A LONG-RANGE WIRELESS BASED WATER LOSS MONITORING MODEL

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A Thesis Submitted to the Institute of Postgraduate Studies of Kabarak University in Partial Fulfillment of the Requirements for the Award of Master of Science Information Technology Degree

KABARAK UNIVERSITY

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DEDICATION

I dedicate this work to my wife Mrs. Mary Kirui as well as my Children Abigael Jepkoech and Deborah Jemuge who fitted well with all my responsibilities during my study. I also acknowledge their dedicated prayers and appreciate their words of great encouragement which pushed me to great heights of hard work**.**

ABSTRACT

Water loss monitoring in most water service providers in Kenya continues to be a challenge due to the manual method of monitoring and managing water loss. This necessitates the need to implement long range prototype that enables audits to be executed remotely, affordably and in an adaptable and efficient model specifically designed to manage data and provide solutions to long-lived water loss. The main objective of this study was to develop a long-range wireless based water loss monitoring model. The model used Wireless Sensor Network (WSN) based on IEEE 802.15.4g standard. The technical standard is a low-cost, low-data-rate wireless access technology for devices that are operated or work with batteries. The IEEE with LoRa protocol is more secured and supports access control, data integrity, privacy and protection. The Wireless Sensor Network collects data remotely, efficiently and accurately at real time for the purpose of water loss monitoring. The specific objective of the study involved systematic review of technological challenges, design, implementation and evaluation of a scalable long-range model to detect water loss remotely and accurately at real time. Research design included an experiment which proved the proof of concept, expert interviews and systematic literature review to develop a scalable, iterative and flexible model for water loss monitoring. The network methodology and implementation used in this study was Prepare, Plan, Design, Implement, Operate and Optimize (PPDIOO) lifestyle approach. The study implemented network data propagation performance tests so as to rapidly design and develop the model. The Goal based evaluation was used to evaluate the model. LoRa is a wireless technology that offers a better solution over other technologies like Wi-Fi, Bluetooth, 2G/3G/4G, RFID and ZigBee to provide the best applicable model for water loss monitoring. The monitoring was retrieved online by logging data propagated through the LoRa gateways in the network. The model result successfully recorded any sudden change in water flow and water pressure than the normal water consistent distribution. Water companies will now be able to monitor water supply and losses at real time using the LoRa technologies project that was successfully set up. The equipment's access was a challenge and most of the hardware had to be amalgamated to form one functional unit. The solar panel to provide green energy was improvised to minimize power consumptions and other operation costs. The security of LoRa wireless sensor network is of great concern and merits for future research. There is a huge gap in the study to consider implementation of artificial intelligence in water loss prediction and water usage patterns.

Keywords: *Water Loss, Long Range, Wireless Sensor Network Model, PPDIOO*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CIA	Confidential Integrity Availability
LoRa	Long Range Technology
LPWANs	LoRa protocol wireless Area Networks
ICT	Information Communication Technology
ISDT	Information Systems Design Theory
IoT	Internet of Things
ICMP	Internet Control Message protocol
IPv6	Internet Protocol version 6
NAWASCO	Nakuru Water Service Company
NACOST	National Council for Science and Technology
PHP	Pre Hypertext processor
UN	United Nation
RF	Radio Frequency
WHO	World Health Organization
WPAN	Wireless Personal Area Network
GIS	Geographical Information Systems
PPDIOO	Prepare, Plan, Design, Implement, Operate, and Optimize

DEFINITION OF TERMS

IoT LoRa Internet of Things are interconnected networks, Applications and interpretation of data collected from LoRa-based Wireless Sensor Networks (WSNs) devices. The LoRa model can be modified to apply techniques like machine learning and artificial intelligence to monitor water loss.

LoRa LoRa (long range) is a chirp spread spectrum (CSS) technology with low-power Wireless Sensor Network (WSN) radio frequency or signals technology. LoRa are Internet of Things (IoT) networks are easy to deploy.

LoRa WAN Low–Power, Wide-Area Networks (LPWAN) supports billions of devices forecasted for the Internet of Things (IoT). LoRa WAN uses gateways connected to the network server from water companies

NRW Non-Revenue Water (NRW) are part of unaccounted water loss which arises due to theft, evaporation, faulty metering, poor data gathering and broken pipes leading to water shortage.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Water service providers suffer from frequent water shortages due to lack of water accountability and poor loss control strategies. Water service providers have compromised clean available drinking, household and commercial use of water. The United Nations World Water Development Report focuses on challenges, opportunities and aims at improving water monitoring (Pltonykova *et al*., 2020). Water service providers have contributed to poor performance due to unattended loss in the distribution network and at the customer's premises. There is quite a number of reported cases on water loss which is commonly referred to as Unaccounted for Water (UFW) despite pumping of large amount of water in the distribution system.

In Turkey, the loss values stand at 35% of water pumped, depending the age of the pipes, quality of maintenance, pipe material, and type of soil, high pressures and hydraulic operations. The UFW in many countries differ for example in Europe is of 9-30%, Malaysia of 43%, Bangladesh of 56%, North America experience water loss of 20-50%.This global volume estimates of NRW loss is 126 billion cubic meters per year where US $39 billion lost every year (Liemberger & Wyatt, 2019).In Kenya and other African low-income countries in next 30 years was overpopulated in towns, the water loss is at 20-50% (Al-Washali *et al*., 2019).

However, due to unreliable water supply and frequent water loss from the main feeder, service pipes, distribution pipes, or storage tank; the sizes of the loss size might change from small cracks to large breaks hence end –user runs short of water. The water loss in some countries exceeds 40% in the supply system compared to the supply network. It is important to reduce water loss for increased distribution at real-time to esteemed clients; this reduces the amount of money used and customer satisfaction. Per capital available Water in Kenya is about 650 m^3/year, where in 2025 projections show that a drop of 235m^3 per capita water supply as a result of population growth. Kenya is undergoing urbanization and in the next 30 years the low-income countries will be overpopulated in cities and towns. The World Health Organization (WHO) recommends at least per capita use 20 litres per day for drinking, cooking and sanitation thus it is critical to manage water loss, for the future populations (Santos *et al*., 2018).

Water companies and other water service providers continue to run at a loss as they can only manage operation and maintenance cost. The challenges of tenants tampering with supply system and meters, while corrupt agents get compromised is a challenge facing most water utilities (McCartney *et al*., 2013). The use of technology-based systems to relay data to the central office at real time reduced incidences of corruption and poor water loss control (Creaco *et al*., 2019).

According to Rice *et al*., (2012), water loss occurs in three categories; The Real loss occur if the source of water is not metered, broken line is not repaired and if overflows not prevented. Apparent loss occurs in utility operation such as customer meter inaccuracies, billing system data errors, and unauthorized consumption and authorized un-metered consumption challenges. Water losses is composed of apparent losses which are unauthorized consumption and customer metering inaccuracies, real losses where it accounts for water leakage on transmission, distribution pipes, leakage at storage tanks and leakage on service connections. The water meters of different flow rates and pressure tests are essential for good performance in Non-Revenue Water management (Karadirek, 2020). McCartney *et al*., (2013) accounted for water thus increasing cost of operation hence distorting customer satisfaction patterns. There is also the authorized un-metered consumption of water, used in flushing water mains and in utilities like firefighting (Al-Washali *et al*., 2019).

Piped water connections to premises still the most affordable and safe system of water provision. The need to strengthen service providers continues to be critical for affordable and quality water provision. Arising from these scenarios there is need for effective technological strategies in water telemetry, most appropriately through a wireless radio system for data transmission within area of jurisdiction to detect measure, reduce or minimize water loss consistently for the growth of water service companies (Boudhaouia & Wira, 2018).

There is need to change the scattered structure and functioning of water loss arising from broken pipes, illegal connection and water theft cases. The current water supply network strategies are costly, inaccurate and time-consuming way of monitoring water loss. Hydro sense is low–cost approaches which provide information on water flow using pressure waves propagated to sensors when valves are open or closed using Bluetooth technology (Tan, 2019).

LoRa (Long Range), technology is a digital wireless data communication IoT technology developed by Cycleo of Grenoble, France which enable a very-long-range transmissions (more than 10 km in rural areas) with low power consumption (Blomqvist, 2012). LoRa RF1276 provides pure loRa p2p (peer to peer) a low cost, ultra-low power, high performance transparent technology for water loss detection (Sanchez-Iborra *et al*., 2018). The IEEE an IoT standard within a building designed to serve more conventional use cases and the communication range is up to 50m compared to LoRa. LoRaWAN network architecture can be deployed using star- topology unlike mesh topology in Zigbee technology. It has IP based -network stations at physical layer to relay data between the sensor nodes and the network server. There are quite a number of wireless technologies which include Wi-Fi, Bluetooth, 2G/3G/4G, RFID, ZigBee and many others that allow IoT network deployment. This depends on the Network coverage, energy consumption of devices and transmission bandwidth (Boudhaouia & Wira, 2018). While there is wide range of technologies in remote telemetry LoRa can improve water balance and water loss control. The LoRa architecture has gateways and nodes which connect thousands of devices with sensors to monitor water loss for longer distance (5-10 km). The need to have a common smart meter for standard information and sharing remotely using LoRa technology is the best pet despite of many other competing technologies (Sanchez-Iborra et al., 2018). LoRa being an IoT network deployment is capable to monitor and locate water loss. The LoRa technology uses low-cost Wireless Sensor Network (WSN) to remotely and accurately collect data in real time. The possibility to connect such devices remotely increases high proceeds and opportunities to most water service providers (Rabeek *et al*., 2019).

1.2 Statement of the Problem

The current approach employed by water companies in Kenya to detect water loss, whereby field officers physically check for leaking pipes or illegal connection, inefficient and inaccurate readings compromises water accountability. Field officers can also be corrupted by water selling companies, thereby compounding the problem. The daily physical check of water loss is cumbersome in terms of operation cost and is time consuming. Siphoning of water along the main lines continues to be a major challenge to water companies. The agent identifying and reporting such water loss takes a long time to address both from identification and reporting. The extent of such water loss has hindered the availability and accountability of water thus reducing the proceeds of water companies. The massive water loss has contributed to low growth of water companies which no longer supply the water effectively to customers due high operational cost. The customers being supplied with less water which is inadequate for their needs are subjected to seek for alternative water sources. The water suppliers are quite expensive and the water quality standards are also dubious. There is need to design and develop a technological solution that is scalable and cost-effective to solve this problem. LoRa technology model was designed to track water distribution from the source 5-10 km in real-time. This model was implemented in both simulation and as a working prototype. The prototype used television whitespaces to send data to the central data collection point. Being a long-range low power battery, the power source is a secure and standardized smart metering technology, can last for more than 10yrs.The wireless smart water sensor meters monitored and controlled water loss remotely. The detection of water loss approach was implemented and validated after obtaining data from LoRa Wireless Sensor Network (WSN). The automatic leakage monitoring using machine learning Algorithms could give the best results in future. The Algorithm monitors water loss by running loops of daily water load curves arising from user patterns.

1.3 Objectives of the Study

1.3.1 General Objective of the Study

The main objective of this study developed a long-range wireless based water loss monitoring model.

1.3.2 The Specific Objectives of the Study

i. To review current technology challenges in water loss monitoring.

ii. To design a scalable long-range wireless based model for water loss monitoring.

iii. To implement a scalable long-range wireless based model for monitoring water loss.

iv. To evaluate the performance of the long-range wireless based model for monitoring water loss.

1.4 Research Questions

The following questions were used to guide the researcher:

i. What are the current technology challenges in water loss monitoring?
ii. How can the scalable long-range wirelesses-based water loss monitoring model be designed?
iii. How can the scalable long-range wireless based monitoring model be implemented.
iv. How can the performance of the wireless based monitoring model be evaluated?

1.5 Justification of the Study

The daily physical check of water loss is cumbersome in terms of operation cost and is time consuming. In spite of available competitive technologies like the Zigbee, sigfox, Arduno UNO and pressure monitoring, the LoRa Model are more affordable, cost effective, adaptable and easy to use for water monitoring in Water companies for effective water distribution to clients.

The use of smart LoRa meters with Wireless Sensors Network enabled data collection of water usage patterns at real –time. The broadband internet within homes and increased connectivity are key success factors to water companies.

The advancement of technology by use of smart phones improved client’s information collected from GSM service providers. The identification and reporting of water loss was more efficient thus promoted availability of water to clients at real-time. Reduction of water loss enhanced customer satisfaction and availability of water. There was more connectivity of water to customers or clients. The LoRa Model more open, reliable and accountable; water is no longer compromised thus improving the companies’ proceeds.

1.6 Significance of Study

The government provided clean, safe available drinking water thus improving people's standard of living hence a health Nation. Water companies are able to supply water efficiently, effectively by managing operational costs. Field officers checking physically water loss are minimized, reducing operation cost hence increasing the company's growth. The LoRa Model promoted use of other appliances for innovation, building third party application and other technological solutions for monitoring water loss.

1.7 Scope of the Study

The study was done in Nakuru County where there is rapid growth of population compared to the number of water companies. Using purposive sampling, Nakuru was chosen, being my residential place prompted this study due to frequent water shortages and unreliable water supply due to large consumption. The associated cost of sensor equipment acquisition, remote connection and data collection was factored in the scope. Nakuru is a cosmopolitan county approximately about 1.7 million residents where 50% live in urban areas and the rest in rural areas. It is the fourth largest city in Kenya which is rich in Agriculture and businesses. The study focused on developing a long-range wireless based model for monitoring water loss from the water points to the clients. The prototype developed served as proof of concept. The evaluation was based on the system requirements and the initial objectives. Model functionalities were determined to water consumption at real –time remotely and accurately re-laying to monitoring effectively.

1.8 Limitations of the Study

The LoRa Model Wireless Sensor Network appliances and devices were limited due to the current area of study. The devices were amalgamated in order to meet the specification and requirement to reduce its cost. The vendors could not supply the appropriate devices or peripherals with required specifications for this study. There is need to apply for more grants and other donation from various government agencies. The limitations in bureaucracy at Nakuru Water Company produced bottlenecks in accessing water infrastructure owned and operated by NAWASCO thus having to implement the pilot prototype under the auspicious experiment site. The mechanical flaws like air lock, irregular flow and intermittent pumping times were experienced during the study period.

Security of the LoRa is highly required to maintain confidentiality, Integrity and availability. The researcher advocated for security monitoring, security key distribution and device authentication such as 128-bit AES encryption. The unique encryptions were done at Network Server and on the application level.

The battery replacement in terms of energy compromised consistency despite model of low-cost. There is need to evaluate the use of solar powered gateway routers. This limited electrical wiring and reduced energy in running the LoRa model. The use of green energy reduced the cost of power thus minimizes operational related cost of water companies. Mechanical flows such as air locks and irregular flow patterns could be captured. There is need to measure flow rate with algorithm formulae, the resulting pressure, isolating valves as guided by Apana method. Apana is a technology and services company that helps businesses to manage water at Real-time with automated information. The method addressed best practices, reduced risk, strengthened efficiency and enhanced sustainability of water.

1.9 Assumptions of the Study

The researcher received financial support and grants from various agencies, parents, guardians' friends and relatives to enable purchase of equipment.

There was a ready, accessible market source for technologies associated with this study to enable purchase and consolidation of the technologies.

The Government through the water service Boards across the country enforced other agencies to cooperate with the researcher for the purpose of reducing water loss and enhancing water availability to clients. The long-range model identified and reported water loss at real time remotely hence addressing the challenges affecting many water service providers.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter presents literature related to the working of water distribution network, its challenges and how they have been addressed. Different technologies and approaches for monitoring water loss are also presented highlighting their strengths and weaknesses. An analysis of various studies related to water loss monitoring is presented leading to identification of the research gap. Theoretical and conceptual frameworks that informed the implementation of the model are presented. The section presents prototype development, design, implementation and evaluation. The approaches are guided by systematic reviewing of current technological challenges in the absorption and usage of competitive technology for the purpose of water loss monitoring. These challenges informed the current strategies that are employed in water loss monitoring.

2.1.1 Challenges in the Water Distribution Networks

Water distribution networks are interconnected series of components which include pipes, storage facilities and components convey drinking water to clients with appropriate quality, quantity and pressure. The water distribution networks carry water from treatment plant and untreated to the consumer. The pressure at the end of the line may become undesirably low as additional areas are connected to the water supply system. The required dimensions of the pipes are economical; calculations are easy and simple to analyze data. The pipe network for distribution of water to the consumers may be to private houses, industrial, commercial, institution and other usage points such as (Bello *et al*., 2019).

Water supply network systems in municipal withdraw water from the source where treatment is done before being pumped to homes and businesses. The type of treatment method depends on quality of the water source. Most water supply systems included several stages filtration where suspended particles like debris and algae are removed. On the disinfection stage bacteria and viruses are removed by chlorination methods using UV (ultra violet) light for water purification. After treatment, water through distribution system is pumped to homes, businesses in large pipes or water mains usually buried under roads and sidewalks (Creaco *et al*., 2019). The Water mains are maintained by local governments through paying water rates or property taxes. The challenges to access safe and affordable drinking water continue to increase due to lack of scalable innovative models for monitoring water loss. Water lines are smaller pipes that transport the water and remain the most affordable and safe supply network (Creaco *et al*., 2019)

Apart from siphoning, Loss in Water distribution networks factors such as bad pipe connections, corrosion of pipes, excessive pipe load, ground movement, high system pressure, excavation damages, age of the pipe, temperature, defects of the pipe, the condition of the ground and poor quality of workmanship. The need to manage loss in pipe networks is of more urgent due to water shortages caused by recent droughts, high environmental demand, social and political Pressures. The High value of non-revenue to customers reflects huge volumes of water loss through loss. It seriously affects the financial viability of water utilities through lost revenues and increased operational costs. The overall objective of a distribution system is to deliver water to the consumer at adequate residual Pressure in sufficient quantity for continuity and maximum coverage at affordable cost. In order to attain this objective water companies need to evolve operating procedures and strategies to ensure a satisfactory, efficiently and continuous system at low cost (Boudhaouia & Wira, 2018).

Deterioration of pipes may be caused by corrosive environment, soil movement, poor pipe layout, pressure fluctuation and vibration and excessive traffic loads. The other challenges faced by water distribution system included urbanization, Poor address of apparent loss particularly illegal connections, poor record-keeping systems (Li *et al*., 2021). A good water distribution network should not get deteriorated easily but of good quality. The layout of the water distribution network should be such that no consumer during repairs would be without water supply (Sadeghioon *et al*., 2018). The regression analysis of NRW is the performance indicators where water is monitored and tracked to ensure availability to clients (Al-Washali et al., 2019) the water loss is quite alarming in distribution system especially the pipes. Most water companies and their customers worldwide are affected by water loss in their water distribution systems (WDS). Water audit determines the amount of water lost from a distribution system due to loss, theft, unauthorized or illegal connection from the systems thus affecting the cost of such loss to the utility.

There are real and apparent water loss. Real loss arises from burst pipes, leaking joints, fittings, service pipes, and connections while apparent loss results from illegal connections, unregistered metering to customers, inaccurate meters, stopped meters, vandalized meters, bypassed meters, billing errors, inadequate meter reading policy, bribery and corruption of meter readers. There is urgent need to manage water loss in the Water Distribution System (WDS) (Creaco *et al*., 2019).

Therefore, researchers and practitioners in the recent past have developed various methods of water loss control which include assessment methods. This focused on quantifying the amount of water lost and water audit provides a detailed account of all water into and out of a portion of the water distribution network based on meter records and flow measurements. This is applied to evaluate water loss in an entire network or large portions of a network which are isolated using valves (side benefit – location and repair of valves).This is done as the water flow in the distribution network and performed for at least a 24-hour period (Li *et al*., 2021).

The water loss detection methods using Sensor solutions for identifying the hotspots are required to monitor water in the distribution network. The leak detection method is based on a distributed low-power wireless sensor network. The system consists of multiple low-cost wireless nodes installed on the pipeline system where nodes are connected to a relative pressure sensor (based on a Force Sensitive Resistor, FSR) and temperature sensors attached to the outside of the pipe using a clip, and it utilizes the expansion and contraction of the pipe due to pressure changes. The various loss control models for current and future loss control levels. Water loss could be reduced by developing a sensor model, monitoring instruments, optimizing pipe maintenance strategy and by maintaining an instant pressure regulation system (De Araújo *et al*., 2018).

The control methods of leaks, maintaining the capacity of pipelines, cleaning of pipelines and relining are the best practices of addressing the water loss. Adopting the best practices of plumbing layout, replacement of old or outdated and corrosive network pipes. The water meters are mechanical devices and keeps on deteriorating in terms of performance due to poor quality. It has been observed that 20 to 50% of the installed meters remain non-working thus compromising water loss. Due to lack of advance equipment, real loss in distribution system is difficult to detect loss thus water balance equation cannot be used correctly for assessment of real and apparent loss (Momeni & Piratla, 2021).

The Lack of funds and inadequate data on Operation & Maintenance caused by Inappropriate system design and poor workmanship, overlapping responsibilities, Inadequate training of personnel, poor emphasis on preventive maintenance, Lack of operation manuals and Lack of real time field information (Saraswathi *et al*., 2018).

Table 1

Different Technologies with Specification and their Key Features

Technology	Specification	Key features	Reference
Zigbee	- Zigbee build in mesh topology -the frequency rate 433 / 868 /915865-867MHZ -RF data rate 250 kbps	-Its flexible in battery draining and configuration. -High density of nodes per network - simple implementation, easy to install and of low costs - low power consumption	(Feng, 2019)
Sigfox	-It can run 12 bytes -Restricted to 140 messages per day. -Narrow band technology	Uses standard radio transmission method known as Binary phase-shift keying (BPSK). - Narrow band to encodes radio waves -Sigfox have both endpoint and base station	(Hemjal, 2019)
Pressure monitoring	-Hydraulic models -Loss flow rate per minute and pressure	-The Hydraulic variations of water pressures in a distribution system determine water velocity, flow rate and pressure. -Listening to noise from rods/sticks and observing the temperature help to determine its variations. -It dissects data into piecewise approximations using algorithm.	(Feng, 2019) (Adsul *et al*., 2016)
Arduino UNO microcontroller	Microcontroller components Arduino UNO has two modules; controller board and Zig-Bee module -The flowrate 10 ltrs/min	- It uses DMA (District Metered Area) loggers or loggers with a high sampling frequency. - Algorithms use leak noise Correlator to identify loss between two points apart. -Algorithms work well in metallic pipes and increases frequency	(Adedeji *et al*., 2018) (Välimaa, 2017)

2.1.2 Design Approaches in Water Loss Detection

The following sections present Performance indicators (PI), Pressure monitoring and various approaches of leak detection to further discussion of water loss in developed and developing countries. There are many other strategies which have been put in place to reduce water loss.

2.1.3 Performance Indicators Strategy

The performance indicator (PI) seeks to better understand more on water loss arising from illegal connection, poor metering, siphoning from corrupt field officers. The indicator was used to set the targets for improvement of water supply using LoRa technology. This promoted more proceeds to water companies by efficiently and effectively identifying and reporting water loss at real time. The performance indicator seeks to measure and compare performance of various metrics to enhance validity and reliability (Sanchez-Iborra *et al*., 2018).It developed standards and guidelines on controlling water loss along the water infrastructure. The indicator monitored compliance of policies governing the water act in line with the international standards. The performance indicator Prioritized infrastructure investments to enhance effective water supply to the consumers (Al-Washali *et al*., 2019).

Non-Revenue Water (NRW) is mostly used in developing countries as it's expressed in terms of system input volume. Although performance indicators (PI) are important it has its challenges which depend on supply time, average operating pressure and level of water consumption. In developed countries the infrastructure loss Index (ILI) is used as technical performance indicator for real water loss. The regulation to detect and reduce water loss in water distribution system should ensure that all water supplied to the network is measured and recorded regularly. The evaluation of performance indicators

(PI) in Ethiopia are based on reliability, resilience and vulnerability of the model. The mode of assessment to this indicator included pressure, water quality as Water Quality Index (WQI), water velocity and pressure. (Tekile & Legesse, 2023). A study In Bangkok, Thailand energy is used to input through leaks delivered to users for performance indicators evaluation. The annual water balance should be carried out and reported to the water Ministry (Lipiwattanakarn *et al*., 2019).

2.1.4 Pressure Monitoring

Pressure monitoring is another way to address the water loss strategy. It considers the direct relationship between pressure and water loss flow rate. The monitoring of pressure avoids burst pipes thus enhances availability of water at real time. The monitoring improved the reliability and continuity of water supply by reducing pipe breaks, illegal connection and related water loss activities. The water loss reduces pressure and water flow rate thus water fluctuations across the system (Adedeji *et al*., 2018).

Pressure monitoring involves use of Hydraulic models which are efficient tools to predict the spatial and temporal variations of water pressures in a distribution system. The water velocity, flow rate and pressure by the model can be predicted. Other approaches of leak detection include searching leak physically i.e. listening to noise from rods/sticks and observing the temperature. The other technique includes acoustic, thermal, electromagnetic, chemical, use of geophones, hydrophone, leak noise loggers and correlators as well as Electromagnetic Field Detection have their strengths and weaknesses and cost though smart technology need to be appreciated on monitoring of water loss (Owen, 2018).

2.1.5 Acoustic Emission Method

Acoustic emission (AE) technique has been applied to detect pipeline water leaks in a water distribution system. They are analyzed using two different methods for water loss detection. The reductions in signal amplitude with increasing distance determined the source or attenuation-based methods. The increase in signal transit time with distance from the source or time-of-flight based methods. The turbulence of gas wide band in the pipeline is less than 600KHz.Acoustic emission technique even at low pressure can detect a distance of 200 ft in surface pipeline. Leaks and bursts that are not visible on ground are required to be located by other means to save loss of water. The equipment-based methods leak noise correlators, acoustic sensing (Lovely, 2020).

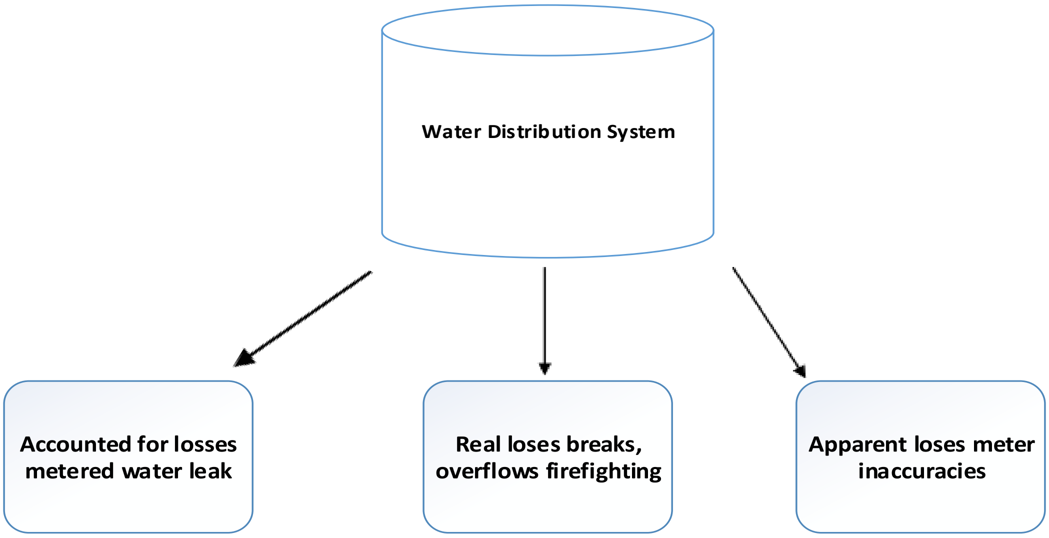
Water distribution is generally installed through underground pipes which are more difficult to monitor loss. Monitoring the underground water pipelines is more difficult than monitoring the water pipelines located on the ground open space. Leaks in pipes may lead to permanent water loss caused by several factors which include the pipe's age, improper installation and natural disasters. Therefore, a solution is required to determine the location of water loss detection. The use of fluid mechanics and kinematics physics based on harness water flow rate data obtained using flow liquid meter sensor and Arduino UNO as a microcontroller. The method is able to work stably to determine the location of the leak which has a maximum distance of 2 meters and leak location with flow rate about 10 liters per minute (Karadirek, 2020).

There are three main components in the solution, namely, accelerometer sensors, Arduino UNO controller board, Zig-Bee module are employed in the water pipeline testbed. The sensor nodes are developed with accelerometer sensor and Arduino UNO controller board (Adsul *et al.*, 2016). The wireless sensor node is connected to ZigBee wireless transceiver for sending vibration data through wireless to storage and processing unit. The water pipeline monitoring test bed system is built to analyze the water pipeline stability. The measurement is to identify the normal pipe and also the loss condition of the water pipeline system. The vibration data is collected on the pipeline system using the contact technique. The prototype of the pipeline system includes the water pump, flow rate meter, pressure meter, leak pipes and two manual valves. The function of a water pump is to generate the water flow rate and the water pressure in the pipeline system. The water system is designed to recycle the water intake during the experiments conducted. Loss detection can be grouped into three groups; leak awareness, localization and pinpointing. However, loss detection can be located by listening for leaks (Stethophon, 2020). There are two ways of water leak; Water Under orifice conditions causing vibration of 500-800 Hz. The second one is Water striking the ground after pipe escapes causing vibration frequency (20-250 Hz). An acoustic leak detector is more digital for correlation purpose (Adsul *et al*., 2016).

There are two types of water losses namely apparent and real loss. Apparent water losses may be as a result of water theft and billing errors while real water losses are physical losses due to leakage (Adsul *et al*., 2016). Overall water loss is the difference between the amount pumped at the source and the amount actually consumed. The accounted for water loss is one that is metered while the apparent loss is not normally accounted for. This scenario is depicted in Figure .

Figure 1

Distribution System loss



Source: American Water Works Association (2006)

Corrosion of metal pipes due to external factors such as pipe characteristic, soil type, pressure within distribution system and installation procedures

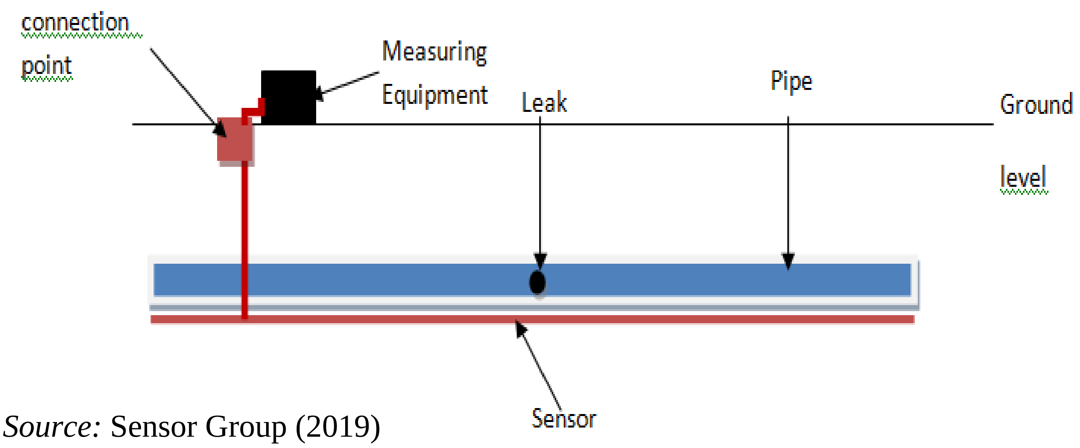
2.1.6 Sensor DDSLID

SENSOR DDS® LID (Linear Impedance Detector) is a new Sensor system which directly detects loss along the water line. The sensing element (SE) is installed parallel to the new pipe within the trench connected to a specified transceiver unit. This new SENSOR DDS Technology installed pipe network tests and monitors loss accurately in real time. The technology can be done both in new and existing installed pipes. The Sensing Element (SE) can measure both remotely and mobile devices. The measuring device contains its own battery which holds enough power to run for some time. The SEs in the inspection chamber is connected by remote device and this was run autonomously. In the event of a loss, the system reports to a Supervisory Control and

Data Acquisition (SCADA) network along the affected SE (Rabeek, Beibei, & Chai, 2019).

Figure 2

The Sensing Element (SE)



Source: Sensor Group (2019)

The technology used is that the Arduino UNO (a microcontroller board based on the ATmega328) generate Electric signal according to water flow rate. The absence of leak water flow rate is constant over the length pipe. On the other hand, when leak occurs, there is a difference in water rate flow. The Flow Sensors sensed the lack of water quantity after the point of leak and give signal to Arduino which generate different outputs like buzzer, LED and text message as per defined in Ardiuno sketch. Buzzer and LED are indicators for loss detection. The GSM module is then used to send message to the responsible person (Boudhaouia & Wira, 2018).

2.1.7 Leak Detection Algorithms

Leak detection algorithms is based on absolute pressure and flow measurements using DMA (District Metered Area) loggers or loggers with a high sampling frequency (>200 Hz) and transient-based leak detection algorithms. The algorithms uses three methods; The first one is the Fixed threshold defined by the user based on historical data basing on the mean value of the relative pressure and temperature difference range during the first 7 days from the same system. A leak is identified in the system if, for a given day, both the temperature difference and the relative pressure readings are flagged. Secondly, threshold criterion is calculated based on a 7-day moving average from the data. The method is more suitable for inconstant normal operational parameters systems. However, a drawback of this method compared to method A is that the moving average can slowly develop leaks as it increases (Li *et al*., 2021).

The third method is based on anomaly detection algorithms, classifies the days with anomalies uses a Seasonal Hybrid Extreme Student zed Deviate (S-H-ESD) algorithm. The method extends a well-established Generalized ESD test by dissecting data into piecewise approximations (Sadeghioon *et al*., 2018). The algorithm integrates a loss model into a Water Distribution Network hydraulic model for solving the network loss flow. The algorithm permits the detection and estimation of critical segments or branches of the network on higher background loss outflow and network point of where pressure control may be performed (Adedeji et al., 2018).

2.1.8 Water Distribution Audit Survey

The difference between the water pumped through distribution network and amount of water billed to customers determine Non-Revenue Water (NRW) in most water utilities. The majority of survey, 45-50% NRP levels is experienced in developed countries. This means that in developing countries the level of water loss is high about 70% due to lack of monitoring system, poor governance and poor physical conditions (Özdemir, 2018). The Town of Olds in Alberta, Canada in 2010, sensors uses GIS to detect loss. In the first six months 21 leaks were repaired and recovered 287,691 cubic meters hence saving revenue of $177,336. Most leaks in the Town of Olds are service line leaks. Water auditing is a systematic and scientific examination of water used in different sectors;

amount of water lost from distribution system due to leakages. A Comprehensive Water Audit facilitates easier, improved reliability and effective management of resources.

A World Bank study shows that 45 billion m3 of water is lost through loss which represents 35% of the water supplied in the distribution system (Neu *et al*., 2006). In general, approximately 60% of the total water loss including that of physical loss and the remaining 40% are accounted for apparent loss. The leak data analysis on service line leaks has helped to target leak locations much more accurately, and non-revenue water loss have been reduced from 39 to 29 %.long range has End Nodes which configures with wireless sensor network devices designed best pet for water companies applications. Location-based wireless devices used to deliver relevant information in real-time when there is water flow.

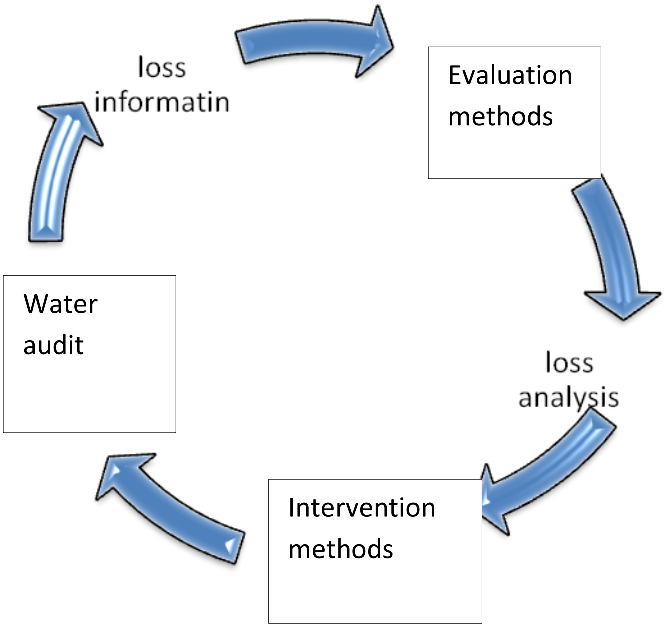
In the United States water utilities and piping systems to clients have suffered considerable loss from poor auditing and loss. The increasing water resources continue to stress many households due to growing populations and climate change. Water loss control and auditing strategies have reduced large volumes of water loss in most water utilities. Water supply in North America has over 50,000 water utilities where less than 10,000 customers are served by small municipalities. Water districts were established to provide water for agriculture and to residential customers. The billing of customers from treated water volume has been a challenge due to loss (Liemberger & Wyatt, 2019).

However, In the United States an estimation of 5.9 billion gallons per day (22.3 billion liters per day) from studies water is lost due to loss, unbilled consumption and poor accounting. This water loss can be able serve at least ten largest cities of the United States. In cities on the East Coast of united states the cost of repairing loss is high hence lead to low water distribution to customers. Water loss reduction through distribution networks has employed both direct and indirect methods the direct method techniques are applied to locate the loss and repaired immediately (Sadeghioon et al., 2018).

On the other hand, indirect method regulates pressure by isolating valves. In some situations, high water pressure can damage roads and property which should be repaired regardless of the cost .Metering helps to Measure or audit supply volumes and consumption on a daily, monthly or annual basis. The manager is able to determine how much water is lost to poor accounting or loss. Figure 3 below shows Water Loss control process program for water quantification.; To quantify water audit and pin point loss the following steps were considered; The identification of the water audit was first done by gathering information on how much water gets in and out of the distribution system using meters or estimates. Secondly, Implementation and intervention plan measures was taken to reduce water loss .The standard performance indicator values is calculated and compared with other water utilities. Thirdly, evaluating the success and intervention analyzed data gaps through comparisons of various values. The intervention includes pipe replacement, additional metering, locating and repairing water leaks, evaluating policies and other maintenance programs (Adedeji *et al*., 2018).

Figure 3

Water Loss Control Process Program

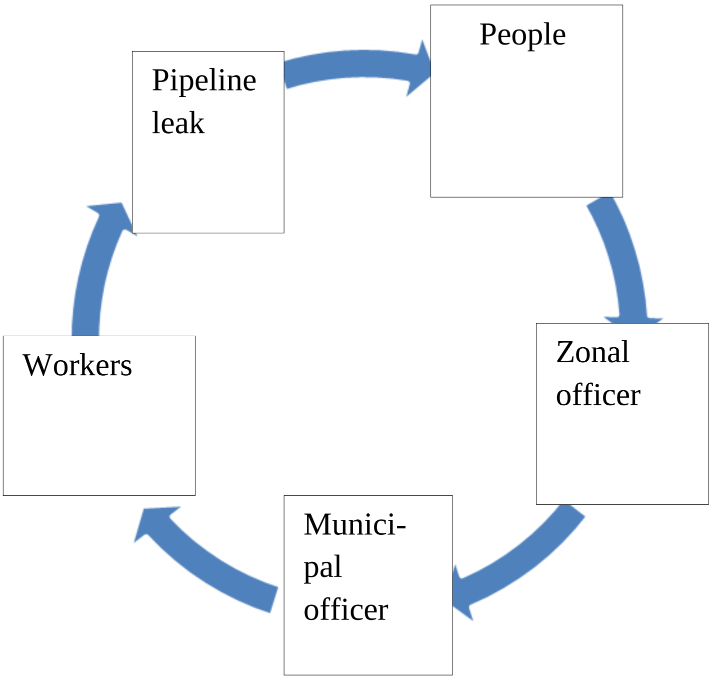


Source: Lemberger & Wyatt, (2019)

In India, the loss control methods is done in the following stages; the total quantity water estimated for town nearly 20% to compensate for loss, thefts and loss. Figure 4 below shows Water loss detection in process; when people in the region observe water loss they complain to the zonal officer. The zonal officer is sent to confirm the water loss then prepares a report to municipal corporation head. The workers then visit the location and repair the water loss. This takes lots of time and too much work force. On the other hand there is also a patrolling team physically with repair equipment to address the leak. The team installs two flow meters in the pipeline to measure flow rate.

Figure 4

Water Loss Detection in Process



Water is a scarce resource which is poorly managed or determines the available supply and use of water in Kenya. Water resources assessment and monitoring has deteriorated in terms of hydrometric network and data recording and reporting system within the country. The Kenya National Water Resources Monitoring Strategy (NWRMS) was set up by water act 2002. It was set up to outline the objectives and strategies that address the major issues and challenges currently facing water loss in Kenya. The guidelines promoted availability of water resources of suitable quality and quantity. The production of accurate data developed water pricing policies and mechanisms. Water supply shortages are having a severe impact on the country with a current population of 40 million people; Kenya has 647 m3 per capita/yr. Mombasa, Nairobi, Nakuru to continue face chronic water supply shortages. In 2010, it was projected that the more than 40 million people required freshwater for use at 540 m3 every year. Water governance is the way water sector institutions (WSIs) are directed and governed to ensure water availability.

The major cause of water loss in Kenya is water theft, illegal connection, Pipe and joint failure (e.g., burst, leak). The improper pipe, fittings, joint type failures, poor installation and maintenance of pipes are notable challenges in water distribution system. The water loss affects the pressure minimizing water loss reduces operation cost and increased proceeds of water companies. The water bodies have not considered solution where water loss can be detected using sensors (Sadeghioon *et al*., 2018).

The use of a long-range model helped to understand the problems and evolve water monitoring devices for detecting loss. The model provided a systematic and scientific data collection, Compilation, processing and retrieval systems to the monitoring. Most urban and rural water crisis and general monitoring continue to be on demand due to increased population. The water billing using meters, poor loss control practices, inefficient operational cost and weak monitoring continue to challenge the availability of water at real time. The water leak detection may take days to be located and reported to the authorities. Therefore, LoRa meter with sensors need to be developed to detect, locate and monitor water loss in water pipeline distribution network at real time. The study aims to predict the leakage using expert knowledge before they occur (Rabeek *et al*., 2019).

2.2 Implementation of Technology based Sensors for Water Loss Detection

The technology-based sensor help to survey water distribution and detects potential loss on the underground pipes. The IEEE 802.15.4g standard sensors detects when a pipe or a valve leak or stop a water system leak. The Wireless Sensor Network (WSN) monitors both physical and environmental conditions such as temperature, vibration, pressure and sound. A variety of sensor technologies have arrived on the market to help water utilities survey their underground pipes and detect real and potential leaks. The Sensors can employ acoustic, chemical detection techniques, electromagnetic and thermal (Sadeghioon *et al*., 2018).

2.2.1 LoRa Technology Devices

It is a set for IoT communications thus enable the connection between remote point-of-use devices and LPWANs for delivery to analytics applications. LoRa Modulation connects long range communication where Transceivers and End Nodes configure with sensor devices designed best pet for water companies applications (Khutsoane *et al*., 2017). The main features of LoRa Technology; Connects devices up to 30 miles apart i.e. 2-5 km urban and 15km in the sub-urban. Long range standards are IEEE 802.15.4g and have a Low Power minimal battery which can last for 10 years. The physical layer of LoRa has Frequency, power, modulation, power and signaling between gateways and nodes. LoRa gateways can connect millions of nodes; infrastructure is cheap and faster to implement (Sanchez-Iborra *et al*., 2018; Seneviratne & Seneviratne, 2019).

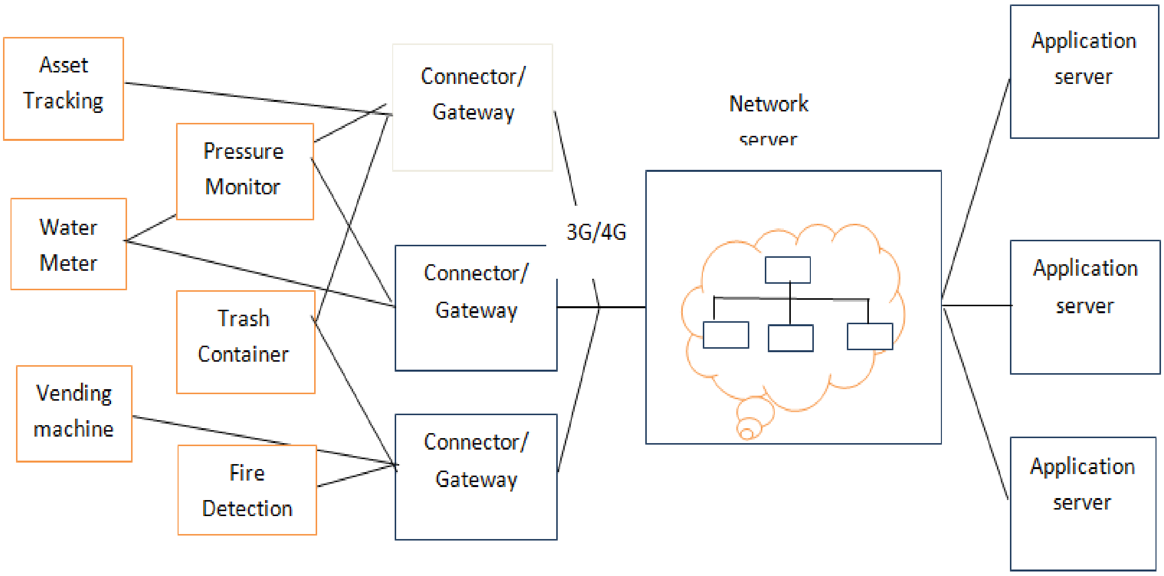
The other LoRa features has an adaptive data rate algorithm which maximize the nodes battery life and network capacity. The LoRa protocol has different layers which include network encryption, application and device level for security communication. LoRa RF1276 provides pure loRa p2p (peer to peer) a low cost, ultra-low power, high performance transparent .It is more secure due to end-to-end AES128 encryption which can maintain confidentiality, integrity and authentication (CIA) (Rabeek *et al*., 2019).

The LoRaWAN networks are of standard IEEE 802.15.4g thus speeds up IoT applications which can be deployed anywhere. The LoRa model consists of Network and application layers where both complete communication protocol in a Wireless Sensor Network (De Araújo *et al*., 2018). Figure 5 below Shows star topology of LoRa. Asset tracking remotely forwards information through nodes and gateways to network server. The Network server then forwards the same information to application server The LoRa

Technology enables GPS best for detection of water loss with high capacity of connectivity at low cost. The use of this technology helps to save operation cost as well as minimal battery replacement (Sanchez-Iborra *et al*., 2018).

Figure 5

Nodes, Gateways Connection to Network Server and Application



Source : Prashant et al., (2018)

There are four LoRaWAN components; The LoRa End Nodes are embedded sensors which transmit data directly to all LoRa gateways within the range. The Sensors help to detect the changing environment e.g. Temperature, pressure, humidity and accelerometer to more than 10 km under Low Power battery (Class A and Class B) (De Araújo *et al*., 2018).

The Class A: Sensors are battery powered and devices transmit data immediately as they are received. The Battery life for Class A devices can last for 2–5 years. This means that the energy must be efficient and must be supported by all devices. The Class B: Battery powered sensors controlled by the network which instruct the device when to transmit data. Class C: Always active and connected to the power source. The LoRa transponder helps to transmit signals over radio transmission method (Seneviratne & Seneviratne, 2019).

The Gateways connected to power source (not on the battery) receive data from LoRa sensors, and sends over IP to the server. The LoRa embedded sensors transmit data to the LoRa gateways which are connected to the internet via the standard IP protocol i.e. server, a network or cloud. LoRaWAN network is more secured as it encrypts data twice i.e. data sensors encrypted by the nodes and IP before being sent to gateways as normal IP network to the server network. The following keys ensures security; Unique Network key (EUI64) based on network level while Unique Application key (EUI64) ensure end to end security on application level and finally the (EUI128) is the Device specific key. Network layer has unique encryptions feature of 128-bit Network Session Key shared between the end-device and network server. It has a Network server solution that can be hosted on the Cloud such as the LoR-IOT Cloud or the Things Network (TTN) (Rabeek *et al*., 2019).

The Application layer has also unique 128-bit Application Session Key (AppSKey) shared end-to-end at the application-level encryptions for security purposes. Application can be hosted in cloud infrastructure solution like the AWS IoT or Azure. Encryptions cannot be done by LoRa transmissions alone because they are simple radio wave transmission. LoRaWAN Bandwidth is more efficient with 100 byte sending 7 messages per second over an extended period. LoRa uses three different bandwidth 25 kHz, 250 kHz and 500 kHz where SF7 to SF12 are used as spreading factors based on data rate requirement and channel conditions (De Araújo *et al*., 2018).

2.2.2 Advantages of LoRaWAN

There are quite a number of advantages of LoRaWAN over other technologies; It consists of Low Powered (long battery life) sensors to last for 2–5 years (Class A and

Class B) and coverage more than 10 kilometers. LoRaWAN Operates on free (unlicensed) frequencies with no upfront licensing cost to use the technology compared to SigFox. The architecture is simple to deploy its Gateway device designed to run thousands of end devices or nodes. It promotes peer to peer /IoT applications and deployment for Low bandwidth. LoRaWAN has Better payload size (100 bytes), compared to SigFox which is 12 bytes. There is No restriction in the maximum number of daily messages (compared to SigFox which is to 140 messages per day).Long range enables solutions such as smart city applications, Low connectivity costs, Wireless, easy to set up and fast deployment. LoRaWAN is secured both in the network and application layers with AES encryption.The technology receives great support with CISCO, IBM and 500 other member companies of the LoRa Alliance (Khutsoane *et al*., 2017; Seneviratne & Seneviratne, 2019).

2.2.3 LoRaWAN Limitation

LoRaWAN is not for large data payloads and limited only to 100 bytes. Class C devices of LoRaWAN provide continuous water monitoring unlike (Class A and Class B). Open frequency may be interfered other frequency thus lowers data rate. GSM or licensed frequency can transmit on that frequency without any interference though pays a large licensing fee to the government.

2.2.4 Comparative Study of Competing Technologies

The sections presented discuss comparatively LoRa with other technologies such as ZigBee, sigbox and Internet protocols version change mechanism in LoRaWAN.

2.2.5 LoRaWAN and ZigBee Standard

Wi-Fi and Bluetooth wireless technologies uses a lot of energy. ZigBee is of low power and transmits for low distance unlike LoRa more than 10km. Semtech is semiconductor

Manufacturer Company which acquired LoRa in 2012and works similar like Sigfox which act as smart meters using sensors. The LoRaWAN protocol includes encryption, authentication, adaptive speed and error correction for maintaining Confidentiality, Integrity and Authentication(Sanchez-Iborra *et al*., 2018). Due to the use of IPv6, LoRaWAN supports large and scalable wireless networks unlike ZigBee which is limited to a single radio standard with defined communication between nodes (Khutsoane *et al*., 2017; Seneviratne & Seneviratne, 2019).

2.2.6 Use of Internet Protocol in LoRaWAN

LoRaWAN is a Low Power WAN Protocol for Internet of Things. LoRaWAN compared to Zibgee still stands a better pet for water loss detection. ZigBee is a wireless 2.4 GHz standard built on IEEE 802.15.4 with mesh topology unlike LoRaWAN star -topology. The mesh network in ZigBee system each node can act as a wireless data endpoint or a repeater which run to the router. It is basically designed for data-rate applications and regularly for home automation and smart lighting unlike LoRaWAN which connects over 10 km unlike Zigbee upto 100m long range star architecture preserves battery lifetime thus enhancing connectivity (Saraswathi *et al*., 2018). LoRa communicates by a method known as Aloha where only data received is relayed at real time. The synchronization to other technologies like Zibgee mesh topology of nodes takes a lot of power thus compromising battery lifetime (LoRaWAN, 2018).

The WPAN LoRa technology is more secure and standard hydro sense smart meter for tracking water from water points to the clients registered with the company. LoRa technology can be able to detect upto 30 miles apart within area of jurisdiction where it measures and evaluates water amount relationship and the resulting pressure (Sadeghioon *et al*., 2018). The easy to install LoRa technology is more powerful when connected to existing or new networks.

The choice of IPv6 than IPv4 is that it supports 128-bit address unlike 32-bit respectively; The IP can be connected or integrated with other networks. The IPv6 allocates addresses, more secure and routing traffic for better communication. The host address and the sub-network prefix can automatically be generated by Media Access Control .They are grouped into eight segments with four hexadecimal digits each divided by a colon. Since the addresses can be large; the preceding zeros can be truncated and consecutive group of zero (0) values two colons (::) only once in an address 0 (:0 :) done with fewer groups of zeros Control (Oliveira *et al*., 2019).

2.2.7 IPv6 and IPv4 Transition Mechanism

The mechanism is implemented in two ways; The first is internet protocol (IP) Tunneling process where existingIPv4 encapsulates data packets to IPv6.Secondly, Dual Stacking is a process where both IPv6 and IPv4 addresses to a network device for propagation LoRa network layer has coordinators which contain information to nodes where it facilitates IPv6 dynamically to other WSN.The LoRa routers connect End devices of star-topologies hence information is sent and received at real –time. The nodes wirelessly forward communication to gateways.

2.3 Theories Informing the Study

The following sections presents Wireless Sensor Network, information system theories, Shannon theories, Lora devices advantages, limitation of loRaWAN, information theories and Wireless Sensor Network.

2.3.1 Wireless Sensor Network

To set up a Wireless Sensor Network for Emergency Response Notification for long range Situations such as fire detection. Lora devices connected to PC with a LoRa Interface Module creates sensing applications. This is developed using 802.15.4 MAC and PHY along with LoRa. The LoRa transceiver design for IEEE 802.15.4 uses matlab/Simulink, Ravikanth Kanna built and simulates using HDL languages Verilog HDL. The use of Minimum Shift Keying (MSK) modulation technique proves a theoretical maximum bandwidth efficiency of MSK is 2 bits/s/Hz which is equal to Quadrature Phase Shift Keying (QPSK) and Offset Quadrature Phase ShiftKeying (Offset QPSK). The results confirmed the viability of theoretical approach by use of mathematical blocks (Ma *et al*., 2019). In the research there are no physical devices. A wireless system for multi-channel transmission of electroencephalographic (EEG) Signals was investigated. The wireless data acquisition and real-time signal analysis system was created for monitoring and analysis purposes. The signal could record the electrical activity of the neurons within the brain. This implies that physiological and pathological information could be collected and used to diagnose and treat brain diseases such as movement disorders, migraine variants, catatonia or patients with coma. The transceiver module is simple to use and do not need any programming language during implementation (Feng, 2019).

2.3.2 Information System Theory

An information system (IS) is all components and resources combined to deliver information in an organization. This combines people, hardware and software, communication networks that collects, transforms and disseminates information within an organization. An information model is a discipline on how people and organization collect, filter, process, create and distribute data using information technology; Wi-Fi and Bluetooth.

The research activities in the field are divided into two paradigms; the design and behavioral science. Behavioral science involves verification and development of theories on human behavior. Design science on the other hand creates new and innovative artifacts. Design science on the other hand extends the boundaries of human and organizational Capabilities. It creates new and innovative artifacts. This study uses design science to develop an information model to track water distribution and its equitable supply to clients. LoRa technology in Information system theory shows how to do something for better solution. The use of IS in LoRa technology produces four major results; Constructs described problems or challenges of a particular solution. The LoRa Model express relationship between various constructs like temperature, humidity and pressure. Methods are set of steps that are used to perform constructs and models while Instantiations are the realization of artifacts in their environment.

The IS theory provide mathematical model for performance of various communication system. It was be observed that random data sources such as music, image signals, wireless or electric singles cannot be distorted by compression. Shannon has led to growth of various applications such as; Statistical Sciences like quantum information theory, Computer science (computability, algorithmic complexity, and resolvability), The Probability theory (deviations in mega data, or various limit theorems) and General Statistics such as hypothesis tests, estimations, and general correlation (Koivisto, 2009).

2.3.3 Shannon Theory of Information

Being the most important theorem of information theorems, Noisy-Channel Coding Theorem (Shannon Theorem) can distinguish messages sent from a noiseless channel. This means that a message at the channel input which experiences a lot of noise and interference can produce the same output message. The theory is achieved when a plain coding system like a repetition code or even a linear error correcting code implemented to simultaneously reduce the rate of transmission the theory is achieved. The transmission rate is approximately equal to the message capacity of the channel.

Data compression and transmission in Shannon theory enhanced LoRa efficient transmission of data. The theory led to growth of various informational sciences or disciplines which include Probability, Statistics and Computer Science. The growth of network communications, propagation, storage of data and other information technologies have been achieved from the Information Theory. The mathematical theory of communication and central devices coordinates in the following ways, the Compression data loss methods which specifies the amount of information within a source and the algorithms as well. It develops optimal compression efficiency as shown by the theory. The channel capacity or bandwidth is indicated by the Shannon theory as well as the amount information Transmitted through a noisy channel. The most critical water loss in LoRa is that of information rate along the distribution network (Lu, 1999; Perinotti *et al*., 2022).

2.3.4 Evaluation Techniques of LoRa

The LoRa RF or radio interface or its physical layer defines the signal to be transmitted by LoRa modules and devices. The properties include the modulation waveform, power levels allowable and bands can be used along with RF protocols. It possible to get information on RF signal and interface. The frequencies bands of 2.4 or 5.8 GHz ISM cover a large area thus LoRa wireless modules and devices achievement in IoT. The data packets travel time from every end node captured by the sensors analyzed for validity and reliability purposes. The cloud gateways send data to online servers where internet control message protocol (ICMP) tested basic connectivity between various sub-networks. The trace route command verified multi-path to ascertain whether LoRa end devices are in star network connected to coordinator for packet evaluation. Data downloaded using comma separated values, analyzed and compared for evaluation purposes in terms of performance.

2.3.5 Research Gap

Studies in the 21st century research trends for water loss control strategies focus on pressure monitoring, active water loss control, pipe rehabilitation, asset monitoring and District Metered Area (DMA) design. In Italy, research team based in Greece continues to look for technological advances in water loss control strategies by collaboration with academic institutions and industries. The main strategy used to reduce water loss is the pressure monitoring of water in distribution systems. This is done by checking optimal settings of pressure reduced through the valve installation. The government commitment, water companies, water operators and the clients are still the most critical stakeholders. The effective implementations of water-loss control strategies continue to be a gap despite of available competitive technologies like the Zigbee, sigfox, Arduno UNO and pressure monitoring. This challenge includes bureaucracies in access of water infrastructure, poor governance expensive water loss control equipment and methods (Özdemir, 2018).

Smart Water Metering System (SWMS) has been brought to Kenya by Earth view Monitoring Company. The availability of Automated Meter Remote (AMR) has loggers which can transmit data over long distance. The ultronic domestic meters with optional valve for prepaid use can transmit data over long distance (AMI). The water balance calculation per neighborhood can easily be retrieved. The dashboard of the Earth view Monitoring company control meters are simple to use and able to share water data distributed to various locations by their clients. Besides water tracking, the smart meters can monitor water sanitation and quality of PH conductivity. The water smart meters compiles and shares real-time data, signals the supplier when the water supply is low and allows easy consumption. In Kenya, the Non-Revenue Water (NRW) being consumed without being paid for stands at 42 percent (Bengtsson *et al*., 2019). The company (Upande ltd) deploys technology to capture and analyze water data (Creaco *et al*., 2019).

The smart meter consists of; Advanced Automated Metering Infrastructure (AMI), Automated Meter Reading Devices (AMR) and Automated Meter Monitoring (AMM) platform. The AMI refers to systems that measure, read and analyze water consumption remotely. The AMR is a remote meter reading systems that permits water utilities to read water meters over long distance on annual, monthly, weekly, daily or hourly basis. The AMM is a simplified water reading to ease data monitoring where the interface can perform and customize all the technical measurement. The customer is able to log in and view analytical data about their consumption. AMR is older smart metering technologies that apply manual reading. The AMI is the latest technology which sends directly data to a computer according to Earth view Director Charles Kaloki. The AMI is fitted with smart meter unit inbuilt or external GPRS, GPS, Radio or Local Area Network communication system (Creaco, 2019). It has a transmitter and communicates one-way. The Radio frequencies sends data directly to a mast before being dispatched to various end-points. The GSM utilizes SIM card and ability to communicate to and fro. The AMI must be powered by the battery or electricity. The Smart meter can also communicate to Meter Data also communicate to Meter Data Monitoring Software (MDMS) (O'Leary, 2020).

The Earth view is a technology company that manages the entire water value chain through from the source to the inlet at the abstraction point. In distribution zones, SWMS zonal meters tell how much water is sold in a day. This helps to lock out cartels which against NRW through illegal connections. The Earth view smart water solution allows companies to ration water through smart valve with LoRa which can be connected or disconnected remotely. This is done to eliminate manual reading of meters which are prone to human errors. When fitted with a SIM card or IOT modules, Smart meter LoRa able to send data to any server (Bengtsson *et al*., 2019). The AMR is installed with high technology smart meter at a location which uses accurate and secure radio frequencies sent to a wireless sensor network (Feng, 2019). The LoRa wireless sensor network is connected to computer or dashboard which helps to generate water consumption from a billing system. This helps to ascertain the amount of NRW in a distribution system. The advancing LoRa Model to monitor water loss at real time is vital for this study. The Data collection techniques using existing system of water meters still a challenge as may give inaccurate information on water usage. The physical checking of water loss is cumbersome and of high cost in terms of operation. Smart meters using LoRa Wireless Sensors Network (WSN) stand the best bet for water loss monitoring accurately and remotely at real time (Liemberger & Wyatt, 2019).

Table 2

Technology Specifications Features and Gaps

Zigbee	-mesh topology -the frequency rate 433 / 868 /915865-867MHZ -RF data rate 250 kbps	-Allows battery draining and configuration. -High density of nodes per network - simple implementation and low costs - low power consumption -Flexible network topology; can use both star and complicated mesh thus easy to install.	Longer configuration time may delay information relay and battery draining affects the battery life. The Zigbee bandwidth frequency is low and fixed. -Zigbee covers 1km or 80 m and used mostly for household set up. -The complicated topologies may lead to difficult configuration	(Feng, 2019)
Sigfox	-12 bytes -Restricted to 140 messages per day. Narrow band technology.	-. Uses standard radio transmission method known as Binary phase-shift keying (BPSK). - Narrow band to encode radio waves. Sigfox have both endpoint and the base station	-The small number of bytes and messages restrictions affects the transfer of information thus delay. Quite expensive end points and base station devices	
Pressure monitoring	-Hydraulic models -Loss flow rate per minute and pressure	The Hydraulic variations of water pressures in a distribution system determine water velocity, flow rate and pressure. -Listening to noise from rods/sticks and observing the temperature is used determine its variations. -It dissects data into piecewise approximations using algorithm.	-Listening to noise of pressure variation may not be accurate for water leak detection. - Pressure reduces water flow rate thus minimal loss detection. - Algorithms draw back the moving average can slowly develop leaks as it increases. The dissections are complex and data configuration takes longer	(Sadeghioon *et al.*, 2018)

-Leak detection algorithms	The algorithm frequency (>200 Hz)	- It uses DMA (District Metered Area) loggers or loggers with a high sampling frequency. - Algorithms uses leak noise Correlator to identify loss between two points apart. -Algorithms work well in metallic pipes and increases frequency	time thus affecting the battery lifetime. -Algorithms only used in metallic pipes only. Plastic pipes have low frequency and attenuates more quickly. This may cause unnecessary delay in addressing water loss.	(Feng, 2019)
Arduino UNO microcontroller	Microcontroller components Arduino UNO has two modules; controller board and Zig-Bee module -The flowrate 10 ltrs/min	-The sensor acts as Microcontroller - locates water loss flow rate about 10 litres/minute at a maximum distance of 2 meters. - Arduino UNO controller uses Contact technique to collect data vibration on the pipeline system. -the water pump helps to generate the water flow and the water pressure along the water distribution system. -comprised of water pump, flowrate meter, pressure meter, leak pipes and two manual valves - The Arduino UNO indicators for loss detection are Buzzer and LED.	-The Arduino UNO controller detection distance is short. - locates water loss flow rate about 10 litres/minute at a maximum distance of 2 meters. -The Microcontroller sensors are expensive and Arduino UNO controller not open source. -The physical Manual valves water meters measurement and records taken regularly is cumbersome and in terms of operation cost.	(Adedeji *et al*., 2018) (O'Leary, 2020) (Uddin *et al*., 2019) (O'Leary, 2020)

2.4 Systematic Literature Review of Technological Challenges in Water Loss Monitoring

Table 3 below shows the summary of results from systematic literature review on challenges of technology-based water loss monitoring.

Table 1

Challenges of Technology-Based Water Loss Monitoring

Challenge	Citation	Review
Large data payloads	(Ma e*t al*., 2019)	A messages restriction affects the transfer of information thus delay. It is quite expensive end points and base station devices.
Low Water Pressure	(Sadeghioon *et al*., 2018)	Pressure at the end of the line may become undesirably low as additional areas are connected to the water supply system. The Hydraulic variations of water pressures in a distribution system determine water velocity, flow rate and pressure.
Short Distance transmission	(Feng, 2019)	Longer configuration time which delayed information relay and battery draining affected the battery life.
IP addressing	(Rabeek *et al*., 2019)	The Gateways connected to power source (not on the battery) receive data from LoRa sensors, and sends over IP to the server or a network to cloud

Following the validation of systematic literature review on security weaknesses and obstacles in the application of LoRa wireless based water loss detection model. It was observed and recommended that LoRa technology identified and reported water loss at real time. The hardware and software abnormalities, modifications of functionalities were considered to ensure reliability and validity. It was noted that LoRa model was the best solution to monitor water loss at real -time. The pressure, humidly and temperature pattern changes determined able to identify the location of water loss (Hartono *et al*., 2022).

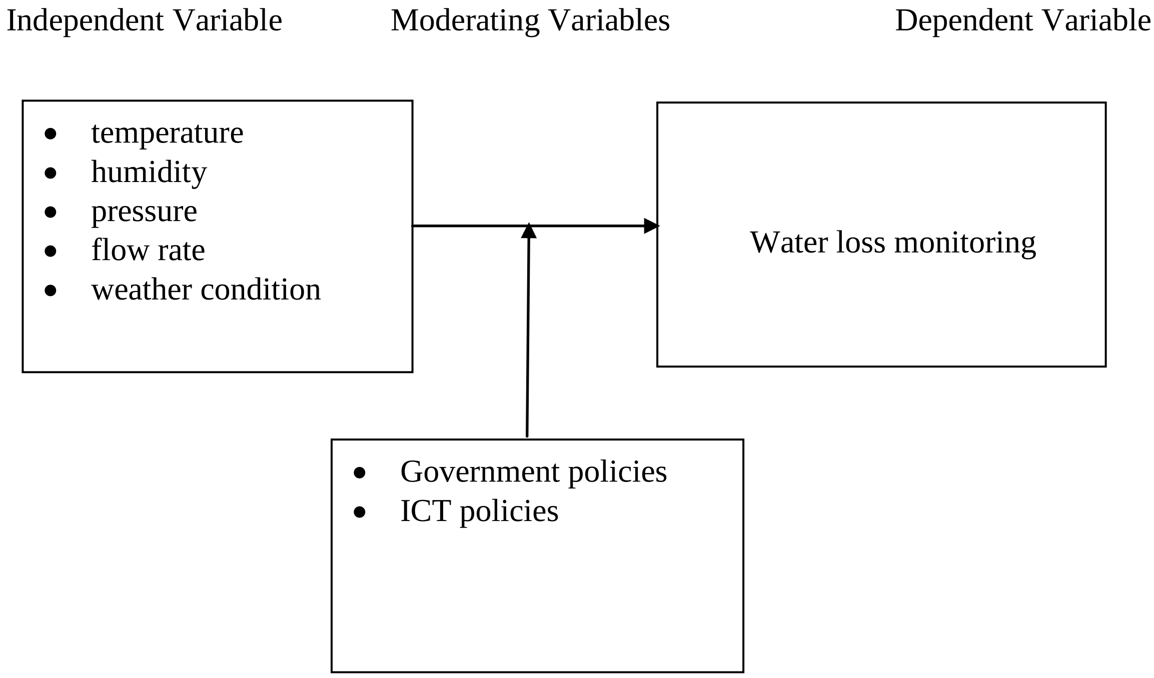
2.5 Conceptual Framework

The LoRa based remote model consist of the following three modules; The Water Device calibration module to identify physical addressing of each water meter, ModBus conversion of analogue water flow to digital reading and LoRa radio frequency module to aid joining, connection and collection of protocol and user data within the Wireless Personal Area Network (WPAN).The meter with LoRa Wireless Sensor Network sends and receives data from Network layer or Network Coordinators (NC) .The smart meter LoRa module is connected to the network server remotely sends data to water companies (Sadeghioon *et al*., 2018).

The Water Company Central Offices (WCCO) receives data from Network servers, forwards to a software system then it analyses for the purpose of detecting any water loss .The software system has the following modules; the data collection module interfaced with system networks and data analysis module generated reports from smart LoRa meter sensors on water loss. The water service providers receive the analyzed information and provide mitigation on the water loss. The figure 6 below shows conceptual frameworks on how the various variables operate for the purpose of monitoring water loss. These remote communications enable analysis, monitoring and loss detection for effective provision water to clients. The technical model has the following components; The LoRa WPAN is made up of smart water meters and a Wireless Area Network (WAN) gateway router which forwards data to the cloud. The WPAN-to-WAN relay data for use by the water service providers Central Office (CO) (Feng, 2019).

Figure 6

Conceptual Framework



Source: Author (2024)

The independent variables seek to give the causes of the water loss indicators which included humidity, temperature, flow rate, pressure and weather. The moderating variables are quantitative variables which collected data of water loss from Wireless Sensor Network for both independent and dependent variables. The moderating variables affected the relationship which included Government policies and ICT Policies. Dependent variable seeks to show the effects or results of identifying and reporting the water loss at real time. The monitoring using Wireless Sensor Network promoted more water pressure in relation to humidity and temperature. The increased water flow rate without loss promoted more water supply and connectivity to clients. The availability of quality water, reduced water contamination and consistent water loss monitoring increased the company's proceeds.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter discusses the research methodology used in designing and implementing a scalable long range wireless Sensor Network model. The elements of the research methodology presented in this chapter include research design and research methods.

3.2 Research Design

The research design chosen for this study was mixed research. The research used both quantitative and qualitative to absorb various methods and procedures. The mixed research designed, actualized, implemented and analyzed various attributes of this study. This also guided in measuring the variables specified in the research problem. The systematic literature review methodology was used to answer the research question one (1). Systematic literature review methodology presented clearly critical methods of water loss monitoring. The literature review identified, defined and assessed the LoRa wireless based model for the purpose monitoring water loss (Liu & Stapleton, 2020). The research question two (2) was achieved using semi-experimental and review study type of approach.

This research design seeks to prove that the hypothesis is precise and truthful, and if implemented, can come to fruition. The research question three (3) was achieved using project as proof of concept and also for research triangulation to implement the model. This involved LoRa model simulation and actual live prototype experiment. The sub-type research design took an experimental design for purposes of creating a working prototype so as to find answers to the research question. The goal-based evaluation was used to evaluate the model where research question four (4) was achieved. This involved collection of various data sets from Wireless Sensor Network through LoRa gateways. The LoRa model remotely proved to identify and reportedly water loss at real time.

This research design framework systematically reviewed the methodology chosen for the purpose of water loss monitoring at real time. The study used mixed types of methods approach, combining both the Proof of concept (POC) which is also referred to as proof of principle by (Schmidt, 2006), and the Prepare, Plan, Design, Implement, Operate, and Optimize (PPDIOO) network research methodologies.

3.2.1 Review of Current Technology Challenges in Water Loss Monitoring

This section presents the methodology that was used to review current technology challenges in water loss monitoring. Systematic literature review presented clearly critical methods of water loss monitoring. The systematic literature review methodology was used to answer the research question one on technological challenges in water distribution. The Secondary data was examined to identify the challenges in water distribution networks.

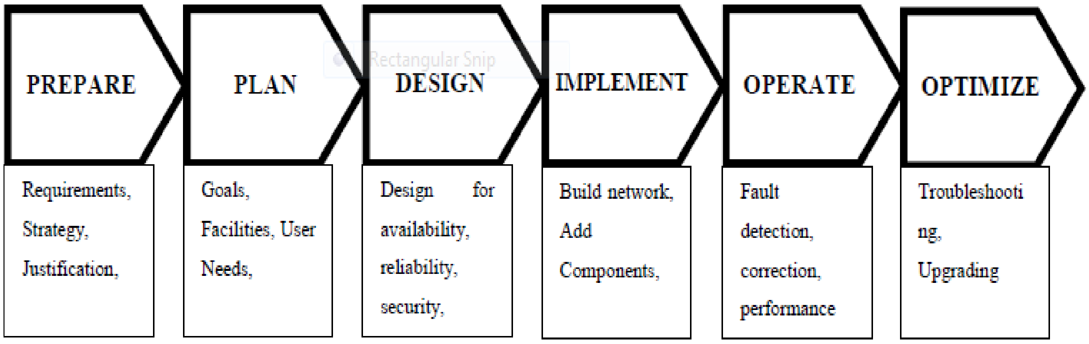
Systematic literature review identified, defined and assessed the LoRa wireless based model for the purpose of monitoring water loss at real time. It has a profound entrenched hypothesis to which it supports, or a philosophical set which has already been discussed thoroughly in the literature review chapters. The results of this methodology provided a guide to inform the design of an efficient long-range model to detect water loss.

3.2.2 Implementing a Scalable Long-range Wireless Based Monitoring Model for Water Loss

This prototype was implemented using the Prepare, Plan, Design, Implement, Operate and Optimize (PPDIOO) network design methodology defines the continuous life-cycle of services required for a network (Froom *et al.*, 2010). Figure 7 below. The PPDIOO methodology was ideal for this study; it helps to lower ownership total cost of network, improves business agility of water companies, enhance network availability, speeds up applications access and services. In implementation stage, the loRa network was built with additional components which were incorporated according to the design specification. The main goal of integrating LoRa devices was to ensure that no disrupting of the existing network or creating points of vulnerability. The Figure 7 below shows Prepare Plan, Design, Implement, Operate and Optimize Network Design and Implementation methodology.

Figure 7

Stages for Optimizing Network Design



Source: Cisco (2010)

3.2.3 Prepare Stage

The prepare stage established network requirements, develop a network strategy and proposes a high-level conceptual architecture. The stage also justified financial viability for network strategy and review the current technological challenges in water distribution network. It assessed the business case for the architecture through expert interviews. The stage seeks understanding of the research problem, defines the network Requirement, Strategy, justification or assumptions. This phase is where LoRa gateways and nodes interconnected with Wireless Sensor Network for the purpose of water loss monitoring promoting creativity and innovation in ICT. The government was able to allocate budget to supply water efficiently and effectively at real time. The physical check of water loss and corrupt field officers was minimized increasing company's proceeds.

3.2.4 Planning Stage

The Planning stage involves identifying initial network requirements basing on goals, facilities and water company needs of water loss monitoring at real time. It involved systematic review sites and assessing any existing networks. The stage identified various gaps in water loss monitoring. The analysis was considered to determine whether the existing system infrastructure, sites, and operational environment have the ability to support the system. It analyzed the observations and synthesizes them to define the core problems of water loss. The planning stage seeks to compare and evaluate various best-practices in network models and matches with the operational environment using sensors for water loss monitoring. Planning phase is done within the scope, budget, and resource parameters with the original business needs of the water companies.

3.2.5 Design Stage

The network design specification is a comprehensive detailed design used to meet the current business and technical requirements of water companies. It was incorporated to support availability, reliability; security, scalability and performance specifications for implementation activities. The stage guided for the development of scalable solution LoRa architecture of a higher level according to the financial assessment on whether it can meet the budgeted cost. The design phase includes LoRa star network topology diagrams, addressing plan, transmission media, Sensors and both end and intermediary devices involved in the set-up.

3.2.6 Implement Stage

During implement stage, the network is built or an additional component is incorporated according to the design specifications for scalable solution architecture. The Sensor Devices and media are procured, installed, configured and calibrated, in accordance to the design specifications. In this phase, new devices are added onto the network, replace or upgrade the existing water loss detection method. The water audit plan should be followed and any un-planned network changes is communicated and documented on time to avoid loop holes for approvals to proceed. During the implementation phase each step include a description, detailed guidelines, estimated time, rollback steps in case of a failure and any additional network information. In implementation stage, the loRa network was built and additional components were incorporated according to the design specification. The main goal of integrating LoRa devices was to ensure that no disrupting of the existing network or creating points of vulnerability. The stage ensures that water companies attend to water loss at real time saving operation cost hence water availability.

3.2.7 Operation Stage

Operation is the final test of the appropriateness of the design. The operational phase involves maintaining the loRa wireless sensor network health through day-to-day operations. This process involves monitoring, managing loRa wireless sensor network components, performing switching, routing maintenance, managing software and hardware upgrades, monitoring and managing general network or device performance as well as identifying and correcting network faults. The operation stage monitors the general flow of data by recording the bandwidth, throughput and good put. This includes maintaining high availability and reducing operation cost. Fault detection, correction and performance monitoring of water loss detection in a distribution system.

3.2.8 Optimize Stage

The Optimize stage involves constant monitoring of loRa wireless sensor network to resolve water loss bottlenecks identified for Troubleshooting purposes. This was critical when proactive monitoring can't predict and mitigate failures. In the event PPDIOO process does not meet expectations in terms of performance, new applications identified to support water companies and technical requirements (Cisco 2010).

3.2.9 Area of Study

The investigation was carried out at a residential house where purposive sampling of twelve (12) houses in Nakuru town. The sampled houses were identified for the purpose of evaluating water flow rate and monitor any water loss. The prototype can be replicated to other areas experiencing similar problem. The researcher concentrated on the stake holder's opinions that included; water service provider's managers, ICT model experts, water engineers, chief executive officers as stakeholders. The expert interview questions given to stakeholders and through their responses were used to validate the LoRa model. The study faced bureaucratic and logistical hurdles as well as challenges in accessing requisite devices. In some cases, peripherals were bought separately and amalgamated into one functional unit. The amalgamate devices were used to produce quality and more affordable LoRa model for the purpose of monitoring water loss remotely at real time.

3.3 Methods and Tools

The design of the LoRa sensor WPAN network addressed using IANA licensed uncast global addresses of 2340: AEBF: 3040: /48 networks. The design was done after prepare and plan stages of Prepare, Plan, Design, Implement, Operate and Optimize (PPDIOO) life-cycle. The research adopted (PPDIOO) network methodology to come up with a long-range water distribution model which created a wireless Sensor Network for water loss monitoring. The PPDIOO defined the continuous life-cycle of services required for a network (Cisco, 2010). The approach is more agile, risk driven, non-linear or iterative and flexible to add other components. The data collection methods included expert interviews and experiment data from wireless Sensor Network.

The methodology seeks to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and testing. The LoRa prototype explicitly simulated a real-life model which remotely collected data from Wireless Sensor Network from remote data logger's. The prototype evaluation and validation were done by use of network tests. These were used to capture, analyze prototype reliability and validity. In order to validate a model various tests were used which include Internet Control Message Protocol (ICMP) for communication from one layer to another.

The network topology diagrams, addressing plan, transmission media using Sensors are put in place to meet current business and technical requirements of water companies for water loss monitoring. The objective was achieved using systematic literature review which revealed that physical or manual check of water shortage by water companies determined the amount of water consumed by clients. This strategy continues to be practiced by comparing and contrasting various data sets on water consumption. The systematic literature review identified, defined and assessed the research topic in a scholarly synthesis for the purpose monitoring water loss. It supported a philosophical set which had already been discussed thoroughly in the literature review. The results provided a guide informing the design of an efficient long range model to detect water loss (Liu & Stapleton, 2020).

The need to evaluate challenges as well as comprehend operational requirements prompted a prototype set-up using sensors to remotely collect water flow data. In addition, data propagation performance testing was carried out to evaluate and validate data sets received from the Network Sensor end devices after model design and development. This operation involves monitoring, managing network components, performing switching, routing maintenance, managing software and hardware upgrades.

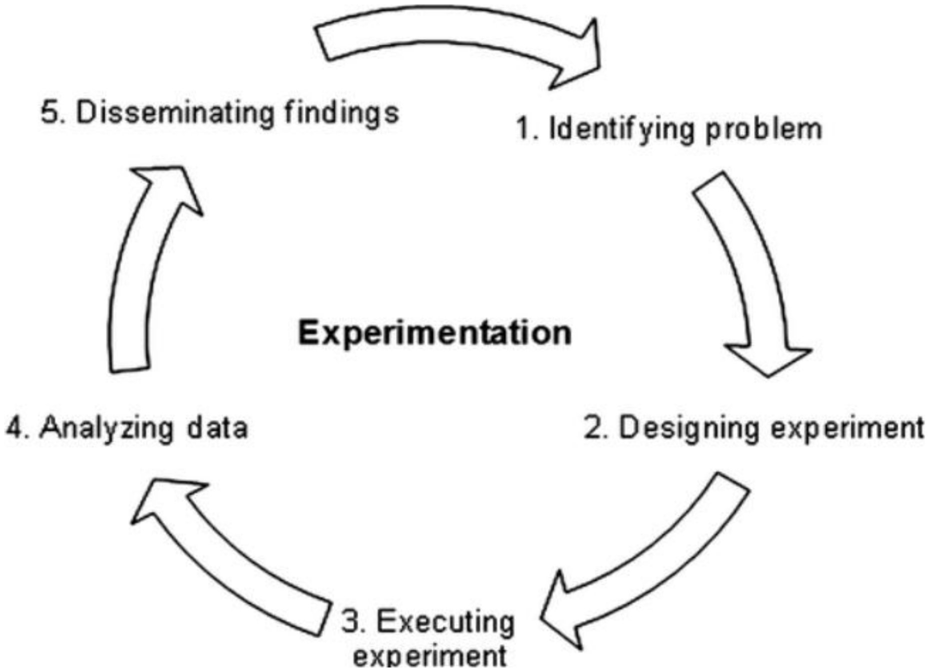
The systematic literature review methodology sought to understand the importance of LoRa technology in water supply. The study purpose to improved water utilities performance, provide quality service delivery and to ensure availability of water at real-time. The digital transformation of water supply supports Sustainable Development Goals (SDG).

The review was carried out to examine and identify the weaknesses, obstacles and application of long range model for water loss monitoring. It sought to identify any weaknesses of the LoRa environment with other devices, various challenges that can be experienced within the LoRa environment and to what degree do the challenges affect absorption of LoRa technologies for water loss monitoring.

The proof of concept (POC) methodology has the sole aim of verifying that a particular concept or theory actually has practical potential. A proof-of-concept research methodology is usually a small application of the concept to ensure the prototype runs to completion. The figure below shows the various steps in experimental research design.

Figure 8

Steps in Experimental Research Design



3.3.1 Water Meter Data Software

The water meter data software consisted of the following modules; the data collection module which interfaced with the data collection networks developed, the data analysis module analyzed the data collected remotely from Wireless Sensor Network. The Reports of the units consumed at the various LoRa meter readers was taken for water loss detection purposes. The Graphs of the network coordinators enabled water loss detection within the devices on the network. The data export module enabled export of data to other LoRa devices or sensors for the purpose of water loss monitoring.

3.3.2 Usability, Reliability, Efficiency and Functionality Validation Metrics

The effectiveness, efficiency and satisfaction usability were used to track both qualitative and quantitative model success. The usability metric evaluated loRa model results by making comparison or benchmarking with other competitive technologies by tracking every success. The metric was used to justify the model usability and quickly spot areas of improvement. The tangible evidence of the problem existing, value and potential return on LoRa model investment were used to justify usability metrics. The satisfaction usability was used to assess emotional responses, user perceptions and preferences. The System Usability Scale (SUS) were used achieve this metric where a questionnaire was sent out to the participants after LoRa model test to assess the perceived usability of the product. The metric promoted the ease use and overall user experience LoRa model to navigate through the experiment without any challenge. The users were able to interact quickly with the LoRa model to accomplish tasks efficiently and satisfactorily to monitor water loss. The metric measured LoRa Model development process effectively, ease learning, error tolerance and efficient to users.

The LoRa model efficiently used minimum resources to achieve the desired results. The efficient usability was used as success rate and the most essential and basic metrics in a task-based where it showed successful participants percentages to those who did not complete the task. The metric ensured that the LoRa model inputs are optimized to produce the desired output leading high productivity to water companies with limited resources. The model efficiency included energy-efficient appliances and implementing solar panels to act as green energy thus saving power cost. Time on task efficiency was used to track how fast and efficient the users performed specific tasks with LoRa model. The operational efficiency ensured that LoRa model minimized waste of deployment time resources and application use with ease at real time. Economic efficiency ensured that LoRa output lowers overhead costs to avoid waste of resources.

The reliability of LoRa model was able to provide consistent results without failure at any specific time. The LoRa set up performed consistently across the platforms with other devices. Test-retest reliability was used to test the consistency of results repeatedly on same sample at a different time intervals. To achieve this result, expert interview questions using questionnaire and Wireless Sensor Network was used to collect data. The Test-retest was used to ensure all samples are tested under the same conditions without interference from external factors. The test included two sets of equipment constituting of a flow meter, a temperature and humidity sensor and a GPS location Modules. The two sets of equipment were placed one meter apart and joined with a pipe and a T-Junction tap. When there is no leakage the sensor values at module 1 are same as the values at module 2. When a leakage is introduced by opening the tap the flow rate and pressure reduces at module 2). Test-retest means that the same LoRa model was tested over time. The interrater or interobserver reliability involved LoRa model testing by different stakeholders like ICT managers, field officers, chief executive officers and clients. The reliability measures data collection and assigned rating scores to one or more variables. The LoRa prototype tested different version of amalgamated devices paralleled designed to be equivalent correlation. To achieve this reliability test, the LoRa model independent, moderating and dependent variables were clearly defined. The detailed objectives ensured all data sets of results had high interrater reliability. The reliability helped to avoid respondents' repetition of same answers or subjectivity arising from data collection.

The Functionality tests of LoRa model involved the ability to perform the intended tasks for the purpose of meeting the LoRa requirement specification for the purpose of monitoring water loss. The tests validated the Data to ensure the accuracy and integrity of data source. The tests were used to confirm whether the model meets the requirements specified from the documentation. The LoRa model was subjected to perform extract, transform and loading data built functions in line with the requirements specification. The functionality metric of the LoRa model ensured reliability, availability and security.

3.3.3 Evaluation and Validation of the Long-Range Wireless Based Monitoring Model for Water Loss

A goal-based evaluation method was used to measure water companies and other service providers' progress towards achieving specific goals or objectives. In goal-based assessment, the emphasis is on assessing the extent to which goals have been met. This was done by the following experts ICT officers, Water engineers, chief executive officers, water field officers and the clients. The need to use goal-based evaluation had the following features; clearly defined and measurable goals or objectives that were set in advance. The Measurable Outcomes quantified and observed the LoRa model progress towards achieving the set goals. The criteria involved setting specific metrics or indicators to track water flow rate progress. Goal-based evaluation Focus on Results to determine whether the desired results have been achieved. It promotes Feedback for Improvement and makes adjustments to strategies or actions to the LoRa model. The model Accountability and Continuous water loss monitoring evaluation help to track progress over time. The tracking helps to make adjustments as needed by water companies for their performance and progress toward achieving the set goals.

The data propagation performance testing is carried out to evaluate data sets received from the LoRa Wireless Sensor Network (WSN) end devices after model design and development. This operation involves monitoring, managing network components, performing switching, routing maintenance, managing software and hardware upgrades. The validity and reliability of the prototype was captured using various metrics follows;

Concurrency Validation tests described how the LoRa network performed when two or more LoRa devices are activated within the water infrastructure. Configuration metric evaluated how every LoRa client operates with every possible transfer of water loss data in the water infrastructure. Functional metric checked how the LoRa network operation functions with every single instance of the water infrastructure. Peak Load validation described how the LoRa networks performed given the heaviest demand like high water pressure and humidity that would be generated at peak user pattern times. Volume metric described how the LoRa network performed with a heavy load on the server, and also with a high volume of data transfers. In order to validate the model, the prototype should perform exemplary well on the above metrics.

The data collected from LoRa Wireless Sensor Network (WSN) are evaluated to check the validity and reliability. The performance was presented in the form of graphs showing the various sensors within the LoRa network for the purpose of monitoring water loss. The trace route commands are verified multi-path. The command ensures LoRa Wireless Sensor Network (WSN) end devices are on a star topology with varying paths to the coordinator. Multipaths ensure that the Wireless Personal Area Network (WPAN) are self-healing, Packets captured using wireshark and evaluated for various data sets. The captured data sets aided in performance of the wireless sensor network for water loss monitoring in a distribution channel. The primary concern of the investigator was safety of the research participant and minimum interference of the existing water distribution feeders. The goal-based evaluation from experts was used to test the validity and reliability of the model.

The researcher received Ethical consideration from Kabarak University Research Ethics Committee (KUREC) for clearance and was approved for Research License from National Commission for science, Technology and Innovation (NACOSTI) which led to the successful completion of the research study.

CHAPTER FOUR

PROTOTYPE DEVELOPMENT AND RESULTS

This chapter discusses a summary of the systematic literature review on the weaknesses experienced in the application of LoRa wireless model for water loss monitoring, as well as the design, implementation and evaluation of long range wireless based water loss detection model to provide available clean water to the clients.

4.1 Design Recommendations for a Scalable Long-Range Model to Detect Water Loss

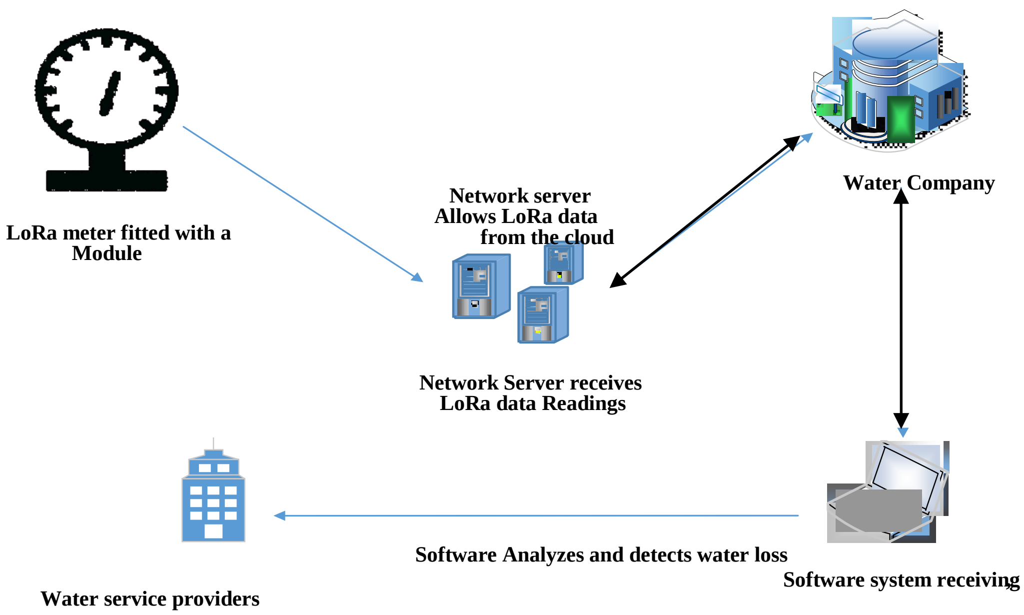
The following key areas were used to apply when designing a secure wireless sensor network for the long range model; The Smart LoRa meters should was used to identify water consumption trend and monitor water loss. The LoRa smart connection in the water network, the Dynamic network topology and mobility promoted accuracy. The resultant of the LoRa system was more scalable with negligible errors.

4.1.1 Results of the Design of a Scalable Long-Range Model to Detect Water Loss.

The meter with LoRa Wireless Sensor Network sends and receives data from Network layer or Network Coordinators (NC). The smart meter LoRa module is connected to the network Server which receives LoRa data readings from the cloud remotely sends data to water companies. The water company Central Offices (WCCO receives data from Network servers and forwards to the software system. the software analyzes the data to determine if there was any possible water loss. The services providers address any water loss at real time to avoid water shortage. The Figure 9 below show the communication setup from the LoRa smart meter for the purpose of designing a Scalable Long-Range Model to Detect Water Loss.

Figure 9

The Design of a Scalable Long-Range Model to Detect Water Loss



4.1.2 Equipment for the Set-up

The project network design was set- up based on the conceptual framework design achieved using the Prepare, Plan, Design, Implement, Operate and Optimize (PPDIOO) network design methodology. The following set of equipment was used to implement the model; The smart flow data collector fitted with LoRa Radio received data from several LoRa devices, The LoRa Radio coordinated the nodes and protocols within the Wireless Personal Area Network .It propagated data to the cloud or an access point and The gate way routers then forwarded data to the cloud where wireless network modules relay data to water service providers. Water device calibration identified the physical addressing for each water meter. Modbus conversion module converted analogue to digital data.

The water flow meter is fitted with improvised solar panel to provide green energy thus saving the amount of energy to be used in the model set up. Figure 10 below shows the water flow meter that collects data integrated with a smart LoRa radio that propagates the data to an access point where it is analyzed by a software system.

Figure 10

A smart Flow Data Collector with Lora Radio

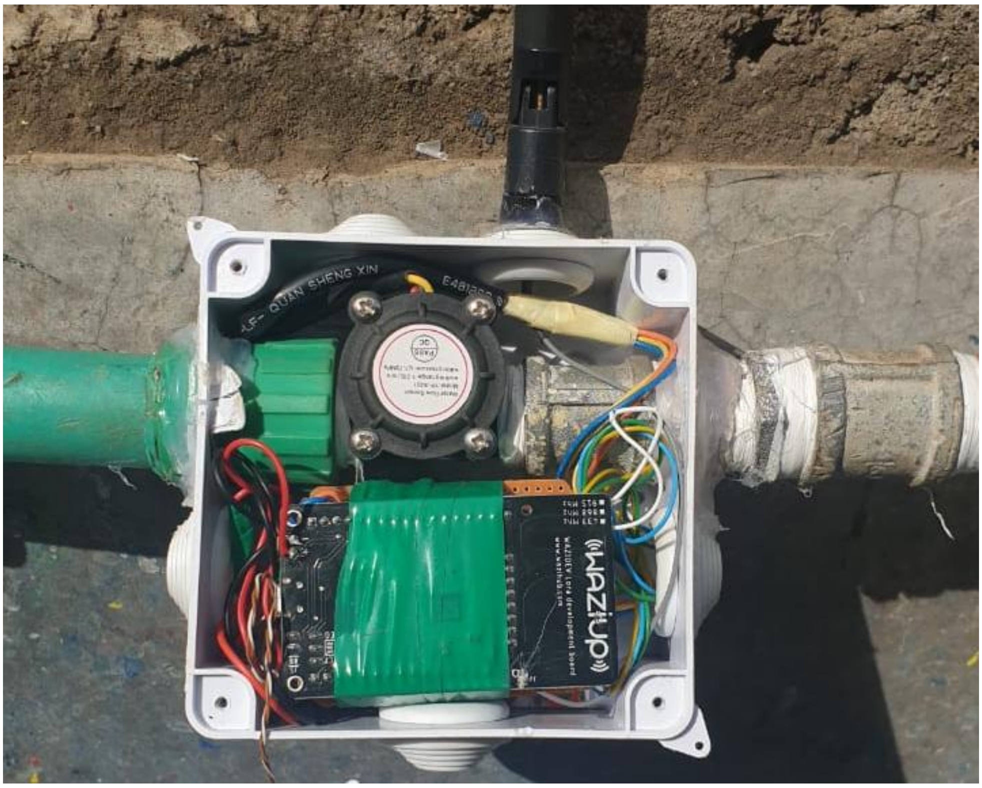


Figure 11, below shows the LoRa radio that receives data from the several LoRa devices for onwards forwarding to the cloud. This radio can support up to 1,000 nodes in its network.

Figure 11

A LoRa radio that coordinates the node

4.1.3 Proof of Concept

Proof of concept was used to develop run a program in order to implement water loss detection. The purpose of this section was to provide guidance towards an approach of designing and implementing a model for water loss detection. Proof of concept (PoC) provided the best methodology to achieve the objective. Proof of concept actualized particular techniques or ideas to show its implement ability or feasibility (Carvalho *et al*., 2019). The PoC principle aimed to verify that a proposed concept or model has a practical potential, which can be implemented successfully. In the field of engineering and technology, a prototype of a novel idea can be constructed as a proof of concept (Sanghera & Sanghera, 2019). The PoC was the approach adopted in this research. The proof of concept involved design, implementation and testing of the LoRa model water loss detection. The environment for development used Wireless sensor network to simulate the model.

Figure 12 below shows the logical diagram for the proof of concept for the LoRa setup which involved the flow meter sensor which captured water pressure readings and flow rate. These readings were remotely captured via LoRa. Any drop in pressure without commensurate readings in flow rate depicts unusual or non-suboptimal disposition which depicts loss at the distribution point. These readings are further sent to the cloud platform that provides further analysis, charts, data detection and prediction.

Figure 12

Logical diagram for the proof of concept for the LoRa setup

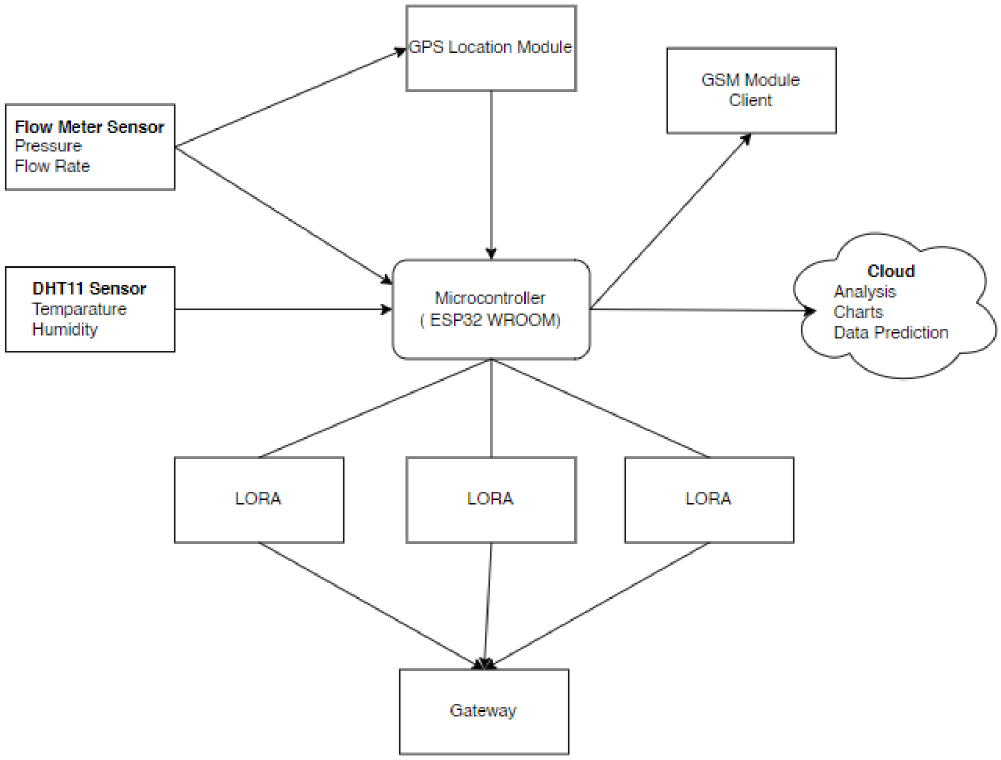
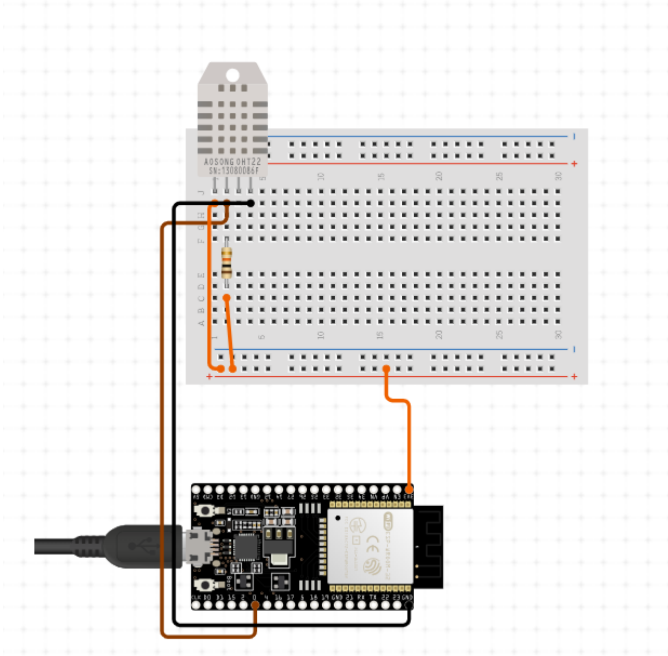


Figure 13 below shows the connection of the microcontroller DHT 11 for purposes of measuring temperature and humidity. This connection measures the humidity and temperature readings in the zone of connection. Any rise in humidity denotes possibility of high presence of water which alerts for possible water loss. This detector is used as a point of triangulation to the possibility of water loss.

Figure 13

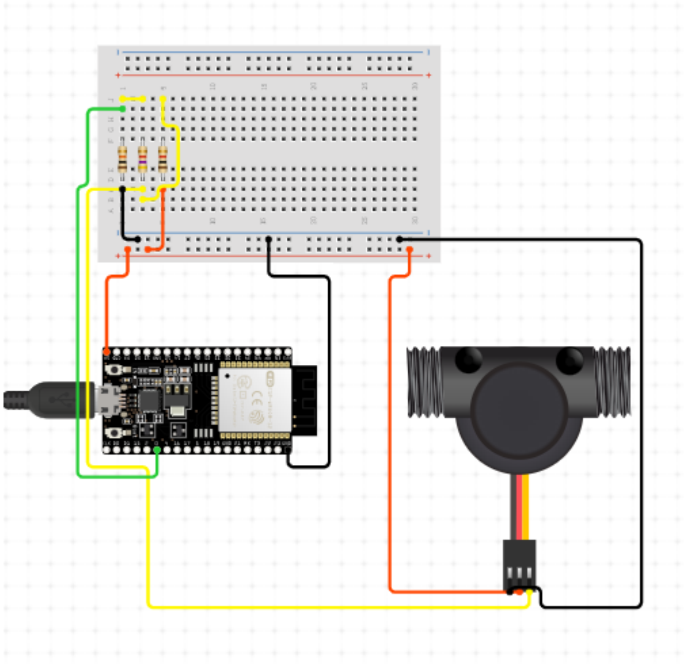
Connection of the Microcontroller DHT 11 for Purposes of Measuring Temperature and Humidity



The connection shown in Figure 14 shows the connection of a digital flow meter with microcontroller for purposes of measuring water flow rate and pressure. These two were measured at optimal live connection with water flowing without any losses and resulting data was captured. Consequently, data would be measured to identify any variation from the norm. Any drop in the water pressure that as not commensurate to the water flow is identified as possible loss.

Figure 14

Digital Flow Meter with Microcontroller



To further proof this concept, Figure 15 below shows a connection that includes an LCD display 20x4 for purposes of providing live readings of both for the water flow rate and pressure. The LCD display can show consistent readings for both flow rate and pressure.

Figure15

A Connection That Includes an LCD Display 20x4

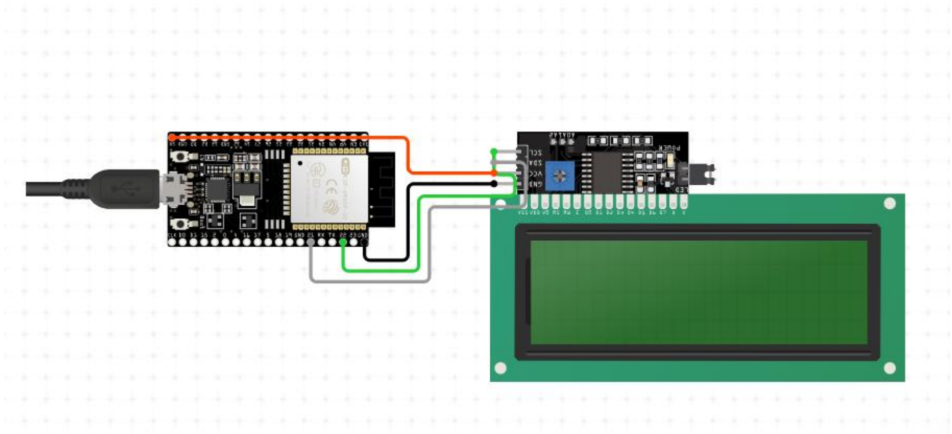


Figure 16 below shows the microcontroller with NEO-GPS location module for purposes of indicating the location of possible water loss. The microcontroller acts as display when there is no wireless connectivity.

Figure16

Microcontroller with NEO-GPS Location Module

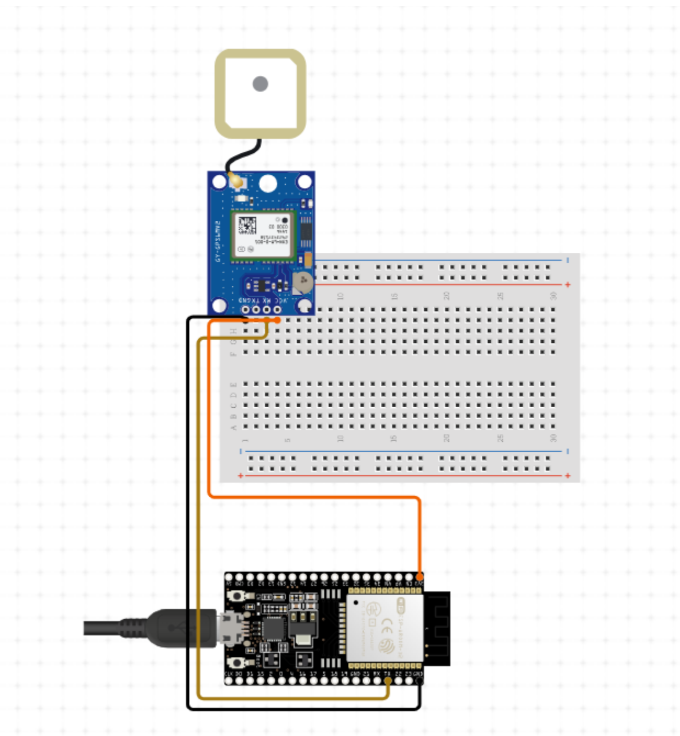
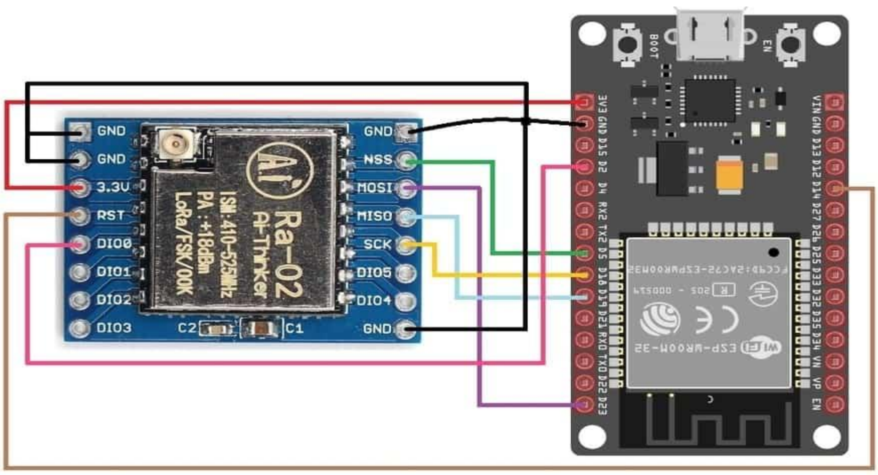


Figure below shows the microcontroller with LoRa RA02 radio module 433 mhz that supports the remote telemetry of results from connection point to the cloud.

Figure 17

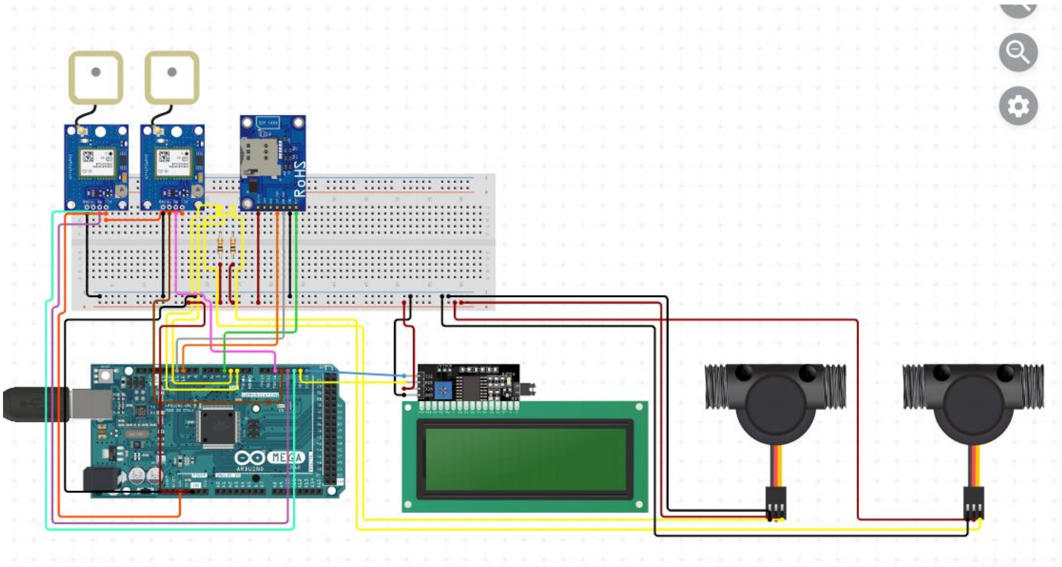
Microcontroller with LoRa RA02 radio module 433 mhz



Finally, Figure 18 below shows the complete circuit diagram with all the various facets and connections.

Figure 18

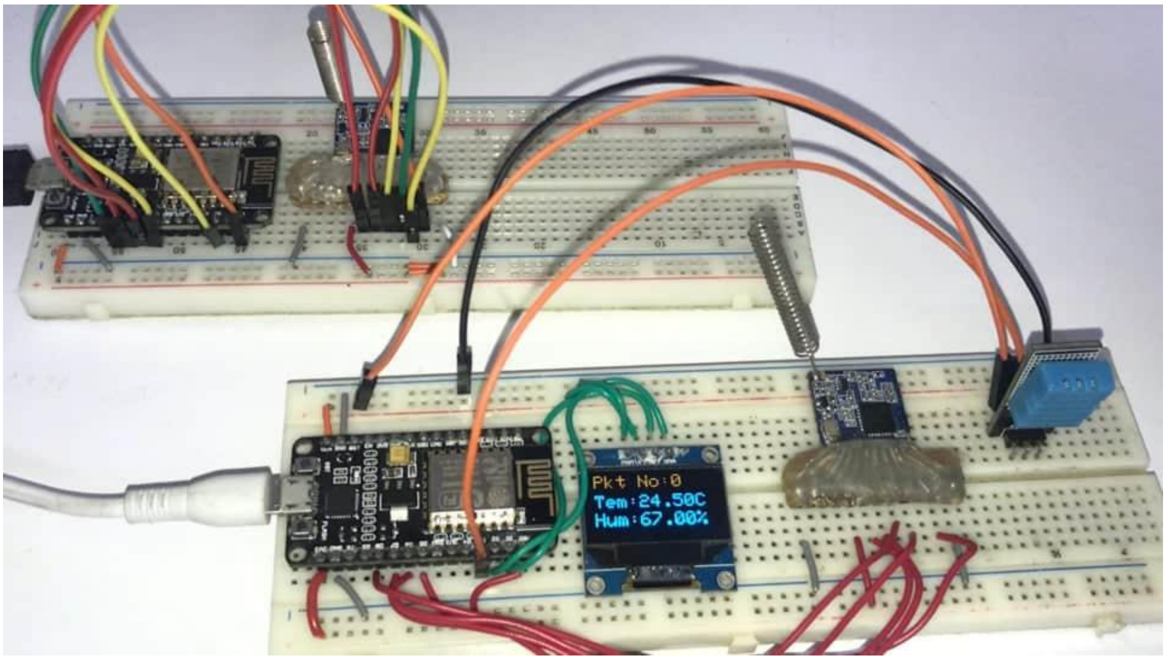
Complete Circuit Diagram with All the Various Facets and Connections



The Figure below, shows the live connections of the set up.

Figure 19

Live Connections



The code below is used to integrate Lora long range and Wi-Fi module. The loRa range is used for data transmission while the Wi-Fi module is used to transmit the same data to the Thing Speak cloud services for tabulation, analysis and prediction. The results are displayed on the cloud and LCD (LiquidCrystal_I2C).

```
#include <WiFi.h>
#include <ThingSpeak.h>
#include <TinyGPS++.h>
#include <HardwareSerial.h>
#include <DHT.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd (0x27, 16, 2); // Set the LCD address to 0x27 for a 16x2 display
TinyGPSPlus gps;
HardwareSerial GPS (2); // Use Serial2 (RX2=GPIO16, TX2=GPIO17) on ESP32 DevKit
DHT dht(5, DHT11);
WiFiClient client;
long myChannelNumber = 2334394;
Const char myWriteAPIKey[] = "9O1LRS6NFKKQDKHL";
const char *ssid = "STEVE";
const char *password = "12345678";
// Replace with your ThingSpeak parameters
const char *server = "api.thingspeak.com";
const char *apiKey = "5WVPL6SPW9YV901V"; // Replace with your ThingSpeak API key
const long channelID = 2319248; // Replace with your ThingSpeak channel number
byte statusLed = 13;
```

```
byte sensorPin = 2;
// The hall-effect flow sensor outputs approximately 4.5 pulses per second per
// litre/minute of flow.
float calibrationFactor = 4.5;
volatile byte pulseCount;
float flowRate;
unsigned int flowMilliLitres;
unsigned long totalMilliLitres;
unsigned long oldTime;
WiFiClient client; // Declare a client object
void setup() {
  // Initialize a serial connection for reporting values
  Serial.begin(9600);
  // Set up the status LED line as an output
  GPS.begin(9600);
  Serial.println("Starting GPS");
  pinMode(statusLed, OUTPUT);
  digitalWrite(statusLed, HIGH); // Active-low LED
  pinMode(sensorPin, INPUT);
  pulseCount = 0;
  flowRate = 0.0;
  flowMilliLitres = 0;
  totalMilliLitres = 0;
  oldTime = 0;
```

```
  attachInterrupt(digitalPinToInterrupt(sensorPin), pulseCounter, FALLING);
  // Connect to Wi-Fi
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.println("Connecting to WiFi...");
  }
  Serial.println("Connected to WiFi");
   Serial.println(WiFi.localIP());
   dht.begin();
   ThingSpeak.begin(client);
}
void loop() {
  if ((millis() - oldTime) > 1000) {
    // Disable the interrupt while calculating flow rate and sending the value to
    // the host
    detachInterrupt(digitalPinToInterrupt(sensorPin));
    flowRate = ((1000.0 / (millis() - oldTime)) * pulseCount) / calibrationFactor;
    oldTime = millis();
    flowMilliLitres = (flowRate / 60) * 1000;
    totalMilliLitres += flowMilliLitres;
      // put your main code here, to run repeatedly:
      float h = dht.readHumidity();
      float t = dht.readTemperature();
      Serial.println("Temperature: " + (String) t);
```

```
    Serial.println("Humidity: " + (String) h);
    ThingSpeak.writeField(myChannelNumber, 1, t, myWriteAPIKey);
    ThingSpeak.writeField(myChannelNumber, 2, h, myWriteAPIKey);
    delay(2000);
// Print the flow rate and total milliliters to the serial monitor
  Serial.print("Flow rate: ");
  Serial.print(int(flowRate));
  Serial.println(" L/min");
  Serial.print("Output Liquid Quantity: ");
  Serial.print(totalMilliLitres);
  Serial.println(" mL");
  Serial.print(totalMilliLitres / 1000);
  Serial.println(" L");
  // Send data to ThingSpeak
  ThingSpeak.begin(client);
  ThingSpeak.setField(1, String(flowRate)); // Convert float to String
  ThingSpeak.setField(2, String(totalMilliLitres / 1000)); // Convert float to String
  int status = ThingSpeak.writeFields(channelID, apiKey);
  if (status == 200) {
    Serial.println("Data sent to ThingSpeak successfully");
  } else {
    Serial.print("Error sending data to ThingSpeak. HTTP error code: ");
    Serial.println(status);
  }
  // Reset the pulse counter
```

```
  pulseCount = 0;
  // Enable the interrupt again
  attachInterrupt(digitalPinToInterrupt(sensorPin), pulseCounter, FALLING);
 }
if (GPS.available()) {
  if (gps.encode(GPS.read())) {
    if (gps.location.isValid()) {
      Serial.print("Latitude: ");
      Serial.println(gps.location.lat(), 6);
      Serial.print("Longitude: ");
      Serial.println(gps.location.lng(), 6);
      Serial.print("Altitude (meters): ");
      Serial.println(gps.altitude.meters());
      Serial.print("Speed (km/h): ");
      Serial.println(gps.speed.kmph());
      Serial.print("Date: ");
      Serial.print(gps.date.year());
      Serial.print("-");
      Serial.print(gps.date.month());
      Serial.print("-");
      Serial.print(gps.date.day());
      Serial.print("  Time: ");
      Serial.print(gps.time.hour());
      Serial.print(":");
      Serial.print(gps.time.minute());
```

```
      Serial.print(":");

      Serial.println(gps.time.second());

      delay(500);

     }
    }
  }
 lcd.init();                    // Initialize the LCD

   lcd.backlight();               // Turn on the backlight

   lcd.setCursor(0, 0);           // Set cursor to the first column of the first row

   lcd.print("Pressure,");          // Print "Pressure"

   lcd.setCursor(0, 1);           // Set cursor to the first column of the second row

   lcd.print("Flow Rate!");           // Print "Flowrate!"

}

Void pulseCounter() {

  pulseCount++;.
```

4.1.4 Implementation of a Scalable Long-Range Model for Detecting Water Loss

Simulation was done after integration of the algorithms; it was critical to evaluate the performance of the integrated machine learning. The LoRa Wireless Sensor Network was set-up with exact same Nodes.

The prototype was implemented to measure and monitor water pressure and forward the same readings through to the LoRa ecosystem. The water pressure measurements were carried out through smart LoRa meters. The generic smart LoRa wireless sensor network was used to collect data in the form of water pressure and propagated this data to the fully functional device (or Bluetooth router).

4.1.5 Methodology for Implementation of a Scalable Long-Range Model

Proof of concept was used to develop and run a program in order to implement water loss detection. The environment for development used data collected from Wireless sensor network to simulate the model.

4.1.6 LoRa Device Specifications

LoRa Modulation connects long range communication where Transceivers and End Nodes configure with sensor devices designed best pet for water companies' applications. The main features of LoRa Technology; Connects devices up to 30 miles apart i.e. 2-5 km urban and 15km in the sub-urban. Long range standards are IEEE 802.15.4g and have a Low Power minimal battery which can last for 10 years. The physical layer of LoRa has Frequency, power, modulation, power and signaling between gateways and nodes. LoRa gateways can connect millions of nodes; infrastructure is cheap and faster to implement.

The other LoRa features has an adaptive data rate algorithm which maximize the nodes battery life and network capacity. The LoRa protocol has different layers which include network encryption, application and device level for security communication. LoRa RF1276 provides pure loRa p2p (peer to peer) a low cost, ultra-low power, high performance transparent .It is more secure due to end-to-end AES128 encryption which can maintain confidentiality, integrity and authentication (CIA) (Rabeek *et al*., 2019).

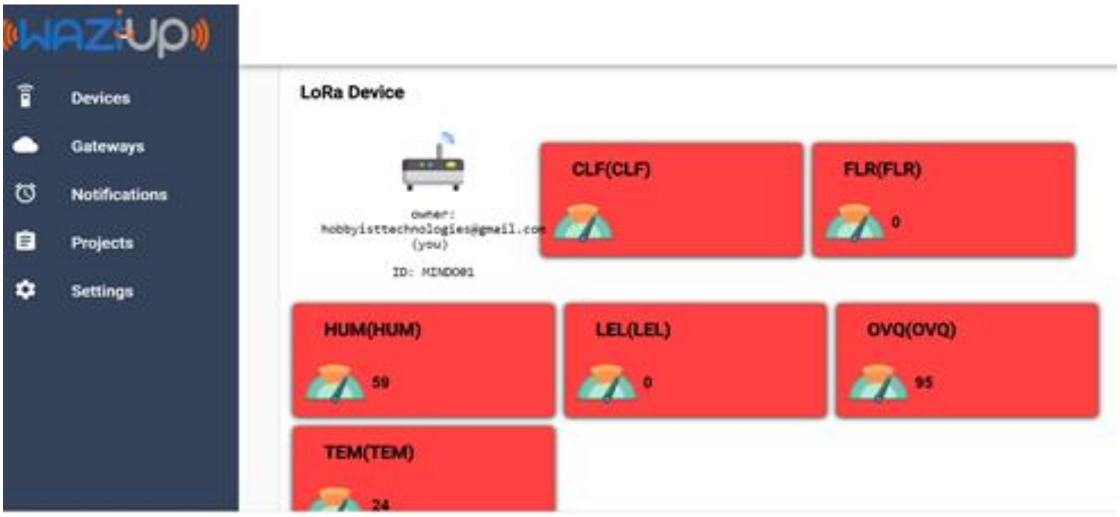
The LoRaWAN networks are of standard IEEE 802.15.4g thus speeds up IoT applications which can be deployed anywhere. The LoRa model consists of Network and application layers where both complete communication protocol in a Wireless Sensor Network (De Araújo *et al*., 2018). The Asset tracking remotely forwards information through nodes and gateways to network server. The Network server then forwards the same information to application server. The LoRa Technology enables Global Positioning System (GPS) detection and locates water loss with high capacity of connectivity at low cost. The GPS mounted with antennae with tiny microprocessors receives information from various satellites. The use of this technology helps to save operation cost as well as minimal battery replacement (LoRaWAN L. A., 2018).

4.2 Results of the Performance Evaluation of LoRa Model

The monitoring of the model was done through logging into web portal. The devices were accessed successfully where data could be propagated through the LoRa gateways in the network and thus any rapid and sudden change in water flow and water pressure would be quickly noted. Figure 20 shows the dashboard for monitoring the model performance using the LoRa Gateway and nodes.

Figure 20

LoRa smart devices and calibrations



Two Scenarios were used to observe the model performance. In the first scenario the model performance was observed without leakage while in scenario two leakages were introduced using a tap. The indicators used to monitor water loss are shown in Table 4.

Table 2

Indicators of Water Loss

Indicator	Explanation
Humidity	High environmental humidity indicates water leakage
temperature	Temperature decreases where there is leakage
Flow rate	Decrease in flow rate indicates leakage
Pressure	Decrease in water pressure indicate leakage

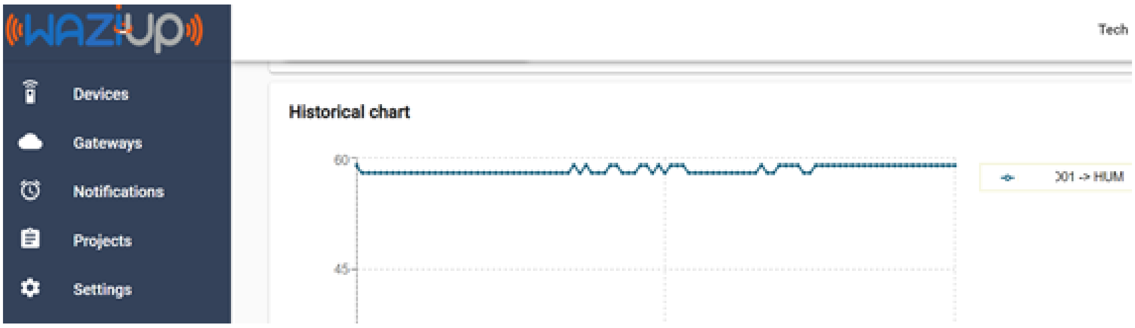
The LoRa model successfully propagated data through the LoRa gateways in the network, and thus any rapid and sudden change in water consistency could be noted and reviewed quickly.

4.2.1 Effect of water leakage on Environmental Humidity and Temperature

Figure 21, below shows the various humidity readings captured ubiquitously on the LoRa network before leakage is introduced into the system.

Figure 21

Humidity Reading on the LoRa Network

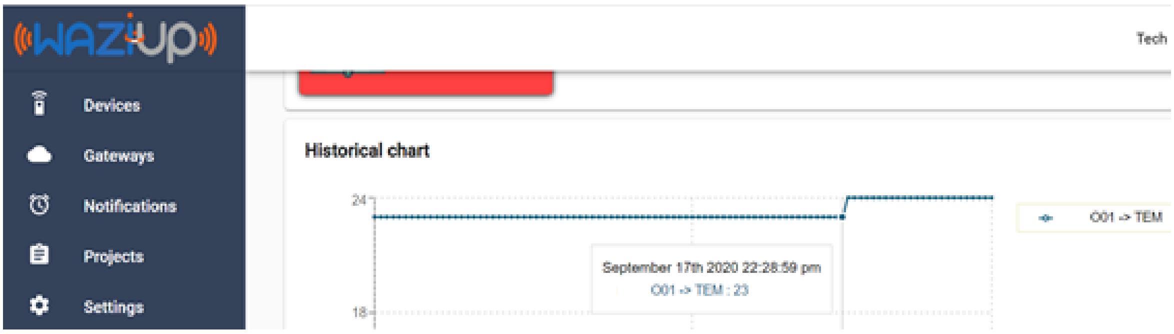


It is expected that when there is water leakage the environmental humidity increases. As can be observed in the graph when the tap is not running i.e. no leakage the humidity is constant on the contrary when the leakage is introduced by opening the tap the humidity fluctuates.

Figure 22 below shows the temperature on the LoRa network that changed in accordance with the environmental disposition.

Figure 22

Temperature on the Water Distribution Architecture



No leakage was introduced hence the graph shows a rather constant temperature throughout the day. Figure 23 below shows the results of temperature against a period of time where leakage was introduced.

Figure 23

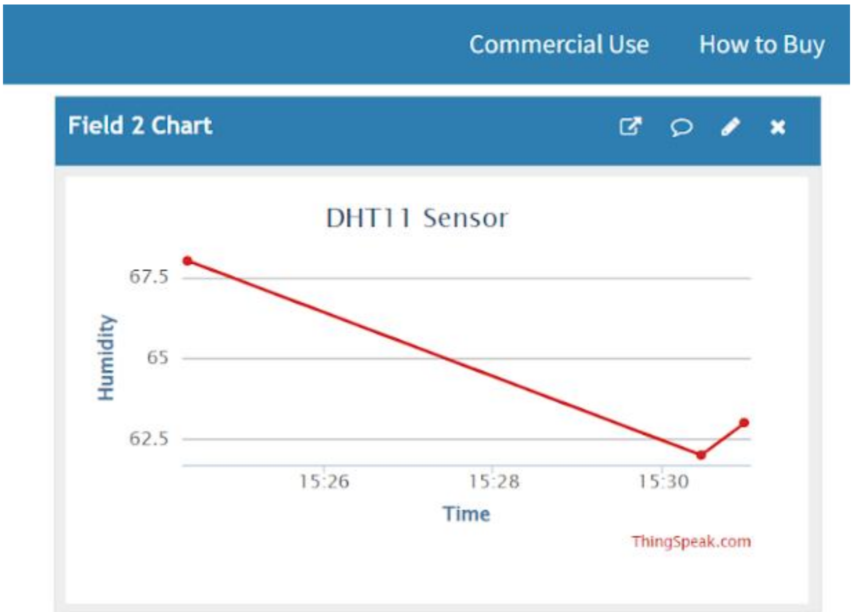
The Results of Temperature before Introduction of Leakage

As can be observed from the graph in Figure 23 the initial temperature reading was 24^0 Celsius. This remained constant for approximately 2 minutes as the sensor calibrated itself. With time the temperature rose to 27^0 Celsius and then leakage was introduced resulting to a fall in temperature.

Figure 24 below shows the results of humidity against a period of time where leakage was introduced.

Figure 24

The Results of Temperature after Introduction of Leakage



As can be observed from the graph in Figure 24 the initial humidity reading was 67.5. This decreased to below 62.5 after approximately 2 minutes as the sensor calibrated itself. After introducing leakage, the humidity rose above 62.5. The above results were meant to assess the effect of leakage on the environmental temperature and humidity.

4.2.2 Effect of water leakage on Flow rate and Pressure

Figure 25 below shows the data set of the output from the connection, with readings showing the flow rate and liquid quantity with time stamp.

Figure 25

Data Set of the Output from the Connection

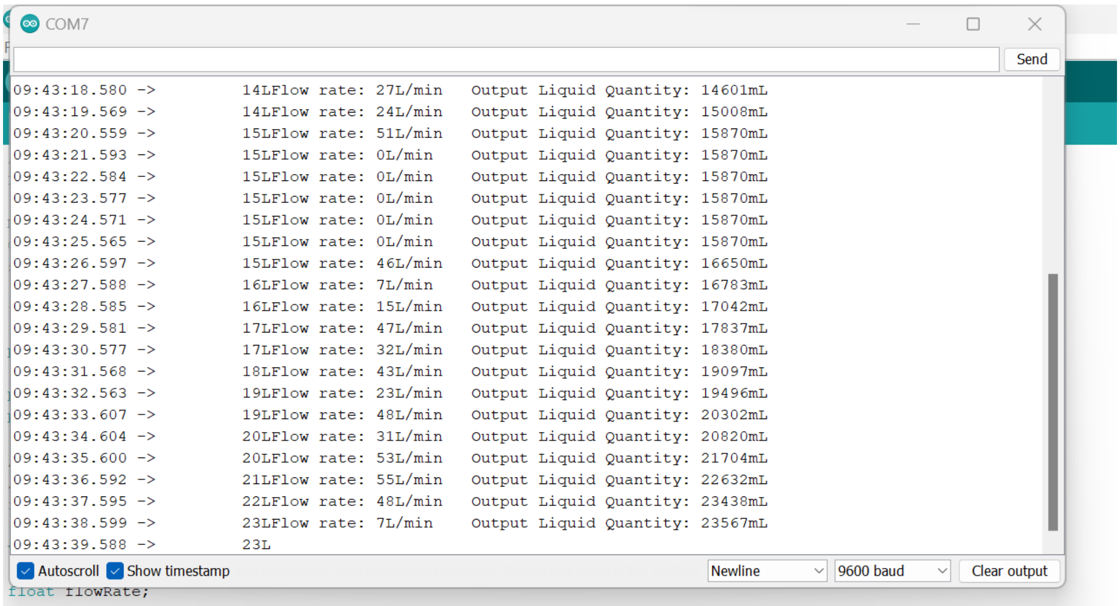


Figure 26 below shows the visualization of the data set. The Flow Meter Rate and Liquid Quantity Reading was Displayed on Serial Monitor. As can be observed from the visualization in Figure 26 increase in liquid quantity increases the flow rate. The increased flow rate enhanced availability of water at real time to clients.

Figure 26

Visualization of the Flow Rate and Water Quantity Data

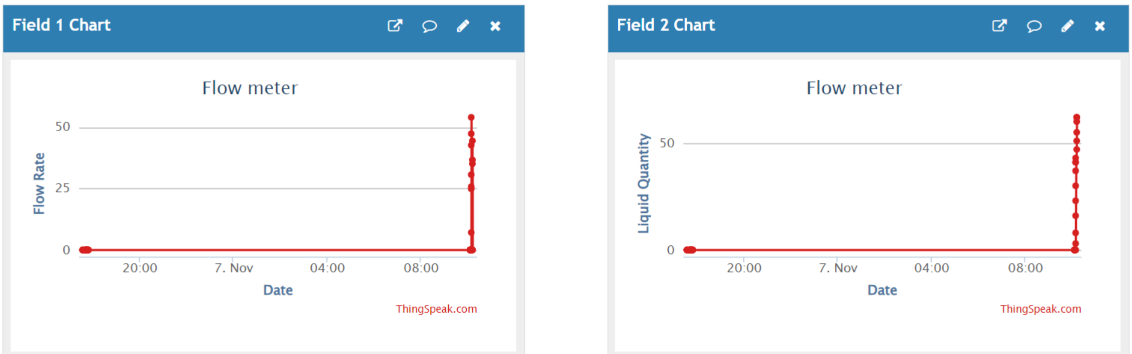
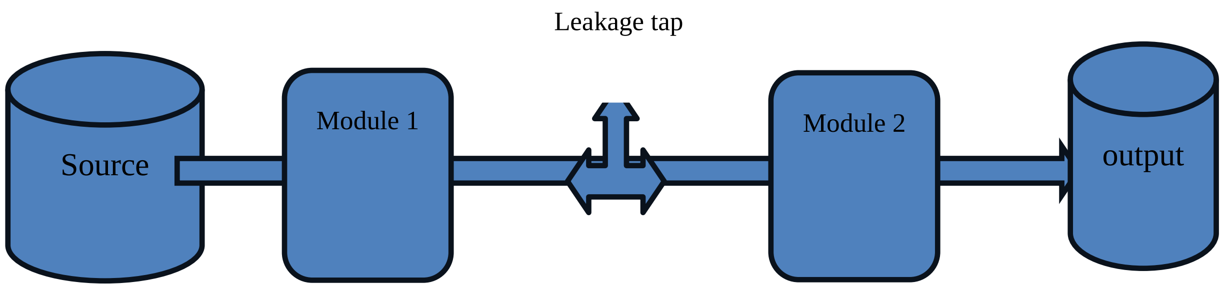


Figure 27 below show Module 1 placed 0.5 meters away from source to get readings of temperature, humidity flow rate, water pressure and GPS location module. Module 2 placed 1 meter away long range (LoRa) from module 1 and 0.5 to the output. When there is no leakage the sensor values at module 1 are same as the values at module 2. When a leakage is introduced by opening the tap the flow rate and pressure reduces at module 2.

As can be observed from Figure 27 below, the setup to generate the data included two set of equipment constituting of a flow meter, a temperature and humidity sensor and a GPS location Modules. The two sets of equipment were placed one meter apart and joined with a pipe and a T-Junction tap. Figure 27 below show the said setup.

Figure 27

Setup of Flow Meter, a Temperature and Humidity Sensor and A GPS Location Module.

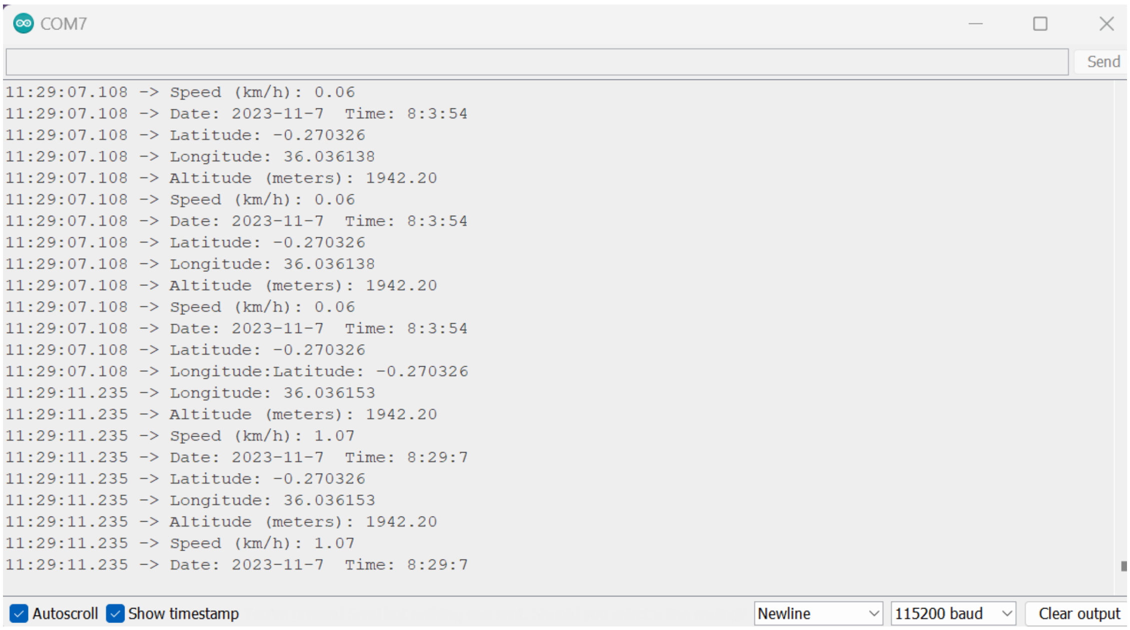


4.2.3 Results of GPS location of the flow meter

Figure 28 below shows GPS location of the flow meter rate, pressure against temperature and humidity at various stages of water flow throughout the water infrastructure.

Figure 28

Results of GPS Location of the Flow Meter Rate Pressure against Temperature and Humidity



As can be observed from Figure 28 above, high environmental humidity, decreased temperature and pressure indicate water loss. The increased flow rate under low humidity, temperature and pressure promotes; reliability and availability of water to clients.

Table 3

Data Collected that Indicates the GPS Location, Flow Rate, Pressure, Temperature and Humidity

Timestamp	GPS (Latitude, Longitude)	Temp Module 1 (°C)	Humidity Module 1 (%)	Flow Rate Module 1 (L/min)	Pressure Module 1 (psi)	Temp Module 2 (°C)	Humidity Module 2 (%)	Flow Rate Module 2 (L/min)	Pressure Module 2 (psi)	Notes
2023-12-19 08:00:00	-0.270326 36.036138	25	50	10	60	25	50	10	60	Normal operation
2023-12-19 08:15:00	-0.270326 36.036138	24	49	10	59	24	49	10	59	Normal operation
2023-12-19 08:30:00	-0.270326 36.036138	24	48	10	58	24	48	10	58	Normal operation
...	...	...	...	...	...	...	...	...	...	...
2023-12-19 12:00:00	-0.270326 36.036138	24	48	10	50	21	40	6.5	46	Leakage detected
2023-12-19 12:15:00	-0.270326 36.036138	21	40	10	50	24	46	8	48	Normal operation
2023-12-19 12:30:00	-0.270326 36.036138	24	47	10	50	24	47	10	50	Normal operation
2023-12-19 12:45:00	-0.270326 36.036138	24	48	10	50	24	48	10	49	Normal operation

2023-12-19 13:00:00	-0.270326 36.036138	20	39	6.5	49	20	41	6.5	49	Normal operation
...	...	...	...	...	...	...	...	...	...	...
2023-12-19 18:30:00	-0.270326 36.036138	18	35	6.5	50	16	35	4.5	45	Leakage detected
2023-12-19 18:45:00	-0.270326 36.036138	18	35	6.5	50	18	35	4.5	45	Leakage detected
2023-12-19 19:00:00	-0.270326 36.036138	18	35	6.5	50	18	35	4.5	45	Leakage detected
...	...	...	...	...	...	...	...	...	...	...

The snapshot Table 5 above show the result generated from the data collected that indicates the GPS location, flow rate, pressure against temperature and humidity at various stages of water flow throughout the water infrastructure. The above indicators according to the data indicates there is leakage in high environmental humidity and when low pressure, temperature and flow rate is low.

4.2.4 Results of LoRa Model Performance Evaluation

The LoRa Wireless Sensor Network successfully collected and propagated data from the cloud solution provider servers. During the course of the study, we encountered challenges in accessing equipment used in LoRa networks. We had to innovate and improvise various aspects of the study. In some cases, peripherals were bought separately and amalgamated into one functional unit. However, the study successfully implemented and satisfied the objective set out in the beginning. Thus, a scalable Long-Range wireless-based model for water loss monitoring was successfully implemented.

The LoRa model proved accurately, remotely, identified and reported water loss at real time. The model also proved that there was no need for manual monitoring using employees or field officers. The Model minimized corruption thus water accountability leading to increased water company’s proceeds. The LoRa model promoted more connectivity and supply of clean quality water standards to its clients at real time. The Government was able to allocate budget to drilling more bore holes and building more dams for availability of water. There was more creativity and innovation in the use of ICT technologies.

4.2.5 Validation Metrics

The model was further evaluated for four software metrics, namely; usability, reliability, efficiency and functionality. As such, six (6) expert interview questions were structured to help obtain corresponding data (responses) for the four validations metrics. The expert responses included three (3) Chief Executive Officers, seven (7) water engineers, five (5) IT officers, ten (10) field officers and eight (8) consumers. The data for validation of the four metrics results were captured as summarized in Table 6 below.

Table 4

Validation Metrics Results

Metrics		Question	Disagree	Agree	Total Responses
Usability	Q1	I like the overall experience with LoRa application	21%	79%	100%
	Q2	I can be able to navigate through the experiment without any challenge	33%	67%	100%
		Usability Means	27%	73%	100%
Efficiency	Q3	I could use the application with ease at real time	39%	61%	100%
	Q4	The deployment time of resources was quite efficient.	27%	73%	100%
		Efficiency Means	33%	67%	100%
Reliability	Q5	The model is able to provide consistent results,	30%	70%	100%
Functionality	Q6	The model is able to perform all tasks.	42%	58%	100%

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides conclusion and recommendations on the research on LoRa networks that involved a model development, prototype development, actual physical set-up and final results of the overall program. It also provides further areas of study.

5.2 Summary of Major Findings

This study was guided by the weaknesses and inadequacies of water flow data manual collection in most water companies in Kenya. The implementations of monitoring tool for water loss to harness water data from clients have not been easy due technological challenges. The study revealed that LoRa wireless based sensor networks solution needs to be implemented since it has many advantages over other competing technologies.

A scalable LoRa wireless sensor water meter network was setup and data logged from the prototype in real time having met a complete conclusive comparison study. In addition, data was successfully collected from wireless sensor network (WSN), analyzed and proved further the viability of the technological solution to propagate data to the cloud. Thus, a scalable Long-Range wireless based model for water loss monitoring was successfully implemented. The study further encourages various water companies to implement this technological solution for water loss monitoring. However, there is an invaluable and considerable contribution towards timely, error-free, efficient collection of water flow data remotely using a LoRa network. There were also bureaucratic and logistical hurdles faced as well as challenges in accessing requisite devices. In some cases, peripherals were bought separately and amalgamated into one functional unit.

There is also need to further investigate security of wireless sensor network mechanisms for better confidentiality, authentication and availability of the LoRa system.

During the course of study, it was established that there were numerous inefficiencies and bottlenecks in the use of current manual methods of data collection and water loss monitoring through use of field agents. The Corruption, human errors and time consuming on identifying and reporting water loss was generally experienced. There was need to design and develop a technological solution which is a reliable, cost-effective and efficient for monitoring water loss at real time. The experiment was set up effectively to meet the objectives of the study as well as propagate data through a radio system to the cloud or access point in accordance to set criteria.

The Preparation, Planning, Design, Implementation, Operation and Optimization (PPDIOO) lifecycle was used to design the LoRa wireless personal area network. Since it supports a continuous lifecycle, the various stages in PPDIOO all worked synchronously towards the objectives and final project as follows; the water flow smart meters connected to a LoRa module was fitted with solar panel for green energy provision thus saving power consumption. The Connected LoRa module Gateway with several nodes propagated data to the cloud or an access point. The resultant network was a real-life model prototype of a WSN which remotely logged data to a repository.

This methodology was ideal as it lowered the total cost of network ownership, increased network availability, flexibility and speeding access to applications and services. The LoRa wireless sensor network was implemented by setting up various hardware peripherals within the set criteria. Modbus protocol was used to capture water flow from the meters and converted measurements into discrete values. A reduced function module was then used to capture the discrete signals from the water meter and consequently relay this data to the LoRa gateway routers. The set up was done within the experiment site.

The LoRa network successfully propagated water flow data efficiently and reliably through a radio system to the cloud or access point. Data was captured remotely and accurately per second and viewed remotely from the web portal. Datasets from the network would then be reviewed and prepared for purposes of producing necessary reports. The network was easy to deploy, it had excellent performance even with high proliferation of wireless signals. It had an appropriate and reliable data transfer of data and bit rate with very low power consumption in the process.

5.3 Policy Recommendations

Water companies should consider the adoption and implementation of LoRa technology in monitoring water distribution so as to identify various aspects of water management like billing, water loss, siphoning, aging infrastructure, accidental bursts and interferences in their water. The Government should lay down best practices of water management to curb frequent water shortages.

5.4 Recommendations for Future Research

There is a huge gap in the study of implementation of machine learning and artificial intelligence in the monitoring of water distribution in detecting and predicting patterns in the usage of water. There is also need to further research in security management, security key distribution, and device authentication of LoRa Wireless Sensor Networks trust centre.

REFERENCES

Adedeji, K. B., Hamam, Y., Abe, B. T., & Abu-Mahfouz, A. M. (2018). Pressure management strategies for water loss reduction in large-scale water piping networks: A review. *Advances in Hydroinformatics: SimHydro 2017-Choosing The Right Model in Applied Hydraulics*, 465–480.

Adsul, S., Sharma, A. K., & Mevekari, R. G. (2016). Development of leakage detection system. *2016 International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT)*, 673–677.

Al-Washali, T., Sharma, S., Al-Nozaily, F., Haidera, M., & Kennedy, M. (2019). Monitoring nonrevenue water performance in intermittent supply. *Water*, *11*(6), 1220.

Bello, O., Abu-Mahfouz, A. M., Hamam, Y., Page, P. R., Adedeji, K. B., & Piller, O. (2019). Solving management problems in water distribution networks: A survey of approaches and mathematical models. *Water*, *11*(3), 562.

Bengtsson, S., de Blois, M., Wilén, B.-M., & Gustavsson, D. (2019). A comparison of aerobic granular sludge with conventional and compact biological treatment technologies. *Environmental Technology*, *40*(21), 2769–2778.

Blomqvist, E. (2012). *Semtech in practice-ida*.

Boudhaouia, A., & Wira, P. (2018). Water consumption analysis for real-time leakage detection in the context of a smart tertiary building. *2018 International Conference on Applied Smart Systems (ICASS)*, 1–6.

Carvalho, L., Mackay, E. B., Cardoso, A. C., Baattrup-Pedersen, A., Birk, S., Blackstock, K. L., Borics, G., Borja, A., Feld, C. K., & Ferreira, M. T. (2019). Protecting and restoring Europe's waters: An analysis of the future development needs of the Water Framework Directive. *Science of the Total Environment*, *658*, 1228–1238.

Creaco, E., Campisano, A., Fontana, N., Marini, G., Page, P. R., & Walski, T. (2019). Real time control of water distribution networks: A state-of-the-art review. *Water Research*, *161*, 517–530.

De Araújo, P. R. C., Filho, R. H., Rodrigues, J. J. P. C., Oliveira, J. P. C. M., & Braga, S. A. (2018). Infrastructure for integration of legacy electrical equipment into a smart-grid using wireless sensor networks. *Sensors*, *18*(5), 1312.

Ethem Karadirek, I. (2020). An experimental analysis on accuracy of customer water meters under various flow rates and water pressures. *Journal of Water Supply: Research and Technology—AQUA*, *69*(1), 18–27.

Feng, N. (2019). *Online Monitoring Framework for Pressure Transient Detection in Water Distribution Networks*. University of Waterloo.

Froom, R., Sivasubramanian, B., & Frahim, E. (2010). *Implementing Cisco IP switched networks (SWITCH) foundation learning guide: foundation learning for SWITCH 642-813*. Cisco press.

Hartono, R., Safi'Ie, M. A., Yoeseph, N. M., Bawono, S. A. T., & Aziz, A. (2022). Improved data transmission of smart water quality sensor devices in Bengawan solo river with LoRa. *2022 1st International Conference on Smart Technology, Applied Informatics, and Engineering (APICS)*, 171–174.

Hemjal, M. A. (2019). *Sigfox based internet of things: technology, measurements and development*.

Khutsoane, O., Isong, B., & Abu-Mahfouz, A. M. (2017). IoT devices and applications based on LoRa/LoRaWAN. *IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics Society*, 6107–6112.

Koivisto, M. (2009). *Mobile information system adoption and use: beliefs and attitudes in mobile context*. Teknillinen korkeakoulu.

Li, W., Liu, T., & Xiang, H. (2021). Leakage detection of water pipelines based on active thermometry and FBG based quasi-distributed fiber optic temperature sensing. *Journal of Intelligent Material Systems and Structures*, *32*(15), 1744–1755.

Liemberger, R., & Wyatt, A. (2019). Quantifying the global non-revenue water problem. *Water Supply*, *19*(3), 831–837.

Lipiwattanakarn, S., Kaewsang, S., Pornprommin, A., & Wongwiset, T. (2019). Real benefits of leak repair and increasing the number of inlets to energy. *Water Practice & Technology*, *14*(3), 714–725.

Liu, F., & Stapleton, P. (2020). Counterargumentation at the primary level: An intervention study investigating the argumentative writing of second language learners. *System*, *89*, 102198.

Lovely, M. A. (2020). *Proton capture on 34S in the astrophysical energy regime*. Colorado School of Mines.

Lu, C.-G. (1999). A generalization of Shannon's information theory. *International Journal Of General System*, *28*(6), 453–490.

Ma, Y., Gao, Y., Cui, X., Brennan, M. J., Almeida, F. C. L., & Yang, J. (2019). Adaptive phase transform method for pipeline leakage detection. *Sensors*, *19*(2), 310.

McCartney, M. P., Pavelic, P., Lacombe, G., Latt, K., Zan, A. K., Thein, K., Douangsavanh, S., Balasubramanya, S., Rajah, A., & Myint, A. (2013). Water resources assessment of the dry zone of Myanmar: final report for component 1.[Project report of the Livelihoods and Food Security Trust Fund (LIFT) Dry Zone Program]. *IWMI Reports*.

Momeni, A., & Piratla, K. R. (2021). Leveraging hydraulic cyber-monitoring data to support primitive condition assessment of water mains. *Journal of Pipeline Systems Engineering and Practice*, *12*(4), 4021054.

Neu, D., Gomez, E. O., Graham, C., & Heincke, M. (2006). "Informing" technologies and the World Bank. *Accounting, Organizations and Society*, *31*(7), 635–662.

Oliveira, L., Rodrigues, J. J. P. C., Kozlov, S. A., Rabêlo, R. A. L., & Albuquerque, V. H. C. de. (2019). MAC layer protocols for Internet of Things: A survey. *Future Internet*, *11*(1), 16.

Owen, D. A. L. (2018). *Smart water technologies and techniques: Data capture and analysis for sustainable water management*. John Wiley & Sons.

Özdemir, Ö. (2018). Water leakage management by district metered areas at water distribution networks. *Environmental Monitoring and Assessment*, *190*(4), 182.

Perinotti, P., Tosini, A., & Vaglini, L. (2022). Shannon theory beyond quantum: Information content of a source. *Physical Review A*, *105*(5), 52222.

Pltonykova, H., Koeppel, S., Bernardini, F., Tiefenauer-Linardon, S., & de Strasser, L. (2020). *The United Nations World Water Development Report 2020: Water and Climate Change.*

Prashant, T., Yashwant, R., & Malvika, M. (2018). Systematic review on association between iodine level during pregnancy and its outcomes. *Int J Health Sci Res*, *8*(10), 269–279.

Rabeek, S. M., Beibei, H., & Chai, K. T. C. (2019). Design of wireless IoT sensor node & platform for water pipeline leak detection. *2019 IEEE Asia-Pacific Microwave Conference (APMC)*, 1328–1330.

Rice, E. W., Bridgewater, L., & Association, A. P. H. (2012). *Standard methods for the examination of water and wastewater* (Vol. 10). American public health association Washington, DC.

Sadeghioon, A. M., Metje, N., Chapman, D., & Anthony, C. (2018). Water pipeline failure detection using distributed relative pressure and temperature measurements and anomaly detection algorithms. *Urban Water Journal*, *15*(4), 287–295.

Sanchez-Iborra, R., Sanchez-Gomez, J., Ballesta-Viñas, J., Cano, M.-D., & Skarmeta, A. F. (2018). Performance evaluation of LoRa considering scenario conditions. *Sensors*, *18*(3), 772.

Sanghera, P., & Sanghera, P. (2019). Planning Project and Scope. *PMP® in Depth: Project Management Professional Certification Study Guide for the PMP® Exam*, 115–153.

Santos, J., Vanhove, T., Sebrechts, M., Dupont, T., Kerckhove, W., Braem, B., Van Seghbroeck, G., Wauters, T., Leroux, P., & Latre, S. (2018). City of things: Enabling resource provisioning in smart cities. *IEEE Communications Magazine*, *56*(7), 177–183.

Saraswathi, V., Rohit, A., Sakthivel, S., & Sandheep, T. J. (2018). Water leakage system using IoT. *International Journal of Innovative Research in Management*, *5*(2), 67–69.

Schmidt, D. C. (2006). Model-driven engineering. *Computer-IEEE Computer Society-*, *39*(2), 25.

Seneviratne, P., & Seneviratne, P. (2019). Introduction to LoRa and LoRaWAN. *Beginning LoRa Radio Networks with Arduino: Build Long Range, Low Power Wireless IoT Networks*, 1–22.

Tan, A. Z. Q. (2019). *An approach for circuit design optimization based on complexity considerations*.

Tekile, A., & Legesse, Y. S. (2023). Overall performance evaluation of an urban water supply system: A case study of Debre Tabor Town in Ethiopia. *Journal of Water, Sanitation and Hygiene for Development*, *13*(4), 250–264.

Uddin, M. A., Ahmed, A., Sabuj, H. H., & Seaum, S. Y. (2019). Leakage detection in water pipeline using micro-controller. *2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT)*, 1–4.

Välimaa, L. (2017). *MQTT client implementation in IEC 61131-3 compatible programming environment*.

APPENDICES

Appendix I: Sample Data from the Project Connection

The Sample data below was collected in the month of September and October 2023 for comparison purposes to check the consistency of the water flow rate, temperature, pressure and humidity.

id gps1 flowrate1 pressure1 gps2 rate2
pressure 2 temp humidity

1 -0.270326 36.036138 1942.20 10.25 53.12 -0.270326 36.036138 1942.20
18.76 76.45 24.15 65.82

2 -0.270326 36.036138 1942.20 8.62 49.27 -0.270326 36.036138 1942.20
15.89 72.74 23.32 66.35

3 -0.270326 36.036138 1942.20 6.79 45.41 -0.270326 36.036138 1942.20
13.45 68.51 24.58 66.10

4 -0.270326 36.036138 1942.20 4.86 42.65 -0.270326 36.036138 1942.20
12.30 65.89 25.04 67.18

5 -0.270326 36.036138 1942.20 3.25 39.84 -0.270326 36.036138 1942.20
10.78 62.01 24.42 66.95

6 -0.270326 36.036138 1942.20 2.14 36.45 -0.270326 36.036138 1942.20
9.16 59.52 22.88 67.45

7 -0.270326 36.036138 1942.20 0.91 32.89 -0.270326 36.036138 1942.20
7.88 56.29 22.17 68.14

8 -0.270326 36.036138 1942.20 0.17 29.32 -0.270326 36.036138 1942.20
6.22 52.47 23.71 67.19

9 -0.270326 36.036138 1942.20 0.00 25.74 -0.270326 36.036138 1942.20
4.51 49.12 23.57 68.39

10 -0.270326 36.036138 1942.20 2.61 51.78 -0.270326 36.036138
1942.20 19.67 76.25 23.89 65.62

11 -0.270326 36.036138 1942.20 1.45 49.03 -0.270326 36.036138
1942.20 17.85 74.82 25.33 66.14

12 -0.270326 36.036138 1942.20 0.47 46.27 -0.270326 36.036138
1942.20 16.02 72.94 25.23 66.53

13 -0.270326 36.036138 1942.20 1.89 43.41 -0.270326 36.036138 1942.20 14.31 70.57 23.92 66.00

14 -0.270326 36.036138 1942.20 3.05 40.65 -0.270326 36.036138 1942.20 12.74 68.35 23.71 66.78

15 -0.270326 36.036138 1942.20 4.38 37.82 -0.270326 36.036138 1942.20 11.02 66.01 25.00 66.14

16 -0.270326 36.036138 1942.20 5.82 34.89 -0.270326 36.036138 1942.20 9.41 63.45 25.22 66.92

17 -0.270326 36.036138 1942.20 6.98 32.05 -0.270326 36.036138 1942.20 7.73 60.92 23.97 66.62

18 -0.270326 36.036138 1942.20 8.52 29.41 -0.270326 36.036138 1942.20 6.29 58.27 24.62 66.13

19 -0.270326 36.036138 1942.20 7.24 26.89 -0.270326 36.036138 1942.20 4.94 55.41 22.79 66.92

20 -0.270326 36.036138 1942.20 5.69 24.23 -0.270326 36.036138 1942.20 3.76 52.61 23.33 67.32

21 -0.270326 36.036138 1942.20 4.07 21.78 -0.270326 36.036138 1942.20 2.67 50.01 25.13 66.78

22 -0.270326 36.036138 1942.20 2.45 19.21 -0.270326 36.036138 1942.20 1.34 47.35 23.97 67.11

23 -0.270326 36.036138 1942.20 0.81 16.59 -0.270326 36.036138 1942.20 0.00 45.02 24.78 68.45

24 -0.270326 36.036138 1942.20 2.22 47.34 -0.270326 36.036138 1942.20 18.19 73.95 22.37 66.15

25 -0.270326 36.036138 1942.20 3.94 44.46 -0.270326 36.036138 1942.20 16.56 71.42 23.71 66.83

26 -0.270326 36.036138 1942.20 5.47 42.21 -0.270326 36.036138 1942.20 15.06 68.75 22.45 66.29

27 -0.270326 36.036138 1942.20 7.13 39.45 -0.270326 36.036138
1942.20 13.32 66.13 22.79 67.07

28 -0.270326 36.036138 1942.20 8.57 37.02 -0.270326 36.036138
1942.20 11.82 63.99 25.15 66.66

29 -0.270326 36.036138 1942.20 10.25 34.61 -0.270326 36.036138
1942.20 10.29 61.35 22.96 67.24

30 -0.270326 36.036138 1942.20 11.96 32.25 -0.270326 36.036138
1942.20 8.61 58.61 24.61 67.16

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1942.20 7.11 56.11 24.48 66.61

32 -0.270326 36.036138 1942.20 14.95 27.21 -0.270326 36.036138
1942.20 5.47 53.76 23.33 66.35

33 -0.270326 36.036138 1942.20 16.23 24.77 -0.270326 36.036138
1942.20 3.75 51.09 22.95 67.12

34 -0.270326 36.036138 1942.20 17.88 22.26 -0.270326 36.036138
1942.20 2.22 49.11 24.17 66.98

35 -0.270326 36.036138 1942.20 19.26 19.61 -0.270326 36.036138
1942.20 0.99 46.43 24.49 67.39

36 -0.270326 36.036138 1942.20 21.02 47.21 -0.270326 36.036138
1942.20 18.37 73.91 23.15 67.03

37 -0.270326 36.036138 1942.20 23.01 44.39 -0.270326 36.036138
1942.20 16.92 71.64 25.04 66.60

38 -0.270326 36.036138 1942.20 24.67 42.01 -0.270326 36.036138
1942.20 15.48 68.79 25.15 66.09

39 -0.270326 36.036138 1942.20 26.17 39.58 -0.270326 36.036138
1942.20 13.97 66.12 23.18 67.11

40 -0.270326 36.036138 1942.20 27.45 37.21 -0.270326 36.036138
1942.20 12.26 63.54 22.74 66.61

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42 -0.270326 36.036138 1942.20 31.45 32.50 -0.270326 36.036138 1942.20 9.35 58.19 22.49 67.20

43 -0.270326 36.036138 1942.20 32.00 29.89 -0.270326 36.036138 1942.20 8.32 56.01 23.87 67.43

44 -0.270326 36.036138 1942.20 30.55 27.45 -0.270326 36.036138 1942.20 6.64 53.65 22.81 67.02

45 -0.270326 36.036138 1942.20 28.78 24.78 -0.270326 36.036138 1942.20 5.08 51.29 22.04 66.75

46 -0.270326 36.036138 1942.20 26.52 22.14 -0.270326 36.036138 1942.20 3.48 49.32 25.10 66.09

47 -0.270326 36.036138 1942.20 25.00 19.45 -0.270326 36.036138 1942.20 2.01 47.49 25.04 67.31

48 -0.270326 36.036138 1942.20 23.52 17.12 -0.270326 36.036138 1942.20 0.83 45.12 24.08 67.13

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50 -0.270326 36.036138 1942.20 19.92 47.21 -0.270326 36.036138 1942.20 18.37 73.95 25.31 66.51

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53 -0.270326 36.036138 1942.20 9:56 AM 4.0 49.4 -0.270326 36.036138 1942.20 11.9 61.3

54 -0.270326 36.036138 1942.20 9:58 AM 3.8 49.3 -0.270326 36.036138 1942.20 12.0 61.3

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57 -0.270326 36.036138 1942.20 10:04 AM 3.2 49.2 -0.270326 36.036138 1942.20 12.3 61.3

58 -0.270326 36.036138 1942.20 10:06 AM 3.0 49.2 -0.270326 36.036138 1942.20 12.4 61.3

59 -0.270326 36.036138 1942.20 10:08 AM 2.8 49.2 -0.270326 36.036138 1942.20 12.5 61.3

60 -0.270326 36.036138 1942.20 10:10 AM 2.6 49.2 -0.270326 36.036138 1942.20 12.6 61.3

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63 -0.270326 36.036138 1942.20 10:16 AM 2.0 49.2 -0.270326 36.036138 1942.20 12.9 61.3

64 -0.270326 36.036138 1942.20 10:18 AM 1.8 49.2 -0.270326 36.036138 1942.20 13.0 61.3

65 -0.270326 36.036138 1942.20 10:20 AM 1.6 49.2 -0.270326 36.036138 1942.20 13.1 61.3

66 -0.270326 36.036138 1942.20 10:22 AM 1.4 49.2 -0.270326 36.036138 1942.20 13.2 61.3

67 -0.270326 36.036138 1942.20 10:24 AM 1.2 49.2 -0.270326 36.036138 1942.20 13.3 61.3

68 -0.270326 36.036138 1942.20 10:26 AM 1.0 49.2 -0.270326 36.036138 1942.20 13.4 61.3

69 -0.270326 36.036138 1942.20 10:28 AM 0.8 49.2 -0.270326 36.036138 1942.20 13.5 61.3

70 -0.270326 36.036138 1942.20 10:30 AM 0.6 49.2 -0.270326 36.036138 1942.20 13.6 61.3

71 -0.270326 36.036138 1942.20 10:32 AM 0.4 49.2 -0.270326 36.036138 1942.20 13.7 61.3

72 -0.270326 36.036138 1942.20 10:34 AM 0.2 49.2 -0.270326 36.036138 1942.20 13.8 61.3

73 -0.270326 36.036138 1942.20 10:36 AM 0.0 49.2 -0.270326 36.036138 1942.20 13.9 61.3

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76 -0.270326 36.036138 1942.20 10:42 AM 0.0 49.2 -0.270326 36.036138 1942.20 14.2 61.3

77 -0.270326 36.036138 1942.20 10:44 AM 0.0 49.2 -0.270326 36.036138 1942.20 14.3 61.3

78 -0.270326 36.036138 1942.20 10:46 AM 0.0 49.2 -0.270326 36.036138 1942.20 14.4 61.3

79 -0.270326 36.036138 1942.20 10:48 AM 0.0 49.2 -0.270326 36.036138 1942.20 14.5 61.3

80 -0.270326 36.036138 1942.20 10:50 AM 0.0 49.2 -0.270326 36.036138 1942.20 14.6 61.3

81 -0.270326 36.036138 1942.20 10:52 AM 0.0 49.2 -0.270326 36.036138 1942.20 14.7 61.3

82 -0.270326 36.036138 1942.20 10:54 AM 0.0 49.2 -0.270326 36.036138 1942.20 14.8 61.3

83 -0.270326 36.036138 1942.20 10:56 AM 0.0 49.2 -0.270326 36.036138 1942.20 14.9 61.3

84 -0.270326 36.036138 1942.20 10:58 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.0 61.3

85 -0.270326 36.036138 1942.20 11:00 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.1 61.3

86 -0.270326 36.036138 1942.20 11:02 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.2 61.3

87 -0.270326 36.036138 1942.20 11:04 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.3 61.3

88 -0.270326 36.036138 1942.20 11:06 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.4 61.3

89 -0.270326 36.036138 1942.20 11:08 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.5 61.3

90 -0.270326 36.036138 1942.20 11:10 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.6 61.3

91 -0.270326 36.036138 1942.20 11:12 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.7 61.3

92 -0.270326 36.036138 1942.20 11:14 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.8 61.3

93 -0.270326 36.036138 1942.20 11:16 AM 0.0 49.2 -0.270326 36.036138 1942.20 15.9 61.3

94 -0.270326 36.036138 1942.20 11:18 AM 0.0 49.2 -0.270326 36.036138 1942.20 16.0 61.3

95 -0.270326 36.036138 1942.20 11:20 AM 0.0 49.2 -0.270326 36.036138 1942.20 16.1 61.3

96 -0.270326 36.036138 1942.20 11:22 AM 0.0 49.2 -0.270326 36.036138 1942.20 16.2 61.3

97 -0.270326 36.036138 1942.20 11:24 AM 0.0 49.2 -0.270326 36.036138 1942.20 16.3 61.3

98 -0.270326 36.036138 1942.20 11:26 AM 0.0 49.2 -0.270326 36.036138 1942.20 16.4 61.3

99 -0.270326 36.036138 1942.20 11:28 AM 0.0 49.2 -0.270326 36.036138 1942.20 16.5 61.3

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101 -0.270326 36.036138 1942.20 11:32 AM 0.0 49.2 -0.270326 36.036138 1942.20 16.7 61.3

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103 -0.270326 36.036138 1942.20 11:36 AM 0.0 49.2 -0.270326 36.036138 1942.20 16.9 61.3

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105 -0.270326 36.036138 1942.20 11:40 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.1 61.3

106 -0.270326 36.036138 1942.20 11:42 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.2 61.3

107 -0.270326 36.036138 1942.20 11:44 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.3 61.3

108 -0.270326 36.036138 1942.20 11:46 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.4 61.3

109 -0.270326 36.036138 1942.20 11:48 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.5 61.3

110 -0.270326 36.036138 1942.20 11:50 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.6 61.3

111 -0.270326 36.036138 1942.20 11:52 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.7 61.3

112 -0.270326 36.036138 1942.20 11:54 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.8 61.3

113 -0.270326 36.036138 1942.20 11:56 AM 0.0 49.2 -0.270326 36.036138 1942.20 17.9 61.3

114 -0.270326 36.036138 1942.20 11:58 AM 0.0 49.2 -0.270326 36.036138 1942.20 18.0 61.3

115 -0.270326 36.036138 1942.20 12:00 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.1 61.3

116 -0.270326 36.036138 1942.20 12:02 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.2 61.3

117 -0.270326 36.036138 1942.20 12:04 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.3 61.3

118 -0.270326 36.036138 1942.20 12:06 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.4 61.3

119 -0.270326 36.036138 1942.20 12:08 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.5 61.3

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121 -0.270326 36.036138 1942.20 12:12 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.7 61.3

122 -0.270326 36.036138 1942.20 12:14 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.8 61.3

123 -0.270326 36.036138 1942.20 12:16 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.9 61.3

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127 -0.270326 36.036138 1942.20 12:24 PM 0.0 49.2 -0.270326 36.036138 1942.20 19.3 61.3

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133 -0.270326 36.036138 1942.20 12:36 PM 0.0 49.2 -0.270326 36.036138 1942.20 19.9 61.3

134 -0.270326 36.036138 1942.20 12:38 PM 0.0 49.2 -0.270326 36.036138 1942.20 20.0 61.3

135 -0.270326 36.036138 1942.20 12:40 PM 0.0 49.2 -0.270326 36.036138 1942.20 20.1 61.3

136 -0.270326 36.036138 1942.20 12:42 PM 0.0 49.2 -0.270326 36.036138 1942.20 20.0 61.3

137 -0.270326 36.036138 1942.20 12:44 PM 0.0 49.2 -0.270326 36.036138 1942.20 19.9 61.3

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139 -0.270326 36.036138 1942.20 12:48 PM 0.0 49.2 -0.270326 36.036138 1942.20 19.7 61.3

140 -0.270326 36.036138 1942.20 12:50 PM 0.0 49.2 -0.270326 36.036138 1942.20 19.6 61.3

141 -0.270326 36.036138 1942.20 12:52 PM 0.0 49.2 -0.270326 36.036138 1942.20 19.5 61.3

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145 -0.270326 36.036138 1942.20 1:00 PM 0.0 49.2 -0.270326 36.036138 1942.20 19.1 61.3

146 -0.270326 36.036138 1942.20 1:02 PM 0.0 49.2 -0.270326 36.036138 1942.20 19.0 61.3

147 -0.270326 36.036138 1942.20 1:04 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.9 61.3

148 -0.270326 36.036138 1942.20 1:06 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.8 61.3

149 -0.270326 36.036138 1942.20 1:08 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.7 61.3

150 -0.270326 36.036138 1942.20 1:10 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.6 61.3

151 -0.270326 36.036138 1942.20 1:12 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.5 61.3

152 -0.270326 36.036138 1942.20 1:14 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.4 61.3

153 -0.270326 36.036138 1942.20 1:16 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.3 61.3

154 -0.270326 36.036138 1942.20 1:18 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.2 61.3

155 -0.270326 36.036138 1942.20 1:20 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.1 61.3

156 -0.270326 36.036138 1942.20 1:22 PM 0.0 49.2 -0.270326 36.036138 1942.20 18.0 61.3

157 -0.270326 36.036138 1942.20 1:24 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.9 61.3

158 -0.270326 36.036138 1942.20 1:26 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.8 61.3

159 -0.270326 36.036138 1942.20 1:28 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.7 61.3

160 -0.270326 36.036138 1942.20 1:30 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.6 61.3

161 -0.270326 36.036138 1942.20 1:32 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.5 61.3

162 -0.270326 36.036138 1942.20 1:34 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.4 61.3

163 -0.270326 36.036138 1942.20 1:36 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.3 61.3

164 -0.270326 36.036138 1942.20 1:38 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.2 61.3

165 -0.270326 36.036138 1942.20 1:40 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.1 61.3

166 -0.270326 36.036138 1942.20 1:42 PM 0.0 49.2 -0.270326 36.036138 1942.20 17.0 61.3

167 -0.270326 36.036138 1942.20 1:44 PM 0.0 49.2 -0.270326 36.036138 1942.20 16.9 61.3

168 -0.270326 36.036138 1942.20 1:46 PM 0.0 49.2 -0.270326 36.036138 1942.20 16.8 61.3

169 -0.270326 36.036138 1942.20 1:48 PM 0.0 49.2 -0.270326 36.036138 1942.20 16.7 61.3

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Appendix II: Questionnaire

This Questionnaire is for water engineer, ICT officers, field officers, Chief Executive Officers and client's respondents. The questions below are for the purposes of analyzing LoRa Wireless Based Water Loss Monitoring Model. The LoRa Wireless Sensor Network performance was aimed to successfully help implement a reliable and efficient LoRa Model. Your opinions as reflected in this questionnaire are important to this study and are held in confidentiality. Therefore you are requested to answer the question in the most free and honest way possible. I really appreciate for taking your time.

Section A: Background Information please tick [√]

1. Age: ……………………. yrs

2. Gender

Male [ ] Female [ ]

3. What is your highest academic qualification? Please tick [√]

Degree [ ] Masters [ ]

PHD Others (please specify) ____________________

4. How many years have you been in the company? ____________________years

Using the key (D= Disagree; A=Agree) [√] tick as appropriate

Statement on Usability, efficiency, reliability and Functionality, Reliability		Rating	
1	I like the overall experience I had with LoRa application	D	A
2	I can be able to navigate through the experiment with ease with without challenge		
3	I could use the application with ease at real time		
4	Using e learning tools make learning more interesting and		
5	The deployment time of resources was quite efficient		
6	The model was able to provide consistent results		
7	The model was able to perform all tasks.		

Any other (please specify)………………………...……

....

....

Appendix II: KUREC Ethics Letter

KABARAK UNIVERSITY RESEARCH ETHICS COMMITTEE

Private Bag - 20157
KABARAK, KENYA
Email: kurec@kabarak.ac.ke

Tel: 254-51-343234/5
Fax: 254-051-343529
www.kabarak.ac.ke

OUR REF: KABU01/KUREC/001/04/08/21

8th September, 2021

Stephen Kipkoro,
Kabarak University,

Dear Stephen,

SUBJECT: ETHICS REVIEW DECISION

Kabarak University Research Ethics Committee (KUREC) received application for a protocol titled "A LONG-RANGE WIRELESS BASED WATER LOSS MONITORING MODEL" on 26th July, 2021. The protocol was reviewed and discussed during a virtual meeting held on 2nd August, 2021at 1000 Hours. The committee considered the application in accordance with the Kabarak University procedures on review of research protocols for ethical clearance and decided as follows:

1. **PROPOSED STUDY SITE**
   Experimental study
2. **KUREC DECISION**
   Approved for data collection for a minimum period of ONE year from 8th September, 2021

This approval is subject to the following conditions:

i. The researcher shall obtain a RESEARCH PERMIT from NACOSTI before commencement of data collection & submit a copy to the Kabarak University Institute of Postgraduate Studies (IPGS);
ii. The researcher shall immediately notify KUREC in case of any adjustments to the protocol;
iii. The researcher shall within 7 days of occurrence notify KUREC of any adverse events associated with the conduct of this study;
iv. The researcher shall apply for extension of the study period should the initial 1 year expire before completion of data collection;
v. The researcher shall submit study progress reports to KUREC after every 6 months and a full report at completion of the study/project

Thank you.

Sincerely,

Prof. Jackson Kitetu PhD.
KUREC-Chairman

KABARAK UNIVE...
INSTITUTIONAL RESEA...
13 SEP 2021
APPR...
P. O. PRIVATE BAG ...

Cc
Vice Chancellor
DVC-Academic & Research
Registrar-Academic & Research
Director-Research Innovation & Outreach
Institute of Post Graduate Studies

As members of Kabarak University family, we purpose at all times and in all places, to set apart in one's heart, Jesus as Lord.
(1 Peter 3:15)
Kabarak University is ISO 9001:2015 Certified

Appendix III: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **606050** Date of Issue: **01/October/2021**

RESEARCH LICENSE

This is to Certify that Mr.. Stephen Kipkurui Kipkoro of Kabarak University, has been licensed to conduct research in Nakuru on the topic: A LONG RANGE WIRELESS BASED WATER LOSS MONITORING MODEL for the period ending : 01/October/2022.

License No: **NACOSTI/P/21/13173**

606050

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

Appendix IV: Evidence of Conference Participation

KABARAK UNIVERSITY

Certificate of Participation

Awarded to

Stephen Kipkoro

for successfully participating in the Kabarak University International Research Conference on Computing and information systems 2021 on 4th and 5th October 2021 and presented a paper entitled ***"Implementation of a Scalable Long-Range Wireless Based Model for Water Loss Monitoring."***

Conference Theme

Development, Protection And Commercialization Of Intellectual Property

Prof. Jackson Kitetu
Dean School of Science, Engineering and Technology

Dr. Moses Thiga
Director Research, Innovation and Outreach

Kabarak University Moral Code
As members of Kabarak University family, we purpose at all times and in all places, to set apart in one's heart, Jesus as Lord.
(1 Peter 3:15)

Kabarak University is ISO 9001:2015 Certified

Appendix V: List of Publication

Proceedings of the Kabarak University International Conference on the Basic Sciences, 9th October 2020 Nakuru, Kenya.

Implementation of a Scalable Long-Range Wireless Based Model for Water Loss Monitoring

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Tel: +254 0721627636, skipkoro@kabarak.ac.ke,+254737070029,nmasese@kabarak.ac.ke
[2]*Laikipia University, P.O. Box 1100 – 20300, Nyahururu, Kenya*
Tel: + 254 721 864 816, kirori@laikipia.ac.ke

Abstract: Water companies experience challenges in detecting water loss and undertaking reliable and efficient water audit. Consequently, mitigation of these incidences of water loss, as well as auditing of water distribution is difficult, largely uncoordinated and inherently cumbersome. A Long-Range (LoRa) based technology prototype is designed and implemented to enable detection of water loss and audits to be performed remotely and affordably. This study enabled the design and development of a long-range Wireless Sensor Network (WSN) model based on IEEE 802.15.4g LoRa standard. This study reviewed the technological challenges, architectural and logical design for the implementation of a scalable long-range model to detect losses in real time. The study used the PPDIOO methodology towards achieving and implementing network design lifestyle. The designs prototypes were set-up in a testbed, monitored, reconfigured and adjusted for efficiency and applicability. The study contributed to the body of knowledge in design of applicable water systems architectures.

Keywords: LoRa, PPDIOO, Water Loss.

1. Introduction

Water companies and other the water service providers continue to run at a loss as they can only manage operation and maintenance cost. The challenges of tenants tampering with supply system and meters, while corrupt agents get compromised is a challenge facing most water utilities (Water Service Trust Fund Report, 2013). The use of technology-based systems to relay information to the central office at real time will reduce incidences of corruption and poor water loss control (Creaco E, 2019).

The American Water Works Association according to their report (2012), water loss occurs in three categories; The Real loss occur if the source of water is not metered, broken line is not repaired and if overflows not prevented. Apparent loss occur in utility operation such as customer meter inaccuracies, billing system data errors, and unauthorized consumption and authorized un-metered consumption challenges and also corroborated by Water Service Trust Fund Report, (2013) Accounted for Water used not properly accounted thus increasing cost of operation hence distorting customer satisfaction patterns. There is also the authorized un-metered consumption of water, used in flushing water mains and in utilities like firefighting (Al-Washali, Sharma, Keneedy, AL-Nozaily, & Haidera, 2019).

Piped water connections to premises still the most affordable and safe system of water provision there is need to strengthen service providers to ensure loss are controlled for affordable and quality water provision. Arising from these scenarios there is need for effective technological strategies in water telemetry, most appropriately through a wireless radio system for data transmission within area of jurisdiction to detect measure, reduce or minimize leaks consistently for the growth of water service companies (Darsana P., 2018)