagages sans frais supplémentaires, comme indiqués ci-dessus au niveau de la colonne bagages.

A l'enregistrement, vous devez présenter une pièce d'identité.

Reçu de paiement

Nom	: **Msibi Nduduzo Arnold (ADT)**		
Numéro de billet	: 157 2498920352		
Mode de paiement	: CASH		
Calcul du Tarif	: ALG QR X/DOH QR JNB118.33QR X/DOH QR ALG118.33NUC236.66END ROE119.783500		
Tarif Aérien	: DZD 28350		
Taxes	: DZD 20DZ	DZD 1500DZ	DZD 1300XE
	DZD 2324G4	DZD 122PZ	DZD 200EV
	DZD 177UM	DZD 1529WC	DZD 1916ZA
Surcharges Appliquées Par La Compagnie	: DZD 28994YQ	DZD 1936YR	
Montant total	: DZD 68368		
Compagnie Emettrice et date	: QATAR AIRWAYS 12Feb20		

Appendix E: Data Request Abstract

Title:	**MANAGEMENT OF A WATER DISTRIBUTION NETWORK BY COUPLING GIS AND HYDRAULIC MODELING: A CASE OF GHAZAOUET**
Main Objective:	To perform a hydraulic modeling and propose GIS based solutions for effective and efficient management of a water distribution network.
Research Timelines:	June - July 2020 (2 Months)
Supervisor:	Dr. Chérifa ABDELBAKI
Local Authority:	Ghazaouet
Case Study Area:	Algeria
Specific objectives	
1. To create a water distribution networks' database of descriptive and spatial operations data.	
2. To develop a methodology for improved management of a water distribution network by coupling GIS with hydraulic modelling.	
3. To propose a tool to network operators for analysing malfunctions and predicting future operating situations.	
ABSTRACT	
Increases in the growth of urban regions along with climate change have contributed to scarcity in water resources. For arid regions, this problem may be aggravated by inadequate management plans and lack of proper data collection related to the geographical location of water distribution networks. A possible solution is the utilization of a geographic information system (GIS) as a tool in decision-making process in the field of water distribution management. Coupling external hydraulic models with GIS can further enhance this management tool. The current study proposes these tools in assessing the performance of a drinking water distribution network. A methodology will be developed by coupling GIS to a hydraulic calculation model. The approach adopted in this work will contribute effectively to the management of water distribution networks. This offers operators a management tool that allows for analysis of malfunctions with an adequate response, to study various solutions and to plan for future situations.	
DATA REQUIREMENTS	
1. NETWORK DATA: Physical elements; pipe catalog, valves, distribution network types (e.g. neural or tree), tank specifications, pump definitions Distribution network blueprints or pipe network layout	
2. CONTROLS DATA: Rules of behavior, reservoir levels, pump operation, reclamation levels or ground levels	

3. DEMAND DATA: Consumption volumes, nodal demand patterns, location	
4. Current Management approaches e.g. SCADA or DMA	
PROPOSED METHODS/ SOFTWARES:	1. **Spatial Analysis**: GIS (QGIS or ArcGIS) 2. **Hydraulic Modelling**: EPANET or InfoWorks WS Pro

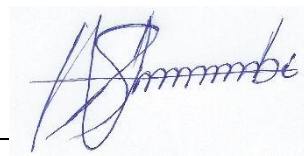
Appendix F : Research Grant Expenses

Receipt Date (DAY-MONTH-YEAR)	Attach ment No.	Description of Expenses	Transaction at Local Currency		Only applicable when transaction at local currency differs from USD						
					Conversion to USD		Comment	Category entry	Total actual expenses /category	Total planned /category	Balance
			Currency Name	Amount	USD value*	Amount					
22-Feb-20	1	Internet data - February	SZL	494.50	14.75	**33.5**	ok	**Material and Supplies**	**484.4**		
20-Mar-20	1	Internet data - March	SZL	699.80	16.124	**43.4**	ok				
22-Apr-20	1	Internet data - April	SZL	699.80	18.093	**38.7**	ok				
19-May-20	1	Internet data - May	SZL	699.80	18.308	**38.2**	ok				
23-Jun-20	1	Internet data - June	SZL	699.80	16.989	**41.2**	ok				
20-Jul-20	1	Internert data - July	SZL	699.80	16.679	**42.0**	ok				
24-Aug-20	1	Internet data - August	SZL	699.80	17.399	**40.2**	ok				
26-Sep-20	1	Internet data - September	SZL	699.80	16.733	**41.8**	ok				
8-Oct-20	1	Stationary (Printing, scanning, paper, notebook, pens, files)	SZL	2,000.00	16.958	**117.9**	ok				
		N/A						Equipment			
		N/A						Data			
12-Feb-20	1	Flight ticket round trip Algiers to Johanesburg	DZD	68,368.00	119.543	**571.9**	Flight purchased by student	Travel	**1062.10**		
14-Feb-20	1	Shuttle service Travel from OR Tambo (SA) to Mbabane (SZ)	SZL	2,300.00	14.750	**155.9**	ok				

27-Mar-20	1	Field transportation	SZL	5,800.00	16.124	**359.7**	ok				
		N/A						Special Activities			
TOTAL EXPENSES in USD						1,524.51			1,546.50		
FIRST INSTALLMENT (to be filled by controller)						1,783.91	(Incluive of flight ticket)				
SECOND INSTALLMENT (+) / BALANCE DUE PAUWES IF ANY (-) (to be filled by controller)**						**-259.40**					

** Any balance due to PAUWES shall be returned to PAUWES Bank account prior to receiving clearance from the finance officer

I certify that all amounts claimed represent actual disbursements made by me during my research

Signature of Claimant (Name) _  **Date** 23-Nov-20

This claim is in conformity with prevailing PAUWES RESEARCH GRANTS Guideline.

Signature of Certifying Officer axel Nguedia **Date** 17-Dec-20