LONG RANGE NETWORK FOR RIVER CONSERVATION MANAGEMENT

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UNIVERSITI MALAYA
KUALA LUMPUR

2024

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DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING SCIENCE

FACULTY OF ENGINEERING
UNIVERSITI MALAYA
KUALA LUMPUR

2024

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Name of Degree: Master of Science Engineering

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[DEVELOPMENT OF WATER QUALITY MONITORING SYSTEM USING LONG RANGE NETWORK FOR RIVER CONSERVATION MANAGEMENT]

ABSTRACT

Scarcity of freshwater resources impacted from anthropogenic reformation pressuring demand of water resources management program. The program includes water quality monitoring to control the water resources from pollution by evaluating the status of water condition. Long Range (LoRa) in wireless network technology recognized in Internet of Things (IoT) for smart monitoring application. This research aimed to implement LoRa in water quality monitoring system with IoT architecture. Designed water quality station embedded LoRa nodes with selected water quality sensors including pH, Turbidity, Dissolved Oxygen (DO), Total Dissolved Solid (TDS) and temperature. The LoRa node was calibrated with transmission power at 14 dB and bandwidth at 125 kHz with three different spread factors of 7, 9 and 12 and. The water stations were placed at Sungai Pantai and Sungai Anak Air Batu, both rivers in Universiti Malaya campus. The accumulated data from LoRa gateway, RAK2245, were pre-processed and analyzed through mesh of K-means and Principal Component Analysis (PCA) method classifying the water quality of both rivers in Class IIB which is in a clean state for other purposes but not drinkable. The best findings for LoRa performance on the Received Strength Signal Indicator (RSSI), Signal Noise Ratio (SNR), packet loss, and path loss were approximately 80 dBm, 8 dB, $< 1\%$, and 64.41 dB, respectively. The minimum value of received sensitivity obtained at -129.1 dBm allow the gateway to decipher the weak signal transmitted. This study proved the use of LoRa in continuous river water quality monitoring while also highlighting areas for future improvement in water station and LoRa network design for better deployment.

Keywords: real-time, Long Range (LoRa), Internet of Things (IoT), water quality, smart monitoring

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[KEMAJUAN MENCIPTA SISTEM PEMANTAU KUALITI AIR MENGGUNAKAN RANGKAIAN JARAK JAUH UNTUK PENGURUSAN PEMULIHARAAN SUNGAI]

ABSTRAK

Reformarsi antropogenik telah memberi impak kepada kekurangan sumber air bersih memberikan tekanan permintaan untuk program pengurusan sumber air. Pengawasan kualiti air masa-nyata termasuk di dalam program ini untuk mengawal sumber air daripada pencemaran dengan kaedah menilai status kondisi air. Julat Jauh (LoRa) di dalam teknologi rangkaian tanpa wayar terkenal dengan Internet Benda (IoT) untuk aplikasi pengawasan pintar. Kajian ini bertujuan untuk melaksanakan LoRa dengan arkitek IoT di dalam sistem pengawasan kualiti air. Stesen kualiti air yang direkabentuk telah terbenam dengan nod LoRa dan sensor kualiti air yang dipilih termasuklah pH, kekeruhan, oksigen terlarut (DO), jumlah pepejal terampai (TSS) dan suhu. Nod LoRa telah dikalibrasi dengan 14 dB tenaga hantaran dan lebar jalur pada 125 kHz dengan tiga faktor rebak berbeza iaitu 7, 9, dan 12. Stesen air telah ditempatkan di kedua-dua Sungai Pantai dan Sungai Anak Air Batu di dalam kampus Universiti Malaya. Data yang telah dikumpulkan melalui get laluan LoRa, RAK2245, telah dipra-proses dan dianalisis melalui jaringan K-means dan Analisis Prinsip Komponen (PCA) mengklasifikasikan kedua-dua air Sungai di dalam Kelas IIB tidak boleh diminum namun boleh digunakan untuk tujuan lain. Penemuan tebaik untuk prestasi LoRa pada Indikasi Kekuatan Isyarat Penerima (RSSI), Nisbah Isyarat Bunyi (SNR), bingkisan kerugian dan laluan kehilangan telah dianggarkan pada 80 dBm, 8 dB, < 1%, and 64.41 dB untuk masing-masing. Jumlah minima sensitif penerima pada -129.1 dBm membenarkan get laluan untuk mentafsir isyarat rendah yang dihantar. Kajian ini telah membuktikan kegunaan LoRa untuk pengawasan kualiti air sungai

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lanjutan sambil memamerkan perkara yang diperlukan untuk rekaan stesen air dan rangkaian LoRa pada masa hadapan.

Keywords: masa-nyata, Jarak Jauh (LoRa), Internet Benda (IoT), kualiti air, pengawasan pintar

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ACKNOWLEDGEMENTS

Accomplishing another chapter for this season required a sacrification of blood and sweat. Covid19 effect declining my health mentally and physically had triggered burnout syndrome within me and cause devoid of motivation. Mercifully, with God's willingness and encouragement from surrounding people urge me to fight in this battle successfully.

Firstly, I am grateful to the Most Gracious and Most Merciful, Allah s.w.t. for His blessing on my health, spirit, knowledge, and strength to complete this studies. My plan had collapsed but I believe His plan is beyond mine.

Next, I would like to express my biggest gratitude to both of my supervisor, Dr. Sofian and En. Mahazani for their guidance and invaluable support throughout my Master's studies. Their mentorsip and feedback allow the navigation of the effective topic and motivation during difficulties. Their kindness and generosity create a supportive environment and trust in me to grow personally while try to achieve the objective in this chapter of my life. Also, I would like to thank to Prof. Suhana that keep push me from back to complete this studies so I can carry on my next chapter.

Then, the biggest appreciation is for my parents, Syed Taha and Juliana for their trust, encouragement, hope and prayer driving a force within me to overcome any resistance in order to finish this studies.

Last but not least, a sincere thank to my siblings and all my friends for their reassurance words and time. Not forget, my thank you to all people that contribute directlty or indirectly in concluding this studies. Thank you very much!

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LIST OF SYMBOLS AND ABBREVIATIONS

LoRa	:	Long Range
IoT	:	Internet of Things
WQI	:	Water Quality Index
NWQS	:	National Water Quality Standard
LPWAN	:	Low-Power Wide Area Networks
WQMS	:	Water Quality Monitoring System
IWRM	:	Integrated Water Resources Management
RSSI	:	Received Strength Signal Indicator
SNR	:	Signal Noise Ratio
WQI	:	Water Quality Index
SDG	:	Sustainable and Development Goals
UN	:	United Nations
GUI	:	Graphical User Interface
PAN	:	Personal Area Network
Wi-Fi	:	Wireless Fidelity
GPRS	:	General Packet Radio Services
GSM	:	Global System for Mobile Communcations
EDGE	:	Enhanced Data Rate for GSM Evolution
SMS	:	Short Message Service
LTE	:	Long Term Evolution
LoRaWAN	:	Long Range Wide Area Networking
NB-IoT	:	NarrowBand Internet of Things
CSS	:	Chirp Spread Spectrum
ISM	:	Industrial, Scientific and Medical

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RF	:	Radio Frequency
SF	:	Spread Factor
OSI	:	Open System Interconnection
MAC	:	Media Access Control
IP	:	Internet Protocol
OTAA	:	Over-the-Air-Activation
ABP	:	Activation by Personalization
TDOA	:	Time Difference of Arrival
GPS	:	Global Positioning System
WHO	:	World Health Organizations
APK	:	Android Application Package
PL	:	Packet Loss
LOS	:	Line of Sight
NLOS	:	Non Line of Sight

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CHAPTER 1: INTRODUCTION

1.1 Background

Malaysia estimately receives more than 3000 cubic meter per capita and per year of average annual rainfall and 97% of supply water came from river and streams to sustain everyday life of the community (Sand, 2020). Rapid in country development, industrialization, agriculture irrigation and population growth highly imposed demand of potable water for its benefit. Therefore, damage to river system can lead to long-term economic losses and affect quality life of inhabitants. Sources of the pollutant originated from domestic and industrial sewerage, deforestation, constructions, vehicle emission, exploitation of aqua resources, and effluents of livestock farm generated from negligent act of human, rapid urban pursuit and vain law regulations indicate to water pollution and inclined towards insanitary environment of river basin. Hazardous chemical from pollutants contained in the river affect the ecosystem habitats, water consumption and public health as water pollution turn into air pollution that can spread to wide space that can penetrate into inhabitant respiratory organ and skin.

In early 2019, Ex-Minister of Energy, Science Technology, Environment and Climate Change (MESTECC) Yeo Bee Yin stated there are 25 dying rivers and 35% of the rivers were contaminated and 58% still in adequate state at Malaysia as concluded based on variables of Water Quality Standard (WQI) and National Water Quality Standards for Malaysia (NWQS) analysis (Abd Wahab, Hassan Che Awang 2020). Additionally, in 2020, pandemic Covid-19 resulting significant impacts on securing adequate amount of clean water for potable drink and self-hygiene such as water wash hand regularly considered as one of Covid-19 chain breakdown approach measure forced into society daily practice. Regrettably, in midst of Covid-19 that drive water utilization under pressure because of necessity hygiene practice and frequent sanitation, Sungai Semenyih

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and Sungai Gong at Selangor state were polluted, and it release putrid smell to environment at surrounding areas (Rosli et. al. 2020). Investigation and analysis on water sample collected deliver the result of contamination cause from animal waste product and compound of palm process from farm and hazardous chemical waste and oil waste spill from factory at Nilai Industry Park and Rawang that not following Standard Operating Procedure (SOP) in handling waste product respectively. A few waters and treatment plants had been forced to shut down as contamination was detected for pipe and water tank cleaning process and pollution treatment. The operation caused water shortage affecting several zones in Selangor state for few days subsequently it had interrupted human activities and socio-economy moreover in Klang Valley where population rate is high.

Though water crisis management were planned beforehand, it is important to keep water resources in observation and protection for its purity and ensure the sustainability as the prediction for emergency water resources able to withstand only for a few days and numerous major issues had been addressed in water resources utilization. Several endeavors initiated by government and non-government environmentalist organizations to preserve salubrious river and manage water resources efficiently through sustainable use of water program, prohibition and control of pollution through strict fine and compound, integrated river basin management, water demand management and extensive research and development (Nordin & Yussof, 2020). One of the fundamental elements of water conservation management in decision-making approach and water quality management is water quality classification used to verify and categorize river class including control for prevention, treatment and consumption purposes determination. Critical analysis and identification core of water quality trend from parameters test of water quality based on collected data and investigation of physical, chemical and biological properties. Both standard WQI and NWQS include six parameters which are pH, dissolved oxygen, suspended solid, biochemical oxygen demand, ammonia nitrogen and chemical oxygen demand respectively except NWQS include color, conductivity, odor, salinity, taste, temperature and faecal coliform (El Shafey, Al-Ghobasy & Ahmed, 2020).

Department of Environment (DOE) collect WQI and NWQS data of parameters feedback to evaluate and benchmark water condition into 5 classes from best to worst state, 1, 2A, 2B, 3, 4 and 5. The manual test sample of water is collected from the river and tested in laboratory for further analysis and water quality identification, pollutant sources and classify the river. Further preventive action is taken if the reading measurement is exceeding the acceptable limit to control preserve the water quality. However, there were few limitations for manual methods in cost, operation, labor intensive, safety hazard and time sampling compared to autonomous system technique. Moreover, the applicability of water sampling data taken cannot represent with the latest time since the time for analysis and decision-making process take considerable time for accurate result (Kumar, Mishra & Singh, 2022). In the meantime, the current autonomous water quality monitoring system had not been applied widely around river in Malaysia thus it unable to provide direct actual condition of water resources at certain overlooked area make it possible to be contaminated and affecting surrounding area for a prolonged period. Besides, Malaysia requiring in advance precautionary method to protect water environment from pollution that can transform into any substance that disturbing the ecosystem, surrounding environment and life cycle while reducing high cost from restoration.

Recently, industry 4.0 theme become an intense topic across global towards changing the earth into digital and data insight era as wave of industry revolution. Evolution of technology in connectivity from internet play a big role introduced Internet of Things (IoT) evolved from machine-to-machine communication into wireless communication

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entering internet platform of borderless information. Alongside embedded intelligence and dynamic characteristics performing to solve some impossible tasks across services, process and verticals for various industry like natural resource reduction, energy management, healthcare, education, agriculture, infrastructure efficiency, disaster prevention, pollution control and etcetera (Anjaneyulu, Srinivas & Kumar, 2021). IoT platform with the purpose of connecting and exchanging data from multiple devices on pyhsical platform while not interrupting the surrounding environment and send the acquired information to gateway to analyze the combination data for data valuable distribution and exchanging information with applications prior to specific industry needs. IoT demand increase with urban development toward new concept of Smart Earth for efficient and accuracy services with less time and cost consuming for better quality life. Implemetation of IoT in water conservation management succor in overcome limitation from manual method of water quality monitoring and provide support decision method for environmentalist for further action to be applied from reliable water-quality monitoring data.

Reliable and functional communication mechanism and equipment to achieve possible highest performance to integrated with water monitoring devices are necessitated to support the IoT system to work in geographic area with communication distance, barrier and circumstance that known as the limitations in communication network. Emergence of LoRa (Long Range) or known as LPWAN (Low-Power Networks) wireless technology from development of mobile network and equipment act as one of the stimulus to access through obstacle in IoT communication technologies (Khan & Park, 2022). LoRa is a wireless radio frequency transmit small data packets operate in long-range range while consume low power and cost. Although it is not an ideal for things that require large bandwith, it is reputed involved with large amount of low power sensors applications needed for small data volumes transmission purposes. The capability of

LoRa for its flexibility and performance to travel far and across the obstacle make it suited in urban environment hence, it is selected for this research as communication devices for its real-time, accuracy, low power consumption, travel ability and continuous data colllection of river water quality monitoring .

This research intention is to overcome the difficulty at stream environment through develop an intelligent system for water quality verification and contaminant identification for river classification for environmentalist. IoT architecture based water quality monitor installed with selected water quality sensors module suitable and durable with outdoor setting assembled, LoRa communication model, LoRa gateway as the base station, data storage and analysis module, low cost microcontroller as main controller and powered up by rechargable battery supplied from enarmous solar energy through solar panel. Water quality stations is built at both river with LoRa mesh network water quality monitor devices installed in Universiti Malaya (UM), Sungai Anak Air Batu and Sungai Pantai that are directly connected to Sungai Klang, the main source of water for Klang Valley residents and industry as preview of IOT water quality application. All stations connected between each other allow communication between devices and equipped with ability to self-forming, self-routing and self-healing network system. The data collected from monitor devices is pushed to gateway and stored in Cloud. Data stored from monitor devices undergo analysis to identify and classify the quality of water. Detail of WQI from software module can be accessed by user in goverment and environmentalist for monitor and decision making while disclosure information is revealed among public to create awareness in river water conservation.

1.2 Problem Statement

Water quality monitoring deliver WQI through water sampling method and analysis to predict the water condition and class. Customarily, this method is conducted in manual

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approach through collecting water samples from the river and transported it to laboratory to be analyzed and classified. Though this method able to predict and present the conclusion of water quality of the river, it is incapable to present the result in actual time cause irrelevant result for elements that can change its properties within time. Besides that, there were several constraints such as labor intensive, safety hazard and relative high cost in operation, trained staff, equipment and maintenance. Nonetheless, traditional technique still preferred for water quality monitoring approach for a specific elements to obtain accurate result.

Automatic water quality monitoring invented for system efficiency and surmount those limitations and in Malaysia there were a few of fixed in situ continuous water quality monitoring station deployed by the government located near the stream of water intakes (Aziz & Aris, 2020). This monitoring system able to send continuous data for early support decision system but the station not widely installed hence it cause disadvantages to overlooked area. The data collection may be unreliable and irrelevant due to transferring and long period of analysis taken in manual manner thus affecting the result of analysis verification of the data obtained. Therefore, improvement of the in situ water quality monitoring is required to so it can be embedded widely at most area while acquire reliable data for analysis and result accuracy to justify the quality of water at river. It is also important to provide immediate support decision for water environmentalist on tackling the sudden change on water quality status.

Development of continuous water quality monitoring is experimented over the recent years along with technology revolution for system efficiency (Wang, Zhang & Liu, 2020). The enhancement carried by the researcher manipulating water quality sensors and wireless connection able to deliver accurate and reliable data of water condition in real time and allow immediate diagnosis of contaminant contained in water and its source to

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assist environmentalist for water conservation. However, a few of the designs are incapable to deploy in outdoor setting. Even though there were design that able to work in outdoor environment, it unable to stay in water in prolonged time, incapable to operate at unstable current river flow, required supervision with trained staff and required frequent maintenance. Furthermore, the wireless network communication devices used by previous researcher consume high power, high cost and have limited range transmission covered affecting the performance of the system of water quality classifier to transmit and retrieve data to the base station in rural setting. The system built also unable to alert and create awareness among community concerning the actual condition of the water source as precaution measure for their action. Consequently, research on selection of water quality sensor based on its potential is crucial so it can operate in turbulent environment while endure the flow of the river and the wireless communication is requisite to has flexibility in long range area transmission and can incapacitate the obstacle in geological environment. These features are important for reliable, functional, cost-benefit and low power consumption water quality monitoring system to operate at river ecosystem.

1.3 Objective

Main objective of this project is to develop and implementing long range (LoRa) mesh network monitoring system for river basin conservation management to reduce several drawbacks from previously water quality monitoring method. It is also aim to help and facilitate environmetalist with immediate result and decison making based on standard WQI to restore water habitat and protect ecosytem as one of the implementation of IWRM. Specific objectives include:

1. To design and implemented an autonomous Water Quality Monitoring System (WQMS) based Internet of Things (IoT) architecture with LoRa network.

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2. To analyze water quality data with statistical analysis.
3. To evaluate the performance and the effectiveness of the developed WQMS on river conservation management.

1.4 Scope of Study

1.4.1 General Purpose of Study

Risk and threat on water resources cause from various water contamination that harmfully affect the environment and ecosystem introduce the importance of water monitoring technology. The problem resultant the purpose of this research to develop and build an autonomous water quality monitoring to support river conservation management with real time monitoring and early decision making by obtaining reliable water quality monitoring data from universal standard water quality indicator based on Internet of Things (IoT) concept. Through understand and implement the concept of LoRa, Long Range wireless communication that offers long range and wide transmission with low power by develop concept design and algorithm of LoRa star topology network into modified autonomous water quality monitoring system to reduce flaw from previous system and improve the existing method. Simulation and testing of the subject were done in the laboratory before actual implementation in actual situation to prove its used in river environment to not bring harmful to the ecosystem. Moreover, to gain awareness importance of water resources, perception of water quality, parameters of WQI for water probe assembly and ability of LoRa to work in long distance and outdoor environment.

1.4.2 Study Area

Universiti Malaya is reputable public research university located in Kuala Lumpur, the capital of Malaysia. Aiming towards green campus, examine and remediate water resources, this research proposes to study and develop wide area continuous water quality

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monitoring system at two tributaries river, Sungai Pantai and Sungai Anak Air Batu that flows directly linked to Sungai Klang. Both continuous river flow onto varsity lake and adequately become the water resources. Sungai Pantai is located upstream of varsity lake and the length is about 1.75km flow from the external residential area within concrete channel inside the campus and pass varsity lake. Another tributary, Sungai Anak Air Batu flows from Damansara area and lastly merges with Sungai Pantai with total length of 1.93km. The built station will be installed along Sungai Pantai to collect data of water quality for observation and study.

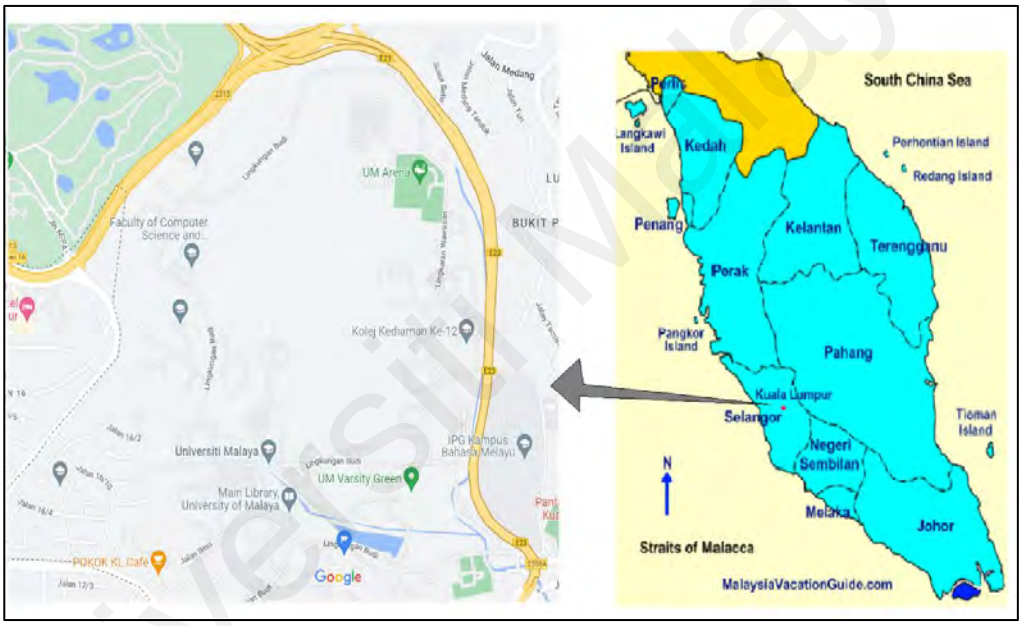

Figure 1.1: Sungai Pantai and Sungai Anak Air Batu in Universiti Malaya

1.4.3 System Development and Device Installation

The item and instrument used to build the hardware is designated to endure natural and outdoor environment and able to work in water environment simultaneously without frequent maintenance. A few of significance based on study and investigation on WQI parameters are taken to select and choose suitable durable and reliable sensors to build water probe for water quality monitoring inspection. Integration of wireless network system is a main core in IoT as it certainly depended to operate with connectivity.

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Accordingly, selecting the best wireless technology based on project requirement on band for accurate assessments, security, power consumption, cost effective and network management are very important for water quality monitoring IoT application system to able update data and information with cost, time and energy effectively. LoRa is selected as wireless technology network in this research to reduce cost and energy consumption while able to connect in long distance and assembled with water probe to be integrated with water quality monitoring system and send water quality data to gateway to notify the user.

1.4.4 Method validation

IoT system required a lot of testing for method and result clarification, and it divided into multistage from every component, sensor, gateway, cloud infrastructure and the frontend. In this research, assembled water probe installed in each water quality monitoring station will collect the data from river send the collected data to LoRa gateway that was integrated with cloud for data storage. The user interface on web service and apps on smartphone will show the user the result to interpret current status of water quality from analysis in visual form whether it suitable and safe for consumption and water activity at Sungai Pantai and Sungai Anak Air Batu at Universiti Malaya. The performance of LoRa is investigated based on chosen network properties which are RSSI, SNR, packet data, path loss and received power.

1.5 Thesis Organization

This thesis studies the compatibility of LoRa to be implemented in automatic water quality monitoring system that can benefit water environmentalists. This research carried out as explained in 5 chapters of this thesis.

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Chapter 1 provide an introduction prior to the purpose of this research and the highlighted issues regarding water pollution that impact the demand of water supply. Also, problem statement, objectives and scope of this research described.

Chapter 2 discussed the material on importance of autonomous water quality monitoring for water sustainability towards Sustainable and Development Goals (SDG) 6.3 on improving water quality. Then, the water quality properties in sensor mode that can be used in this research based on WQI and previous study were explained in this chapter. Besides that, IoT and comparison of wireless network briefly described including their benefits in application. Furthermore, LoRa architecture and its implemented study by previous researcher also reviewed in this chapter.

Chapter 3 described the flow chart of this research, water station design, devices of water quality monitoring sensor and LoRa setup used, experiment place setting and analysis method on water quality data. Additionally, the network properties of LoRa that will be evaluated also provided.

Chapter 4 demonstrated the result obtained from analysis of accumulated water quality data and classify the experimented river water into the class based on WQI benchmark. In this chapter also presenting the performance of LoRa network based on evaluation on its selected properties. The evaluation determined the capability of LoRa to be embedded in continuous water quality monitoring.

Chapter 5 concluded this research on achieving its objectives based on the discussion in chapter 4. A few of recommendations also listed as reference for future study.

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CHAPTER 2: LITERATURE REVIEW

2.1 Overview

This chapter review the objective, properties and design of water quality monitoring program for water resources preservation. Hence, collecting information on significant water quality parameters for this study became crucial for the aim of continuous water quality monitor. Furthermore, this chapter also inquiry the concept of IoT in continuous water quality monitoring application. At the final of this chapter, review on LoRa and its implementation by previous researcher in were discussed.

2.2 Water Quality Monitoring

Integrated Water Resources Management (IWRM) concept is water strategic approach involved with coordinated of water resources, management of wastewater, controlling of water hazard like flood, water droughts and landslide and last but not least the aspect in uses of water capacity and its benefit in life cycle and environment. Integral of natural hydrological environment in engineering and economic water solution for information in control and decision making on water management in timely manner.

Quantity and quality of water are the most significant factors correlating to each other determine the ability to meet water resources demand for living things and country development. Quantity water of river is measured by water level, velocity and discharged and it is influenced by watershed, climate change and water quality status. Natural phenomenon that affecting the condition of water may be unavoidable however artificial chemical products contaminating the river harmfully cause deteriorate in water quality status substantially and producing health and ecosystems hazards hence affecting water deliver (Rahman, Alam & Islam, 2020). Consequently, water quality monitoring series is a fundamental as it included in national legislation and was commenced sustaining water

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resource, enhance the ecosystem and water environment preservation with effective implementation of extenuation measure.

Initiation of water quality monitoring programme is a production from political obligation and scientific duty to achieve objective of following water quality trends. It is included in IWRM Policy involving water strategic approach involved with coordinated of water resources, management of wastewater, controlling of water hazard like flood, water droughts and landslide and last but not least the aspect in uses of water capacity and its benefit in life cycle and environment (Mohd & Zakaria, 2020). Acquire information of current and future water trends considered to oblige economic progression, population growth, agriculture and industrial urbanization, further socio-economic development and climate change. The objective of this system is based on risk benefit and cost value depend on its circumstances while meet highly desirable goal towards sustainable development of earth growth. Importance of approach coordination for wanted achievements to optimize the method and instruments on accessible ground and water resources while completely avoid keeping any negative impacts towards environment.

Water quality monitoring is an evaluation method of water content through determination and analysis of water sample and on-site measurement data by comparing the result to water quality guidelines as water status indicator. Importance of acquiring reliable data from various of monitoring techniques manually and automatically respectively obtained from water resources to deliver required result differ to the research purposes on water content for securing universal health, determine peculiar mineral solvent and unusual behavior of water resources. Identifying the water resources quality status necessitated efficient and authentic method and system thus it is imperative to recognize behavior of variables to be embedded in the monitoring analysis system. Below

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flow chart demonstrate the water quality monitoring system process (Kadlec & Cerný, 2020).

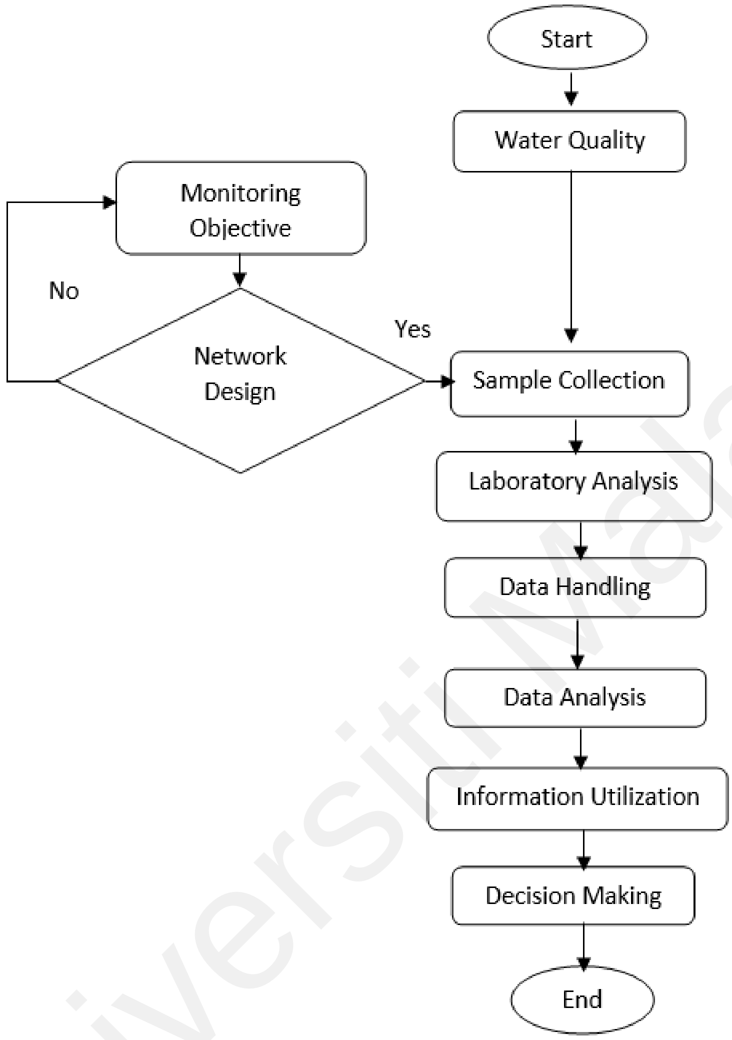

Figure 2.1: Flow of Water Quality Monitoring

2.3 Water Quality Parameter

Water quality monitoring can be based on comprehensive data and observation on its properties of physical, chemical and biological. The abundance of biological life and crystal-clear water in a stream can provide clues about the health of the stream based on the physical attributes of water quality evaluation. Several physical quality parameters, such as water transparency, color, odor, vegetation near the river's interface, aquatic life state, and substance residue, can be visually observed and tracked based on understanding the origin of the stream and its usual use. Measure the width, depth, and flow velocity of the stream as well as its quantity to establish a baseline for the impact of its unique physical characteristics.

Whereas biological properties provide significant evident and view into functional quality of the environment research such as water turbidity and temperature. Predictions of effect from human activities in water revealed by changes in the composition of biological specimens around their habitat. Monitoring particulate matter, microorganisms, vegetal, insect, vertebrate and invertebrate aquatic organisms like planktonic, algae and fish muscle insight can provide useful information on nutrition capacity and period of pollution effects. Moreover, the sudden existence of irregular or invasive species around river ecosystem like suckermouth catfish is an indicator for clean status as all biological life require specific spectrum circumstances to live in the surrounding area. Investigation on sensitivity of the organism on water ecological able to classify the quality of water into 4 rank, excellent, good, fair and poor.

The mainly epitome properties of water quality that been clarified and used worldwide for water quality monitoring is chemical properties because of its reliability can determine sources of pollutants and specify type of pollutants hence it applicable for analyzing drinking water suitability. The fundamental chemical parameters tested on water are based on pH, temperature, dissolved oxygen, conductivity, total of suspended solid, biochemical oxygen demand, ammonia nitrogen, chemical oxygen demand and nutrients contained. All of the chemical parameters stated are included WQI and NWQS for Malaysia to justify and analyze condition of river water quality to be classify the river class for action and observation determination. Furthermore, potential parameter core group for river as described in plotting of monitoring methodology by UN for

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environment programme in SDG Indicator 6.3.2 are classified as Table 2.1 below (Wang, Zhang & Xue, 2020).

Table 2.1: List of Core Group Water Quality Parameter

Parameter Group	Parameter
Oxygen	Dissolved Oxygen
	Biological Oxygen Demand, Chemical Oxygen Demand
Salinity	Electrical Conductivity *Salinity, total dissolved solid*
Nitrogen	Total Oxidized Nitrogen *Total nitrogen, nitrite, ammoniacal nitrogen*
Phosphorus	Orthophosphate *Total phosphorus*
Acidification	pH

Every core parameter group listed is essential element for its crucial function in river ecology. Aquatic life depends on oxygen level for the photosynthetic activity of aquatic plants and the diurnal respiratory system for aquatic organisms. Although they are not as dangerous as the presence of artificial compounds, turbulence and ripples on the surface of water lower the amount of oxygen that is naturally present and influence temperature and salinity. Salinity factor assessed dissolved materials like salt to determine how to characterize a body of water depending on how much it deviated from the norm. The salinity volume might vary naturally, for instance due to an increasing period of river flow, but it can also identify anomalous defects on the river caused by pollution in the water body.

Nitrogen and phosphorus are equally essential to aquatic life as oxygen. However, the effects of excessive volume on different biological species vary. For example, phosphorus can boost the concentration of algae and underwater plants. However, it is affecting the ecosystem thus no ideal for human usage. Therefore, conducting quality analysis using an analytical lab method within 24 hours is strongly advised as the concentration change over time that can lead to measurement errors. On the other hand, combination of nitrate

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and nitrite producing an excess of dissolved inorganic oxidized nitrogen damages freshwater ecosystems and jeopardizes drinking water quality.

Henceforth, another crucial factor in define the water body characterization that influencing both biological and chemical processes factor is acidification through pH measurement value. Change on pH value is affected by hydrogen ion commotion that easily manipulated by natural factor of river flow additionally during rain occurrences. Sudden change from standard range denote unusual possible polluted inorganic solvent formed around river water ecosystem. Hence in-situ method is more preferrable for acquisition accurate results as the change of pH value vary over time. Classification of river condition can reflect the purpose for every core parameter in water ecosystem conservation studies.

Measuring the national capacity of water quality indicators using universal standard capable to highlight the crisis in river water trends and condition whilst maintaining good river class. Therefore, Table 2.2 show water class determination range of each core items mentioned based on DOE Malaysia WQI classification and calculation formula on WQI outcome studies constructed from range obtained as in equation (1) (Mohd Fauzi et. Al, 2020).

$$WQI = (0.22 * SIDO) + (0.19 * SIBOD) + (0.16 * SICOD) + (0.15 * SIAN) + (0.16 * SISS) + (0.12 * SipH) \quad (1)$$

Where,

SIDO = SubIndex of Dissolved Oxygen
SIBOD = SubIndex of Biochemical Oxygen Demand
SICOD = SubIndex of Chemical Oxygen Demand
SIAN = SubIndex of Ammoniacal Nitrogen
SISS = SubIndex of Total Suspended Solid
SipH = SubIndex of Ph

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Table 2.2: DOE Water Quality Index Classification

Parameter	Unit	Class				
		I	II	III	IV	V
Ammoniacal Nitrogen	mg/l	<0.1	0.1-0.3	0.3-0.9	0.9-27	>2.7
Biochemical Oxygen Demand	mg/l	<1	1-3	3-6	6-12	>12
Chemical Oxygen Demand	mg/l	<10	10-25	25-50	50-100	>100
Dissolved Oxygen	mg/l	>7	5-7	3-5	1-3	<1
pH	-	>7	6-7	5-6	<5	>5
Total Suspended Solid	mg/l	<25	25-50	50-150	150-300	>300
Water Quality Index (WQI)	-	>92.7	76.5-92.7	51.9-76.5	31.0-51.9	<31.0

Outcome from calculations based on the WQI equation determine the condition of water quality based on index range either clean, slightly polluted or very polluted to be classified its class status. The input based on Table 2.2 is the basis to develop WQMS by comprehend the method of river class determination from WQI calculation and NWQS consideration for accurate water quality analysis illustrate the significant to keep conserve river, targeting and maintain at class I river for health and ecological sustainability. Henceforward, Table 2.3 below reveal the applicability of river towards environment and living form for each class.

Table 2.3: Water Class and its Uses

Class	Uses
I	Natural environment preservation Water Supply I: No treatment required practically. Fishery I: Biological aquatic very sensitive towards the surrounding.
II	Recreational uses for water contact. Water Supply II: Required conventional treatment. Fishery II: Sensitive biological aquatic species towards the environment.
III	Suitable for livestock drinking water supply. Water Supply III: Extensive treatment is necessary for water delivery. Fishery III: Common, economic and species that tolerant to
IV	Irrigation for crop productions.

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V	None of the above.

The implementation of an evaluation program and monitoring application is directed towards the visionary aim of water sustainability, which is to establish good water status that is acceptable for ecological development and world health. Therefore, the approach of the water quality monitoring program is still developing and conducted in accordance with water trends, constraints, and goals led by research. Both

2.3.1 Automatic Water Quality Monitoring

The process of gathering data, analyzing it, and producing an output are dependent on the design of a water quality monitoring program. A wide range of goals are to be achieved by monitoring systems, including limiting pollution, assessing the current trend in water quality and the effectiveness of waste management while ensuring the health and well-being of living things with the quantity and quality of water (Kumar & Kumar, 2022). Reliable data from proficient water quality monitoring gain trust from stakeholders by potentially provide an insight for the policymakers to make an immediate decision making for river resources maintenance or restoration. Additionally, it helps humans by preventing frequent contact with contaminated water bodies for activities and domestic purposes, as well as by preserving the water ecosystem from contamination.

Manual water sampling method has been practiced since the establishment of water sustainability management. The samples are taken from the water channel and sent to a lab for in vitro and in vivo array analysis. A thorough analysis in laboratory mode is able to outline the contents of water for water quality benchmarking study to expound on the activity in water course conservation. By creating an eco-heart shape from the analysis of water sampling, a recent study by the Water Warrior team monitoring water resources at the Universiti Malaya demonstrates how their approach improve the awareness on the

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state of the water quality (Sakai et Al, 2018). Nevertheless, limitation on water sampling methodology urge support decision system to provide early respectively timely result for water security and hazard insurance.

In situ water quality monitoring is used in water bodies to supplement the manual field sampling procedure by providing frequent monitoring. Constant monitoring with the ability to forecast communicating water resource circumstances in a timely manner for water resources preservation. Current applied in-situ real time drinking water quality monitoring embedding wired sensor in large water system (Zhang et. Al, 2020). Implementation of sensing devices and network systems provide intelligent continuous water course monitoring to provide independent, dependable measurable data to help decision-making. Standard assessment of autonomous water quality monitoring system comprises of steps from collecting data, data transmitting, data processing, data organization, data computing and graphical user interface (GUI) for administration.

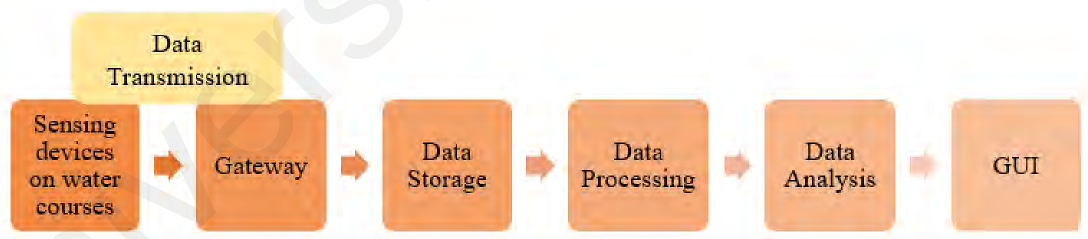

Figure 2.2: Assessment of Water Quality Monitoring

Common sensing device used for water probe by previous researcher for quick support decision system are based on studies on WQI parameter and capability for in situ implementation namely pH, temperature, electrical conductivity, dissolved oxygen, turbidity and total suspended solid to demonstrate compound in water. Summarizing, sensing devices collect stimuli from nature and transformed into signals and figures form to be stored in database platform for required functions. Type of sensing devices for water quality in situ monitoring were selected for their capability and reliability to operate in

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water environment pressure, endure any kind of weather and a contaminated environment. Furthermore, the effectiveness of wireless sensing devices can reduce the financial cost on human labor and maintenance while assisting with safety precautions. (Kumar & Kumar, 2020).

Accessing data from sensing devices into applications and devices demand data transferring routine for data collecting and storing is essential part to ensure the process of observation, investigation and analysis in monitoring system. Implementing wireless network system demanded lot of consideration and study for its ability and limitation to transfer the information to the gateway for further analysis.

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2.3.2 Summary of Literature on Water Quality Monitoring

Table 2.4: Summary of Literature Review on Water Quality Monitoring

Water Quality Monitoring				
Author	**Year**	**Method and Study**	**Discussion**	**Conclusion**
Rahman, M. M., Alam, M. J., & Islam	2020	- Reviewing existing literature on the impact of pollution on water quality and human health. - The search parameters included phrases relating to water contamination, human health, and epidemiological research.	- Water contaminants might be chemical, physical or biological. Water pollution impact on vulnerable groups, such as children, pregnant women, and those with weakened immune systems.	- It is important for immediate action to prevent water pollution through effective waste management techniques, wastewater treatment infrastructure development, and regulatory changes. - Water quality monitoring and research is important to gain a better understanding of the causes and consequences of contamination.
Kadlec, J., & Cerný, M.	2020	- Identification of criteria include water quality parameters, spatial coverage, and monitoring frequency. - The parameters selected based on literature review and expert judgements.	- Evaluating many factors is significant when selecting water quality monitoring stations, as a single-criterion approach can result in inferior solutions. - The framework was used to a case study in Switzerland, and able to identify the most	- The MCDA framework is suitable for decision making as it integrates various forms of data and expert opinions. - The framework can be applied to other countries or regions with similar water quality monitoring needs

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		- Water quality data from existing monitoring stations was collected and examined. - The MCDA framework was used to choose the most appropriate monitoring stations.	acceptable monitoring stations based on the given parameters.	
Mohd Fauzi, M. A., et al.	2020	- Assess WQI of river basin in Malaysia using weighted score system. - WQI was calculated based on physico-chemical parameters, including pH, temperature, turbidity, dissolved oxygen, biochemical oxygen demand, total suspended solids, nitrate, phosphate, total coliform bacteria, and fecal coliform bacteria.	- pH and dissolved oxygen were the most critical factors determining the WQI. - Land use patterns impacting WQI, with higher levels of agricultural and industrial activity resulting in lower water quality.	- WQI is a technique for evaluating and categorizing water quality in river basins. - The result show the importance relating numerous parameters when evaluating water quality.
Kumar, P., & Kumar, S.	2022	- Water quality sensors to measure parameters such as pH, temperature, turbidity, and dissolved oxygen. - Waste management sensors to detect levels of hazardous chemicals, heavy metals, and other pollutants.	- Real-time monitoring of water quality and waste management in industrial areas is important to reduce potential risks to human health and the environment. - The proposed system able to reduce labor costs, and improved decision-making.	- The system can be scaled up for use in other industrial areas and can be modified to include additional sensors and features.

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		- A microcontroller unit to collect data from the sensors and transmit it to the cloud-based server. - A cloud-based server to store and analyze the data in real-time. - A mobile app for real-time monitoring and alerting.		
Zhang, Y., Zhang, Y., Li, J., Zhang, X., & Zhang, Q.	2020	- Measuring water quality wirelessly with GSM. - Used sensors including pH, turbidity, conductivity, TSS and temperature in the proposed design.	- The result provided significant to the expected outcome as proposed hypothesis. - Utilization of safe drinking water led to economic growth.	- The system is efficient, economical, low cost, reduce human labour while operate automatically. - System is flexible for future maintenance on replacing sensors and adjust the software.
Nobumitsu Sakai, Fatimah M. Zeeda, Affan Nasaruddin, Siti Norasiah Abd Kadir, M.Shahrul Amin M. Salleh, Abd Halim Sulaiman	2018	- Sampling site and surface water collection within a day. - Water quality analysis done in lab. - Eco Heart Index based on standard Malaysia water quality index (WQI).	- User and environment friendly. - Accurate measurement. - Provide general water quality. - Community impactful with Eco Heart as the indicator for water quality.	- Accurate measurement, economical and user friendly - The output relevant to the policy. - The eco-heart index more informative than WQI and impactful for the community.

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2.3.3 Wireless Network as Technical Factor in Water Quality Monitoring

Telecommunication system for environment application based on the objectives of water quality monitoring necessitated to optimize its used on the sampling location, methods and frequency while minimizing the budget benefit. The required minimum wave from the system also obliged to avoid interruption on water ecosystem and prevent from causes negative impact on environment. Henceforth, choice of networking system that able is a key for ensured data transmission to be recorded in database that compulsory for water content examination while extracting its ability and reduce its limitation for decision making system.

Invention of wireless networks manipulate radio frequency between nodes to connect client devices with internet for broadly range of applications and business introduces IoT. End devices controlling appliance devices within tolerable distance that securely communicate with IoT platform. The IoT platform collecting information and merges data from multiple operate devices to be applied in analytics computation to be reported to end devices for user pursue the specific industrial needs (Zhang, Zhang & Li, 2020).

It is significant to contemplate the performances, possibilities and drawbacks of the connectivity wireless technology to be embedded into water quality monitoring system to reduce power and cost consumption while provide adequate efficient distribution of message across nodes involved in the system. Balancing cost, power, size and weight with minimum maintenance is desirable for all IoT application including continuous water quality monitoring (Fares & Al-Turki, 2020). Selecting type of network to be used by reflecting on its requirement and type of data involved during transmission between nodes and towards gateway is necessary to enable cloud computing storing and analyze massive amount of data in water quality monitoring process. Thus, Table 2.5 discussing the type of form wireless technology properties that cogitated in IoT purpose [48].

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Table 2.5: Summary of Wireless Network

Network Type	Description	Range	Output Power/W	Requirements	Advantages	Disadvantages
Zigbee	High level communication protocol build PAN wireless mesh network targeting on battery-pwered devices	10-20 m line of sight	0.001	Zigbee base devices	- Low cost - Low power consumption - Suitable for small scale applications. - Low latency communication.	- Data transmission depend on power output and environmental conditions. - Low data transmission rate.
Bluetooth	Exchanging data using UHF radio protocols build PAN in short range.	20 m line of sight	0.003	Bluetooth 'base station' embedded in devices.	- Efficient with devices stay near to each other. - Low power consumption. - Free ISM license band	- Low data transmission rate - Short data range communication
Wi-Fi	Wireless router in confined space point to multipoint using standard communication IEEE 802.11n	50 m	0.1	Router and access point for internet connection.	- High data rates suitable for application require large bandwith in a fixed location and power accessibility.	- Limited range, required a lot of extender for wide application. - High power consumption.

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					- Free ISM license band. - Small and cheaper antenna	- Poor signal penetration.
GSM	Second generation of circuit switched network optimized for voice exchanging purpose including data in GPRS and EDGE form.	35 km	2	Contract with mobile services provider.	- Long ranges. - Able to use for tracking and movable object.	- High power consumption. - Require expensive regional frequency.
LoRaWan	- Low speed but long range and low power communication. - Open specification make it easy to apply its protocol to be embedded into the equipment.	5-10 km (dependent on line of sight)	0.025	Base station need internet connection and power.	- Low power consumption. - Low cost of chipset. - Operate in private network. - Suitable for sensor that required infrequently sending data. - Free ISM license band.	- Limitation on frequency band may cause high latency on delivering message. - Limitation in coverage of pivated network.
Sigfox	A proprietary network and protocol. Usually mean for meter	15 miles	0.025	Sigfox coverage and subsciptions.	- Applicable for meter reading. - Low power consumption.	- Low speed - Free license but base station only run by Sigfox hence cannot

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	reading also applicable for data uplink				- Long range. - Usable for non-requiring downlink messages to devices.	install own base station. - Setup cost is expensive.
NB-IOT	Operate in mobile phone radio spectrum and ride on former GSM channels or free space among LTE channel	10-15 km	0.2	Subscriptions of mobile telephone provider, sim card, data costs and hardware.	- Since it is upgraded version of GSM, it is suitable for sensor readings, fleet management and tracking.	- Require expensive reserved frequency or channel. - Coverage is not apllied widely.
LTE	4th generation of mobile network system. Supports voice calls and designed for improved scalability and wireless broadband	2 km	0.2	Subscriptions of mobile telephone provider, sim card, data costs and hardware.	- Reliable and secured. - High bandwith make it suitable with data that require larger bandwith like moving motion graphic.	- Require expensive reserved frequency or channel. - Not compatible with devices work in low power and long range end that operates years with batteries since it consume more energy and power.

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Conventional wireless technologies applied in water quality monitoring systems are Zigbee, Bluetooth and Wi-Fi. Both Bluetooth and Zigbee are lightweight and low power users but were not recommended for long range data transmission as both exhibit short transmission range and low in rate transmission causes its efficiency to drop and increase in latency as nodes distances increases. Although the efficiency problem can be solved by expanding the number of nodes and developing mesh network topologies that can aid in self-healing and increase data transmission range for PAN networks, this results in greater costs and energy usage. Nevertheless, both are still practical and popular for transmission between sensor nodes to controller and non-required large bandwidth in close proximity smart application like smart home application for its low energy and build cost consumption (Zhang, Zhang & Chen, 2020). In water quality monitoring study performed by previous researcher, PAN network was applied as radio frequency module and use GPRS, an extension mobile network version from GSM as data transmitter (Wang, Zhang & Chen, 2019). The network system applied accomplished its goal in provide data of water quality condition, but it consumed unnecessary additional power for two combination network and required SIM card to activate communication with networks.

While Wi-Fi widely used network technology for data transmission between devices for LAN type of network as stated by Institute of Electrical and Electronics Engineer 802.11 Standard (Katz, 2019). Complemented with high data rates and low-cost antenna source of its popularity to be applied in the system that require large amount of frequency bandwidth in immediate delivery within its range moreover in IoT application. Wi-Fi is popular among previous researchers to embed it in automatic water quality monitoring system as data transmission from controller to IoT data platform (Patel, Patel & Patel, 2019) (Bhisekar et Al, 2018) (Dilshad & Abishek, 2018). The advantage of the embedded network capable of transmitting large amounts of data of water quality to be analyzed

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increase the accuracy and achieve its objective for support decision system (Samsudin & et Al, 2018). However, it requires extendable points for long range applications like in river setting and because it is known to consume a lot of power, the extension will save wasteful power consumption and operational costs for low packet data. Nonetheless, Wi-Fi remains the industry standard in broadband connectivity and reliability for IoT applications that connect to a large number of objects that demand faster data rates and low latency at the lowest possible cost, but at a higher power consumption.

GSM or known as 2G is a mobile communication standard developed from analog cellular networks, 1G that was optimized for voice exchanging purposes. Originally, it introduced as circuit switching networks, but it was upgraded with the implementation of packet switching and integrated with GPRS. It was then modified further by 8PSK modulation to improve data transfer rates for internet evolute into EDGE (Al-Shammari & Al-Shammari, 2020). There were researchers embedding GSM module along in real-time water quality monitoring system to provide measured value to the monitoring center through SMS function for further analysis (Ranjbar & Abdalla, 2017). Equipped with ability of long-distance travel and good data transfer rate, it efficiently sends constructive water quality data to be updated in the monitoring center for support decision system. Nevertheless, it is disfavor for massive IoT application like water quality monitoring system as it gratuitously utilizes higher power consumption and require expensive regional frequency from mobile network provider.

Study and result from GSM extension, harvest its successor 3G, LTE. 4G and 5G improved in transfer rate capacity and higher bandwidth frequency for wide internet access in daily and industry application with high security, lower latency and greater capacity (Kumar, Singh & Rani, 2021). Requirement of subscriptions with mobile provider, data costs and hardware and reserved expensive frequency channel cause this

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type of network a bit challenging for IoT application. Though its disadvantages affect the network selection session, there was researcher used 3G as data transmitter for water quality monitoring system. The result obtained from the study allow the validation of water quality monitoring data as the network used as medium achieved its objective for transmission between local host database to remote database (Joseph Bryan et Al, 2018). Nevertheless, reducing cost and energy consumption is one of the main IoT application objective towards Smart Earth concept hence the choice of network selection still necessitate investigation for water quality monitoring system.

NB-IoT, Sigfox and LoRaWAN are networks that achieve transmission effectiveness over long distances that enables connection between devices require small amount of data, low bandwidth and low power utilization (Singh, Kumar & Mittal, 2021). Similar to the previous network revealed before, NB-IoT is a narrowband IoT require subscriptions with mobile network provider include data cost and hardware for operation as it trips through mobile network spectrum. Furthermore, regard the comparison with other LPWAN free licensed ISM band offer by operators cause a hesitation to invest in NB-IoT in the system applied unless acquire good services, local market status and collaboration partner. Although the cost minimization will be affected, collaboration between Ericsson, city officials and university researcher attempt to replace the current technology used, cellular 4G LTE to NB-IoT in smart water monitoring system developed tested at Stockholm to make sensors more efficient and across wider area (Ericsson Research, 2019).

As for Sigfox-radio compliant interface, another known network provides LPWAN service while offer low transmission power level with maximum range capability of 40km (Liu, Chen & Wang, 2022). Here at Malaysia, Sigfox run by Xperanti provide highly efficient devices solution that deliver high quality data suitable for massive business and industries products with very low power consumption for tracking, control and prediction

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(Safarzadeh et Al, 2022). Though it is free ISM licensed band, it requires Sigfox coverage and subscriptions hence the base station only can be built and run by Sigfox operator cause expensive cost expenditure. Still, Sigfox network had been used in water quality monitoring developing system by previous researcher. The contribution of the network success in deliver the georeferenced data of water quality to the IoT platform for decision maker (Di Gennaro et Al, 2018). However, minimal cost mass IoT system is not recommended to implement Sigfox network due to its high-cost plan and base station setup although cheaper than cellular network.

Next, the latest and most popular network among IoT applicators is LoRaWAN which is the leader of long range and low power connectivity has been approved by IoT market developments and analysis (Rabbani, Khan & Kumar, 2022). LoRaWAN is an open specification network, and its protocol is applied straightforwardly embedded into the equipment but to be reminded the base station need internet and power for operation. Furthermore, limitation on frequency bandwidth may cause high latency when operate with critical type of data and video data type thus is more compatible with sensor that seldom sending data as in massive IoT case for Smart Earth application. Since it is compatible with monitoring system, previous researcher had developed automatic water quality monitoring system with LoRaWAN and tested in garden pool and laboratory (Zhang, Zhang & Chen, 2020) (Patel, Patel & Shah, 2022). Analysis and status shown in IoT platform resultant the success of the system objective while being cost effective, but modification is necessitated to be applied in geographical area due to the bandwidth limitation and sight-to-sight factor moreover in urban area (Ahmed, Hassan & Hassanien, 2022).

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2.3.4 Summary of Literature on Various Wireless Network in Autonomous Water Quality Monitoring

Table 2.6: Summary of Literature Review on Application of Wireless Network in Water Quality Monitoring

Application of Wireless Network in Water Quality Monitoring				
Author	**Year**	**Wireless Network**	**Discussion**	**Conclusion**
Wang, S., Zhang, J., & Chen, Z.	2019	Zigbee and GPRS	- Time synchronous algorithm to wake nodes for reliability and stability communication. - High accuracy, real-time and stable communication.	- The system is effective and high accuracy. - The method has the practical value and wide application aspect.
Patel, K., Patel, R., & Patel, D.	2019	WiFi	- The system can monitor multiple parameters simultaneously. - The challenges of data security, power supply, and maintenance.	- The system built at low cost, and more efficient. - Data analysed, processed and viewed at real time able to improve decision making.
Bhisekar, C., Meghare, H., Parate, S., Prajapti, S., Meshram, B., & Bobade, P.	2018		- The volume of alkaline and its turbidity determine its drinkability.	- The system is economical, reduce human labour flexible. - Had wide application spectrum and extended value.
Dilshad, A., & Abishek, K.	2018		- Developed smart interacting GUI fetch data from ThingSpeak through TCP protocol. - The end used had authorities to monitor and maintenance their area.	- Public able to view the actual water quality condition. - Control industrial waste in fast manner.
Samsudin, S., M. Salim, S., Osman, K., Sulaiman, S., & A. Sabri, M.	2018		- Real-time monitoring of pH and turbidity level based IoT application.	- More water quality parameter for accuracy improvement.

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				- Water class IIB suitable for recreational contact.
Ranjbar, M., & Abdalla, A.	2017	GSM	- The abnormality of water quality condition alerting the user with SMS and provided with buzzing sound.	- The system monitor water quality monitoring at low cost.
Ericsson Research	2019	4G LTE	- Water modelling algorithms apply big data analytic method for sensor data filtering. - Distribution network phase monitor on bacteria contamination in freshwater.	- Predict and early warning for water quality status. - Can direct laboratory sampling at changes occurred area. - Future project using NB-IoT technology for improvement.
Di Gennaro, P., Lofú, D., Vitanio, D., Tedeschi, P., & Boccadoro, P.	2018	Sigfox technology.	- Power consumption of WaterS node was evaluated, and it was significantly lower than other commercial sensors. - WaterS node accuracy is comparable with commercial water quality sensors	- The Sigfox technology used in the WaterS node able to reduce power consumption and cost while cover wide area. - Monitor water quality parameters in real-time, enabling early detection of potential contamination
Zhang, Y., Zhang, J., & Chen, X.	2020	LoRaWAN	- Reference methods for water quality monitoring was compared with sensor readings. - Packet loss rate <1%.	- Real-time monitoring allows for rapid detection of changes in water quality. - Energy efficiency
Patel, R., Patel, N., & Shah, M.			- The mobile app allows users to view real-time water quality data	- The potential applications of the system can be deployed in

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	2022		and receive alerts when parameters exceed safe limits. - The built IoT-based system provide real-time data, reduced costs, and increased accessibility.	various settings, including municipal water supply systems, industrial processes, and agricultural irrigation systems.

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2.4 LoRa Overview

The abbreviation of LoRa came from Long Range refers to its offer to travel in long distances while consume low power become de facto for IoT applications worldwide though transfer at low bit rate (Al-Khasawneh & Hamdi, 2020). LoRa is a spread spectrum modulation technique derivation of Chirp Spread Spectrum (CSS) technology purposely for air interface communications for LPWAN applications. CSS technology is long range communications used by military and spaces agencies for its capability withstand interference and robust against network or congest attack thus LoRa become the first commercialized low-cost infrastructure modulation implemented. It is also an application from Semtech Corporation where transmission runs within license free sub-gig ISM band (Raza, Hassan & Alamri, 2019). Besides, LoRa development also aim to exclude repeaters, enhance network capacity, support large number of devices while reduce device cost employed, increase battery lifetime. The radio modulation had been designed to allow extremely low signal levels to be obtained at lower power transmission while being optimized to provide function in communications for IoT.

LoRa is preferred choice for battery operated sensors that obligate small packet data to be transferred and received because it super low-power consumption measured in micro-ams. LoRa technology included two sub-technologies that correlated to each other. LoRa is the operated radio modulation technology and LoRaWAN is the media access protocol (MAC) and system building network manipulated for long range communication promoted by LoRa Alliance (IBM, Semtech, Cisco and others) established in 2015 (Al-fatih & Al-Shammari, 2019). The long range over distance transmission can be accomplished due to spreading methods correlation mechanism that allows even small signals perish in the noise affecting the receiver to efficaciously demodulated it. Additionally, the CSS technique improve spread spectrum and promote resilience

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frequency between receiver and transmitter (Wang, Li & Zhang, 2020). The receiver proficient to decode signals until 19.5 dB beneath the noise.

LoRa enabled sensors and gateway are produced commercially globally available with stable pace and non-required specific operator or expensive band license for operation become advantages for system building. Operating in star topology network, LoRaWAN utilize LoRa modulation to allow communication between end-devices with gateway by provide medium access control mechanism for data transmission to IoT platform (Zhang, Li & Chen, 2020). A common building of high-level system development included end nodes which are the sensors, gateways, network server and application server. Below illustrated the overview of LoRaWAN system architecture to acquire and study the essential component for system development.

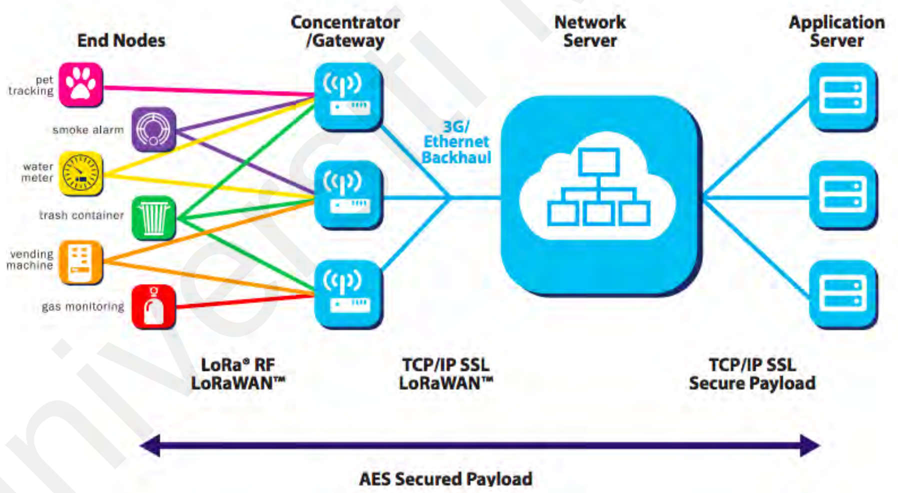

Figure 2.3: LoRaWAN Star Topology System Overview

LoRaWAN building system is specifically made for low power and wide area network protocol wirelessly designed for battery activated things focusing on IoT requirements on bidirectional communication, mobility, geolocation services, reliable end-to end security and global standardization. Furthermore, the cost effective of LoRa RF module embedded in end nodes collecting required data worth the investment on the developed system for the mass IoT industry.

2.4.1 LoRa Radio Modulation

Derivation from CSS modulation technique produce proprietary spread-spectrum modulation for LoRa to compromise the relationship between sensitivity and modified data transfer capacity. This chirp frequency bandwidth is equivalent with signal of spectral bandwidth. The carrier of data signal adapting into chirp carrier signal to be fragmented to higher data rate from end nodes to gateway. This chirp also not require expensive highly accurate clock since LoRa modulation generate chirp signal that continuously fluctuate in frequency to achieve the signal spectrum spread as represented in Figure 2.5. This works either at fixed bandwidth channel 125 or 500 kHz for uplink channel and 500 kHz for downlink channel. This method also generates equivalence of timing and offsets between transmitter and receiver hence reduce the complexity in designing the receiver. Furthermore, the variable error correction scheme implemented in LoRa modulation able to improve robustness in transmitted signal.

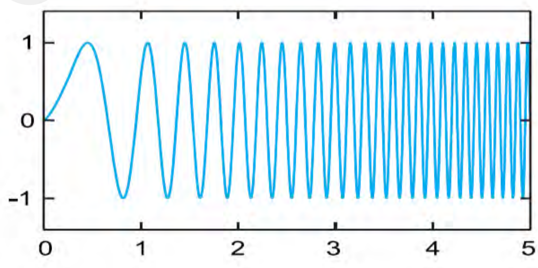

Figure 2.4: Chirp Spread Spectrum in LoRa Modulation

LoRa processing is gained within radio frequency channel using spreading code or chip rate to increase data signal for increment in total signal spectrum through frequency components. This processing assists in maintaining signal data rate but reducing power output level for transmission. Moreover, CSS implementing orthogonal spreading factor

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(SF) allow plausibility of synchronous transmission within similar channel frequency utilizing the diverse spreading factor to encode the information. The effect on frequency offsets that equals to timing offsets within the transmitter and receiver can be straightforwardly diminished in the decoder and acquire resistance to Doppler effect properties without interrupt decoder performance (Zhang, Zhang & Li, 2020). This effect contributes to non-requirement for extreme accuracy for crystal embedded in LoRa transmitter hence reduce the price for the transmitters. This spreading factor method also adapting optimizations of each nodes power levels and data rates allow battery life preservation while increases the efficiency of receiver to distinguish signal with even lower signal-to-noise ratio (SNR) by demodulate signals between -7.5 to -20 dB below noise floor.

Spreading factor play important role in LoRa modulation to ensure attribute of the services. Integration of spreading factor, bandwidth and coding rate conclude the practicable data rate. The data rate will be higher, and airtime is low when spreading factor in lower range. LoRa modulation possess total of six spreading factors from SF7 to SF12. The relationship of SF and BW deducing data rate (DR) expressed as equation (2) below.

$$DR = SF * \frac{1}{\frac{2SF}{BW}} \quad (2)$$

The further distances of end nodes from gateway, the higher spreading factor required for transmission cause increased in processing gain and sensitivity of reception while decrease in data rate. Table 2.7 LoRa show different spreading factor on message uplink using 125kHz channel including bit rate used to complement the estimated range which is dependent on the landscape and the dwelling time on 11-byte payloads.

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Table 2.7: LoRa Spreading Factors on 125 kHz Uplink Channel

Spreading Factor (For UL at 125 kHz)	Bit Rate/bps	Range/km (Depends on Topography)	Time on Air/ms for 11-byte payload
SF10	980	8	371
SF9	1760	6	185
SF8	3125	4	103
SF7	5470	2	61

Bandwidth, spreading factor and code rate are parameters to customize LoRa modulation. 2^{SF} chirps are the composition of LoRa symbol that covers entire frequency band. The symbol rate and bit rate are proportional to the frequency bandwidth trigger doubling the bandwidth that efficiently doubling the transmission rate. Data transmission for SF relationship with BW and duration of symbol (Ts) route to bandwidth BW is described as in equation (3) below.

$$T_S = \frac{2^{SF}}{BW} \quad (3)$$

The generated diverse data transmission differs from the difference in the spread factor, as the LoRa data transmission can be determined every second. The symbol rate is denoted by R_s expressed as in equation (4).

$$R_s = \frac{BW}{2^{SF}} \quad (4)$$

LoRa frame start at preamble that commence with a sequence of constant upchirps that envelop the frequency band and last two upchirps is encoded in sync word. Sync words are deciphered in one-byte value used to differentiate LoRa networks that using similar frequency band.

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LoRa modulation also implements low-rate data optimization which implemented in transceivers of Semtech. This property become compulsory when LoRa modulate using spreading factors of 11 and 12 paired with bandwidth of 125kHz or lower.

LoRa implemented at physical layer which at the lowest layer administrates the radio frequency signal aspects in transmission line between endpoints and gateway. The properties of signal managed included frequencies, modulation waveform, tolerable power level and specific frequency band (El-Saleh, Al-faisal & Al-Mamunur, 2022). The signal values gained at IoT platform must be suitable for the sensitivity level of transceivers. Below (5) reflecting aspects corresponding to the losses and gains during transmission operation with P_{rx} as the received power.

$$P_{rx} = P_{tx} + G_{tx} - L_{tx} - L_{rx} - L_{fs} - M + G_{rx} \tag{5}$$

Where P_{tx} is the transmission power and G_{tx} and G_{rx} are the transmitter and receiver gains, respectively. The L_{tx} and L_{rx} are representations of the loss antenna and cable connectors at the transmitter and receiver, respectively, including the loss due to environmental influence, L_{fs}. M represents the fading margin between the receiver sensitivity and signal strength level.

In free space propagation, attenuation occurs as the power spreads over the areas. The power flux, which is the signal strength, is calculated as shown in (6).

$$P_d = \frac{P_{tx}}{4\pi d^2} \tag{6}$$

The effective area of an isotropic antenna, G_e is used in LoRa, as shown in equation (7).

$$G_e = \frac{\lambda^2}{4\pi} \tag{7}$$

Equation (8) generate received power in free space.

$$P_{rx} = P_d G_e \tag{8}$$

$$P_{rx} = P_{tx} \times \frac{\lambda^2}{4\pi} \tag{9}$$

General path loss is adapting equation (10):

$$L_{fs} = P_{tx} - P_{rx} \tag{10}$$

Substitute equation (9) in (10):

$$L_{fs} = 20\log_{10}(4\pi) + 20\log_{10} d - 20\log_{10} \lambda \tag{11}$$

In free space, as λ (in km) = 0.3/f turn equation (11) into equation (12):

$$L_{fs} = 32.44 + 20\log_{10} d + 20\log_{10} f \tag{12}$$

The propagation path loss model of the earth plane entailed attenuation from the earth plane influence in Equation (13).

$$L_p = 40\log_{10} d - 20\log_{10} h_t - 20\log_{10} h_r \tag{13}$$

However, there are still non-definite specify path loss model to evaluate loss for Lora hence previous researchers implied and derived model from experiment data as an alternative based on different frequency, different standards and various of propagation condition (Parades et. Al, 2019). Previously, there were implementation of Lee propagation model in urban environment around cities at Newark, America that able to determine proper set of parameters for propagation performance of LoRa technology (Dobrilovic et Al, 2017). However, better evaluation at urban area can be obtained with the empirical Okumura-Hata model if the frequency of the radio link within frequency range of 100 and 1500 MHz (Saeed, Ali & Ali, 2020). The path loss of the wireless

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communication estimated from operating frequency (MHz), the heights of transmitter and receivers (meters), correction parameter, a(h_r) that affected by type of surrounding whether at urban or country area, and distance between transmitter and receivers (km) refer to below equation (14).

$$L_H = 69.55 + 26.16 \log_{10} f - 13.82 \log_{10} h_T - a(h_R) + (44.9 - 6.55 \log_{10} h_T) \log_{10} d \quad (14)$$

Where h_R and h_T are the receiver and transmitter heights, respectively. While f is the operating frequency (MHz); d is the distance between the transmitter and receiver, and $a(h_R)$ is the environment-dependent correction parameter. $a(h_R)$ for a major city environment (refer to (14)).

$$a(h_R) = 3.2[\log_{10}(11.75 \cdot h_R)]^2 - 4.97 \quad (15)$$

In previous work by Sanchez, the received power set at -120dBm as two LoRa transceivers were implied to ensure receiving function hypothetically within good margin and include all possible additive path losses (Sancehz-Iborra et Al, 2018). Applying Okumura Hata Model calculate the expected range by different output transmitted power of 0, 5 and 14dBm and operating frequency set to 865MHz. The recorded result from implied Okumura-Hata model shows the compatibility to be embedded in urban environment for Distributed Management System (DMS). The range can be extended with upgraded antenna that greater than 3.16 dB. In addition, considering the requirement for wall penetration and indoor application, the noise floor value specified is deduced in equation (16).

$$Noise\ Floor = 10 * log10(k * T * BW * 1000)dBm \quad (16)$$

Where,

k = Boltsmann's Constant

T = 293 Kelvin or room temperature

The modulation characteristics is different for each region as defined by LoRa Alliances in LoraWAN Regional Parameters Documents. Physical layer operates on 433, 868 and 915 MHz in ISM bands differing to the location at region deployed (Li, Liang & Chen, 2022).

Since LoRa had been recognized with its abilities in the air data transmission and operation within ISM band frequencies had attracted researchers and developers to explore LoRa modulations characteristics for further application in studies and industries. A lot of researchers had performed tests in its coverage range at different region on range limitation and performance on field test. Team from Mesh-Net had performed sight of range test across hills and proved the modulation reached around 15 km without attained any signal degradation, but the further range test was not performed due to time limit (Oliviera, Guardalben & Sargento, 2017). Some author intent to study the impacts of environment structure on LoRa performance and gain communication range of 5.6 km and 2 km for suburban and urban areas respectively (Petäjäjärvi et. Al, 2016).

Deliberating the application on IoT system around suburban area for Smart City development, CSS technology embedded in LoRa technically mentioned to be resistant to interference investigate by researcher (El-Saleh, El-Rewini & Kamal, 2020). The researcher analyzed the chirps function by portraying the way of chirps to be setup independently with number of orthogonal chirps and prove orthogonal CSS become for various applications. There were also authors that compared the performance of LoRa and Frequency Shift Key (FSK) for IoT applications in residential area. The author stated LoRa capacity is better than FSK in most every circumstance and emphasizes the transmission range of LoRa successfully up to 10 km in residential scenarios (Sanchez, Sanchez & Skarmeta, 2017).

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There were also researchers who studied the ability of LoRa to track moving human and found that it was not practical to trace a human trail in urban area. Researchers highlighted that 200m is the achievable packet reception rage and start losing packet at 600 m (Radclife et. Al, 2017). A propagation analysis of LoRa on underground soil to evaluate the electrical conductivity of soil had been presented by authors in their study. They declared rain effects on the successful packet reception ratio and the performance declined during heavy rains (Wan et. Al, 2017). Engagement of LoRaWAN protocol in next layer based on OSI Seven-layer network model allow increment of spreading factors at the end-devices if transmission with lower spreading factor fails. Maximizing the capacity of network through adaptive data rate (ADR) that used to reduce battery power consumption of LoRaWAN end nodes. Transaction between battery power and distances initiate higher spreading factor to let connection gateway to end-nodes that located at distant allow triumph at higher delivery ratio.

2.4.2 LoRaWAN Network Protocol

LoRaWAN is open networking protocol that obligate for securing bi-directional communication, mobility and services as regulated and sustained by LoRa Alliances (Kumar, Kumar & Kumar, 2022). It is constructed to simplify MAC architecture to reduce any difficulty of end devices and network. Located at MAC layer as shown in Figure 2.8 developed for employing LoRa physical layer. This platform allow connection for wireless sensor networks to exchange packet data with server through LoRa frequency radio modulation at low data rate and implied time intervals.

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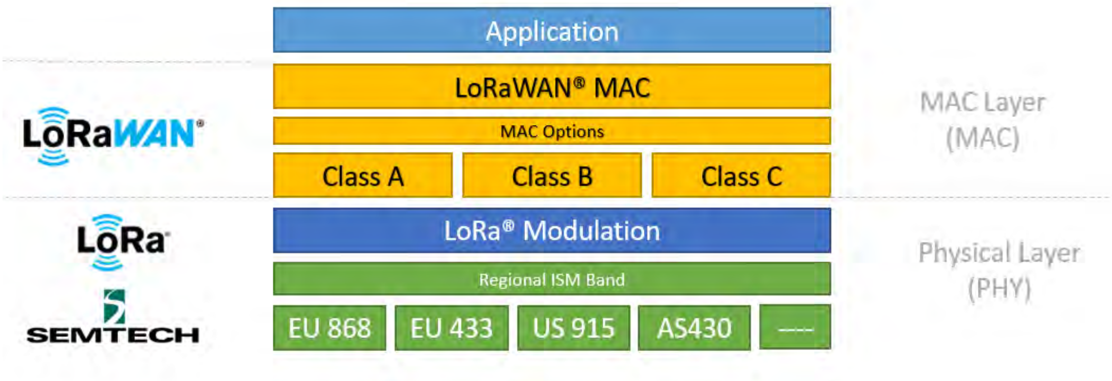

Figure 2.5: LoRaWAN Network Protocol

Connection to LoRaWAN network required components which are end-devices, gateways or known as base stations and the network server as indicated for LoRaWAN specification. Deploying star topology architecture manipulating gateway to act as transparent bridge between end devices and platform server for message relaying. Gateway that connected to network server applying standard IP connections by convert radio frequency modulation packet onto IP packet and vice versa. Noting the IP traffic is backhauled through Wi-Fi, Ethernet or Cellular connection for transmission from gateway to network server. Henceforward, end devices are linked to LoraWAN network server that obligate to distinguish repeated packet and select the suitable gateway that operate at end of physical layer to forward LoRa radio messages with the best Received Signal Strength Indicator (RSSI). RSSI estimating power level measurement of any possible loss signal to indicate the performance of device on hearing, receiving and detect signals from remote connected client radio.

Commissioning and activation devices on the network at beginning of operation is required for security verification in protecting network protocol and user data, authorizing the service quality, costing and etcetera requirement. The networks and each end device are ensured to be affiliated in commissioning process with detailing on crucial provisioning parameter such as encryption keys, identifiers and server locations.

LoRaWAN offer two types of activation which are Over-the-Air-Activation (OTAA) and Activation by Personalization (ABP). Table 2.7 present summarize the difference for both OTAA and ABP type respectively.

Table 2.8: Activation Types of LoRaWAN

OTAA	ABP
Manufacturers of the device autonomously provide essential provisioning parameter.	Less secure and simplified commissioning process.
Secure keys can be renewed regularly.	IDs and Keys are personalized fabrication.
Allow devices to store multiple identities that can be securely switch network and its operators along its lifetime.	Join procedure is skipped as devices powered up immediately functioning.
Options are available for tamper-proof security and high-grade.	- Devices are bind to a specific network. - The NetID is a portion of device network address.

LoRaWAN reflects the application address, downloading, and energy constraints. It planned three classes for downlink communication: Class A, Class B, and Class C. All LoRaWAN end devices support the default Class A, whereas Classes B and C are optional. Class B mode scheduling initiates downlinks from periodic beacons and gets network windows with regulated latency. The Class C mode leaves receivers of end devices open except during transmission, resulting in fading of latency (Liu & Chen, 2020). A summary of the class mode applied by the LoRaWAN is shown in Figure 2.9.

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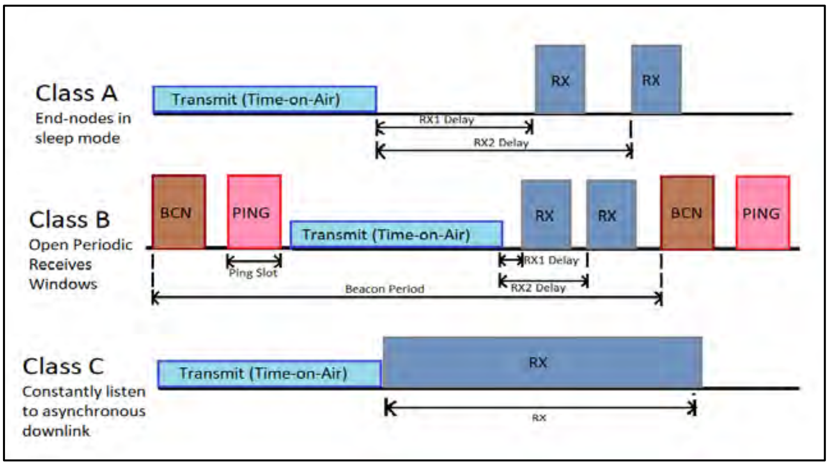

Figure 2.6: Summary of LoRaWAN Downlink Communication Class

Class C mode initiate the downlink transmission at any time from the network server while conjecturing state of end devices open resulting in no latency. Nevertheless, this mode cause power drain of the receiver hence more suitable for continuous power application. Though, it is still applicable for battery-powered devices by temporarily switching mode between Class A and Class C and it is effective for intermittent projects like updates of firmware over-the-air. Gateway deployment density is greatly depended for system resolution. Ertürk et al. discovered that the performance of LoRaWAN on successful packet transfer is affected by huge numbers of end-nodes after modeling the Class A mode on the MAC layer using MATLAB.

LoRaWAN network promote geolocation by applying RSSI or Time Difference of Arrival (TDOA) methods from 200m to 20m resolution without depend on any additional hardware (Ahmed, El-Sheimy & Rafaat, 2020). The determination of end device location not specifically require any specific frame or protocol message and it is sufficient by any received data frame by at least 3 gateways. As GPS coordinates of the gateways is fixed and recognized, the node location can be extracted by GeoLocation solver using TDOA. The LoRaWAN inbuilt GeoLocation function become an alternative to reduce energy consumption from GPS modules and cost of additional hardware.

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The LoRaWAN is known to suitable with most applications but since the networks applied ISM frequency bands that known being free and not require specific license, it is limited for private network solutions. These bands are regulating its maximum transmission power and duty cycle. Duty cycle limitations is decoded as delays between successive frames received by a device. The main limitation is at 1% duty cycle in most cases and a device have to pause until at 100-times the duration of the last frame before transmits at the same channel. Furthermore, the collaboration between multiple gateways trigger interference causes traffic in the network but the attenuation is possible through limit the amount of downlink and have specific channel differ to its purpose (Mukherjee et. Al, 2022). Authors from Turkey test the efficiency of LoRaWAN performance as there were designed issue of its performance when involving high number of end nodes. The simulation by implementing MAC layer operated in Matlab with configuration using A Class mode and resulting in the increment number of nodes affecting the transmission of successful packets (Ertürk et Al, 2019). There were also where authors studied traffic generation for LoRaWAN by evaluating radio transmission interference in node to gateway from generated traffic and concluded the gateway can be affected by unexpected data outburst (Delobel, Rachkidy & Guitton, 2017). Since LoRaWAN implement star topology network, previous researchers investigate the alternative approach to extend the conduct by analyzing concurrent transmission flooding mechanism to multi-hop networking LoRa for indoor performance enhancement (Liao, Kuwabara & Fujimoto, 2020).

2.4.3 LoRa and LoRaWAN Application from Previous Study

Providing services that can operate and extended at large range and low energy consumption with free licensed cause industry and academia to target LoRaWAN as wireless connectivity standard for IoT. LoRaWAN protocol had been implemented in IoT

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applications since the protocol is publicized in 2015. LPWAN technologies is famous for Smart Cities, Smart Farming, Monitoring Environment condition, Smart Grids and Smart Healthcare (Alippi, Borghi & Farella, 2020). Many scholars had associated LoRa with various applications for environmental monitoring and one of them presented the environmental changes by designing system that able to keep on track with floating-point cases for rivers and seas (Zhang, Li & Li, 2022). While other authors were presenting its result experiment on river quality monitoring on air and water temperature, river depth, barometric pressure and energy supplied from solar performance (Zhang et Al, 2020). At Switzerland, researchers had developed prototype of river level node for flood early warning system alerting on Twitter using LoRa as data transmitter with receiver node located at 500m away from sensor node without losing any data packets (Leon et Al, 2018). There was also a proposal on application of LoRaWAN network on drone to monitoring river water quality to compare the efficiency from manual labour and provide real-time result to be analysed (Singh, Singh & Singh, 2019). A study on monitoring wildlife had been demonstrated by previous researchers using LoRa can obtain up to 2% frame loss at distance of 5.5.km with power of 20dBm (Wotherspoon & Althaus, 2017).

Tanumiharja implemented LoRa for water level monitoring using WSN for system designed for cattleman to monitor manger ubiquity from their personal devices for Smart Farming function. Through measuring bandwidth from varying the distance of nodes and gateway at 8 m high on top of the house causing conclusion made by authors requiring horizontal antenna polarization for this design. Furthermore, a development on system that can stay online till approximately 5 years with 400 mAh for perceiving cattle heat using LoRa by researchers could be extended over 10km (Bellini et Al, 2018). Academics from Italy evaluated their built LoRaFarm which is an architecture of Modular IoT based on Smart Farming using LoRawAN to improve the management of generic farms in highly modified method testing at real farm. The developed system managed to collect

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relatable data on air and soil temperature and humidity to analyze the factor for farm products growth for three months period (Codeluppi et Al, 2020).

Moving towards Smart City development, industries and academia aim to produce mechanisms that able to support this urbanization applying wireless connection technology to enhance way of life while sustaining the environment. Teizer and Mostafavi built real-time positioning for construction sites by employing LoRa as data communicator to enable data collection and exchange for construction applications. The system was used to monitor and track the resources in construction logistics to support the goal of the industry to reduce waste production and they concluded the capability of LoRa to record and analyze big volume of data of construction is achieved. Besides that, other researchers had deployed LoRaWAN to measure greenhouse gas emissio3 around Nordic cities on their continuing project. The constructed system measuring CO2 levels using two sensors technologies for 6 months powered up by battery forwarding received data to alert citizen (Ahlers, 2020). Entailing on IoT fundamental role, developer at India had developed smart parking system to detect parking availability based on LoRa to be viewed from Android phone using TTGO-ESP32 LoRa as transmitter (Kodali, Kumar & Suresh, 2020). Moreover, there were debate among researchers to implement LoRa for solid waste management system and being argued on reflecting the radio frequency mesh network is more proficient for private setting however LoRa is the sufficient solution when entangle with inter-probability scenario (Bharadwaj, 2020).

Smart Grid application industry taking interest in LoRaWAN integration as its modulation technique known for lower power wide area that perfectly suitable for large scale function. Previous authors had used sensor network configuration defined from LoRa parameter to evaluate the use of LoRa in Smart Grid context in various scenarios. Findings from their investigation presented that LoRa performance affected by quantity

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of nodes shown by negative correlation between Data Extraction Rate (DER) and volume of nodes consequently increase power consumption. Though, LoRa network is discerned not highly affected by distance between base station (Abassi, Ben & Sghaier, 2020). Additionally, researchers found that LoRa is the most feasible network for controlling remote SCADA system in energy-saving manner after analyzing and comparing LoRa, RadIoTeletype and Very High Frequency (VHF) wireless technology (Tershmila, Iqbal & Mann, 2017).

Promotion of Healthcare System based on IoT is widely used for its potential to track and monitor patient physical health data. Though there had a claimed that LoRaWAN is not suitable for health monitoring due to the requirement for immediate feedback loop, authors at Malaysia had developed human body signal monitoring system through biomedical sensor to collect data information and conduct analysis on patient state using LoRa and MySignal platform. The accomplishment of their study presented by the effectiveness of system performance in obtaining human body data that fit with IoT based healthcare solution (Shahidul et Al, 2019). Recent issue of SARS-CoV 2 virus trigger awareness on isolation and causes difficulties to follow up health condition for elderly people that living by themselves. Henceforward, authors had proposed IoT concepts system to monitor and support elderly people through LoRa communication accessing on allowing family member, neighbours, security force and authority to acquire information on the health condition, the necessity and the circumstance of habitability of system user. However, they found the limitation on the designed system due to availability of weak network of gateway in the region and constraint on LoRa capability on sending large volume of data nor permanently connected with high recurrence hence improvement is required to allow the system operate as desired (Lousado & Antunes, 2020). Besides, previous study from researchers had built eHealth device to evaluate the suitability of LoRaWAN in eHealth application. They discover that this network is adequate to track

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on measuring the timely basis health data such as weight or glucose level and etcetera but Frame Air Times and moderated duty cycle is crucial for real-time patient tracking (Buyukakkaslar & Aydin, 2020).

Different applications and scenarios resultant in different ability of LoRa and LoRaWAN performance outlined based on previous cases study. The wanted output and performance can be acquired when the application is operating perfectly harmonized with LoRaWAN advantage stay in power and cost effective. Though, improvement is required to improve the capability of the system for better future services in various industries. Contrarywise, when the system built linked to the disadvantages of LoRaWAN affecting the system performance whether on frame loss or crash in duty cycle and etcetera cause result gain is not desired as in the system proposal. However, there were arguments on possibility of improving the LoRaWAN network to be utilized effectively in the developing system to function and robust as desired by the creator and stakeholder.

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2.4.4 Summary of Literature on LoRa Application in Various Setting

Table 2.9: Summary of Literature Review on LoRa Application Investigated by Previous Researcher

LoRa Implementation Review from Previous Study				
Author	**Year**	**Method and Study**	**Discussion**	**Conclusion**
Paredes, M., Bertoldo, S., Carosso, L., Lucianaz, C., Marchetta, E., Allegretti, M., & Savi, P.	2019	- Propagation measurement for in urban environment	- Determine set of parameters for propagation performance. - Predicts interference during transmission.	- Empirical Okumura Hata Model improve the evaluation of interferences
Dobrilovic D, Malic M, Malic D, et al	2017	- Lee Propagation Model simulate LoRa behaviour in urban areas. - COMSOL Multiphysics software for signal simulation.	- The Lee model neglects multipath fading and urban obstacles in signal propagation	- Lee model approximate signal propagation in urban area with good calibration.
J. Petäjäjärvi, K. Mikhaylov, A. Roivainen, T. Hänninen, and M. Pettissalo,	2016	- Analyse the throughput of LoRa link - Analyse doppler effects on LoRa radio performance. - Assess LoRaWAN communication range by evaluating gateway coverage	- Distribution of the end devices within cell limit the LoRaWAN scalability solution. - Low SF least affected by Doppler effects, suitable for mobile scenarios. - 14 dB transmission power and SF 12 enable over 60% packet data transmission up to 30km range.	- Suitable for monitoring and actuating applications. - Deliver SF, bandwidth, and modulation schemes.
Leon, E., Alberoni, C., Wister, M., and Hernández-Nolasco, J.	2018	- The WSN deploys high-precision ultrasonic sensors for water distance and mass measurement with RF 915 MHz. - Alert the user through Twitter.	- Receive nodes that located 500 m without lose any packet data. - Collected data had margin error or 1 cm at certain time but still accurate.	- Additional of protocols to the EWS prototype is for mesh functionalities and security purposes.

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Codeluppi, G., Cilfone, A., Davoli, L., and Ferrari, G	2020	- Ad-hoc-level module applied to provide middleware the transmitted sensor data from farm area.	- Deployed nodes able to transmit data accurately for 3 months observation. - Location in the greenhouse and vineyard affects sensor node results. - Few samples lost during rainy day due to lack of solar light.	- LoRaWAN architecture, built around middleware and ad-hoc modules for Smart Farming applications.
Teizer, J., & Mostafavi, M.	2020	- A LoRa gateway installed at the construction site. - The System uses RSSI and TDOA to estimate LoRa device location.	- LoRa able operate in harsh environments undergrounds or buildings. - It improves site construction logistics by tracking equipment, personnel, and materials on time.	- Real-time visibility into equipment location enhances the safety. - Delays was reduced and improve project timelines. - It also optimize the equipment allocation and scheduling.
Ahlers, C.	2020	- A measurement-driven approach was used to estimate urban greenhouse gas emissions in Nordic cities, focusing on CO2, CH4, and N2O emissions. - Field measurements were combined with data on energy use, traffic, and waste management to estimate sector-specific emissions.	- The energy of battery recharged assisted by streets light. - Measurement-driven approaches improve emission inventory accuracy.	- Provide accurate data for air quality indicator. - Make Nordic cities urban greenhouse gas emissions insights accessible to municipals and citizens.
Kodali, P. K., Kumar, P. S., & Suresh, G.	2020	- Employ ultrasonic sensor for vehicle detection.	- The data from WSN of ultrasonic sensor received by	- The system benefited for driver for lack of parking spaces.

	2020	- TTGO LoRa receivers located near to parking lot. - Parking availability viewed in Android application.	LoRa transferred to cloud (IBM Watson). - Data can be inspected via IP address on an Android phone.	
Abassi, A., Ben Ghezala, H., & Sghaier, H.	2020	- Utilize LoRa in smart grid application and simulated in various scenarios.	- LoRa sensitives to number of nodes. - Energy consumption increase due to increase in number of nodes. - Applying directional antenna can approximately fixed the DER value.	- LoRaWAN affected from mostly from number of nodes, energy consumption and interference. - Study directional antenna might assist the problem on network interference.
Shahidul Islam, M., Islam, M., Almutairi, A., Beng, G., Misran, N., and Amin, N.	2019	- MySignals development shield deployed LoRa to operate with ECG sensor, body temperature, pulse rate and oxygen saturation. - Physiological data analysis and statistical method used to analyse the effectiveness of sensor and wireless platform.	- MySignals succefully integrated with ECG, temperature, oxygen saturation and pulse rate sensors. - LoRa mesh topology for large area reach 88.49% success while star topology reach 58.7%.	- LoRa is compatible with highest number of sensors used system at low energy consumption. - LoRa suitable for IoT based healthcare.
Lousado, J., and Antunes, S.	2020	- Monitor health of elder people using LoRa. - The GUI show information on health and basic circumstances.	- Allow family members and authorities to gain information on elder condition in real time.	- High repetition caused from permanent connection. - LoRa capability was constrained due to low coverage of LoRa in that region.

CHAPTER 3: METHODOLOGY

3.1 Overview

Development of LoRa in network industry improve IoT application for devices integration towards Smart Earth solutions vision. Furthermore, the water quality monitoring system is associated with SDG 6 from SDG agenda for water quality ambience improvement. Real-time results allow decision makers identify the state of water bodies to protect both ecosystem and human health. This study develop the system of autonomous water quality monitoring based on IoT architecture with LoRa as its communication system. This chapter discussed the method, development process and limitation to build the prototype of continuous water quality monitoring system. It also describes the type LoRa network properties to be analyzed in this study.

3.2 Flowchart of Study

The progress of the research is simplified as in flow chart in Figure 3.1. This research began from reviewing work of previous researcher on water quality monitoring, system application based on IoT architecture and LoRa employment study. After determine the network properties to be observed, the first development involves the different of setup LoRa network parameter on SF and antenna gain to the end-node. The designated water quality sensors were embedded with the end-node. The system was integrated to the gateway and the water quality monitoring station was designed and developed after output of water quality data was verified. The water stations then were situated at their planned location. The LoRa network performances were evaluated to select the parameter of LoRa to be implemented in water quality monitoring station. The water quality monitoring dashboard were designed and developed to display its result extracted from the cloud integrated with gateway. The classification of water quality is concluded from the analysis of water quality data. The evaluation of LoRa network properties also were analyzed and discussed to determine its ability for future reference.

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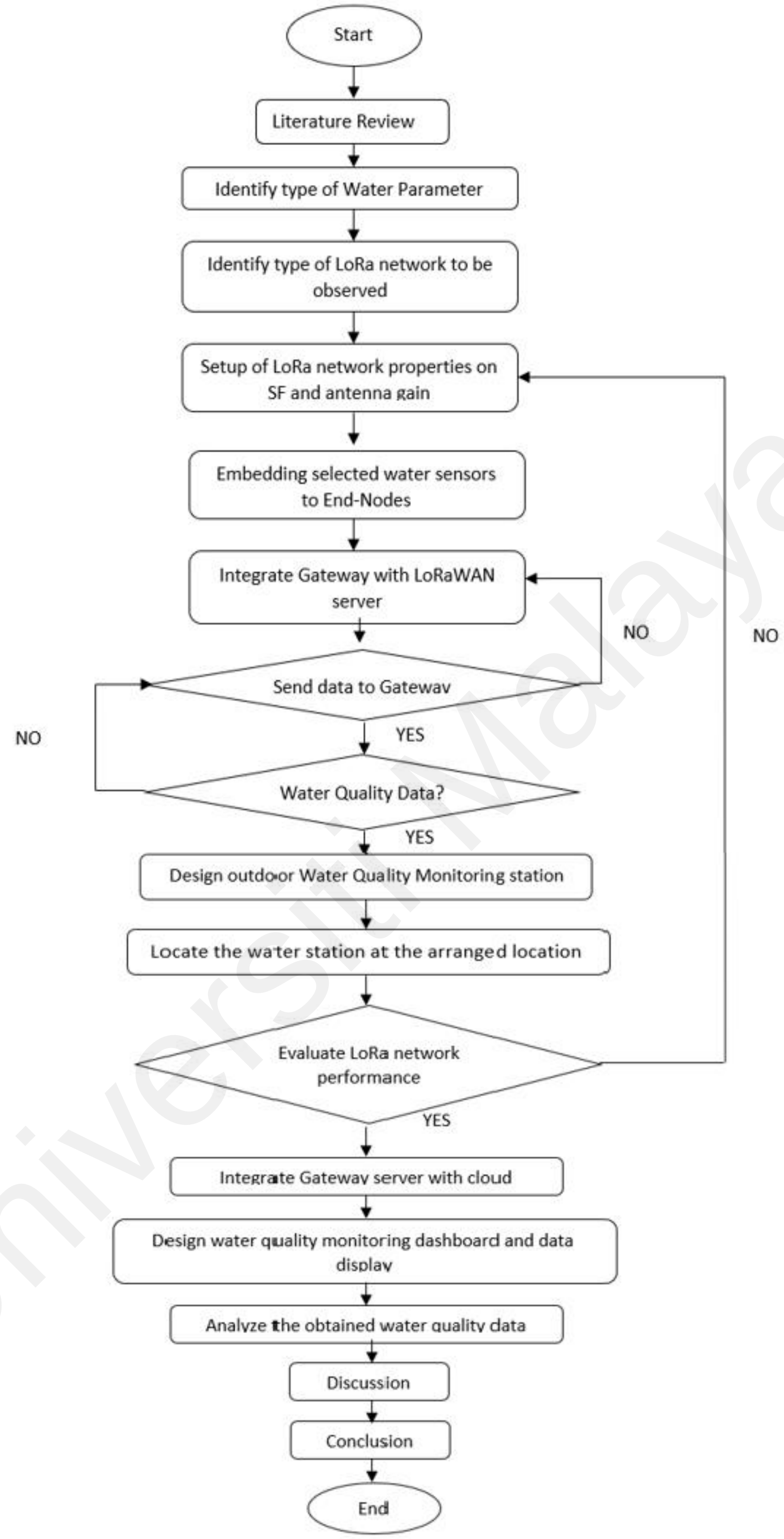

Figure 3.1: Process of Water Quality Monitoring System with LoRa Implementation Study

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3.3 Water Quality Monitoring System Architecture

The type of water sensors embedded in the continuous water quality monitoring system were significant to water properties based on guides and regulations of WQI, NWQS and WHO target of 6.3: Water Quality and Wastewater. The reliability and durability of sensors to operate in water environment continuously referred from recommendation of previous researchers and specification and datasheet from DFRobot (Zhang, Li & Li, 2022) (Patel, Patel & Shah, 2022). Table 3.1 listed water quality sensors assembled in water quality monitoring station prototype.

Table 3.1: List of Water Quality Sensor

Water Quality Sensor	Functions
SEN0237 Dissolved Oxygen	Examine amount of oxygen volume for aquatic living
DS1820 Temperature	Variable for others water properties
SEN0189 Turbidity	Water Opacity
PRO SEN0169 pH Meter	Acidification
SEN0244 TDS	Salinity and Total Dissolved Solid

Water sensors were embedded to the microcontroller board, ESP32-LoRa32 that act as end node, the integrator between physical realm and digital realm through wireless network. The end node able to operate at frequency of 868/915 MHz with transmission power that can be regulated up to 20 dBm. The device deployed Frequency Shift Keying (FSK) modulation mode equipped with data rate of 1.2 Kbps up until 300 Kbps. Table 3.2 described the parameter setup for end nodes in this research.

Table 3.2: LoRa End Nodes Parameter Setup

Parameter	Value		
Spread Factor	7	9	12
Bandwidth (kHz)	125		
Frequency Plan	868/915 MHz		
Transmitted Power (dBm)	14		
Antenna Gain (dBi)	3		
Data Transfer Rate (kbps)	5.47	1.758	0.25

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The SF in this study deployed three different values for analyzing its advantages from each distance to the gateway. It also known the data transfer rate based on different SF will give a different performance based on its condition as mentioned in Chapter 2 (Mnguni, S, 2021). Hence, this study analyzed the significancy change of SF in adapting the urban environment for water quality monitoring.

Next, the water quality monitoring assembled water quality sensors and LoRa end nodes with power supplied from 6W 6V polycrystalline solar panel station. Figure 3.2 and 3.3 display the design prototype of water quality monitoring station.

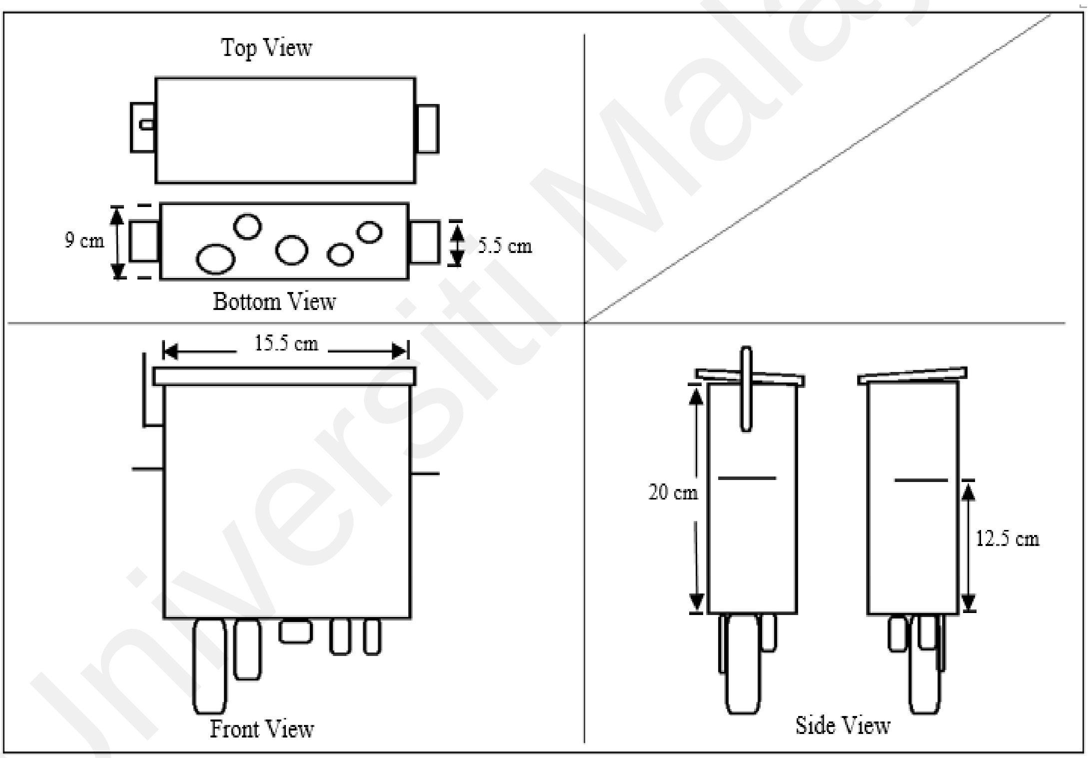

Figure 3.2: Block Diagram of Orthographic View on Design of Water Quality Monitoring Casing

Figure 3.3: The Prototype of Water Quality Station

3.4 LoRa Gateway Configuration

The LoRa gateway basic station was deployed through Raspberry Pi 4 with RAK2245. It is based on Semtech® 1301 that able to manage packets from many remotely dispersed end-points due to the dual SX1257/58 front-end chips. It is a full-fledged of eight channels of LoRa concentrator that was improved from previous generation of RAK831 product. Furthermore, the transmitting power can be adapted to 27 dBm while the sensitivity of receiving power can be lowest as -139 dBm at SF 12 and BW 125 KHz. It also has better resistance to noise due to the improvement in chain filtering of RF.

As Malaysia is within Asia region, the gateway was set to operate with the supports global license free frequency band AS920-923 Class A as referring to The Thing Stack Documentation. The selected antenna gain for gateway used in this research 5.8 dBi to has bigger spread and greater range in perceiving the transmitted data in urban environment. Figure 3.4 display the employed RAK2245 LoRa gateway.

Figure 3.4: RAK2245LoRa Gateway

The LoRa gateway deployed with Balena io. and connected to The Thing Stack V3.16.2 that runs the newest Semtech Packet Forward protocol. The data of water quality were transmitted to The Thing Stack V3.16.2 through LoRa gateway. The data of water quality can be viewed in live data activity as in Figure 3.5 below. Here also shown the RSSI and SNR included sent uplink and received downlink that can be used observation of packet loss.

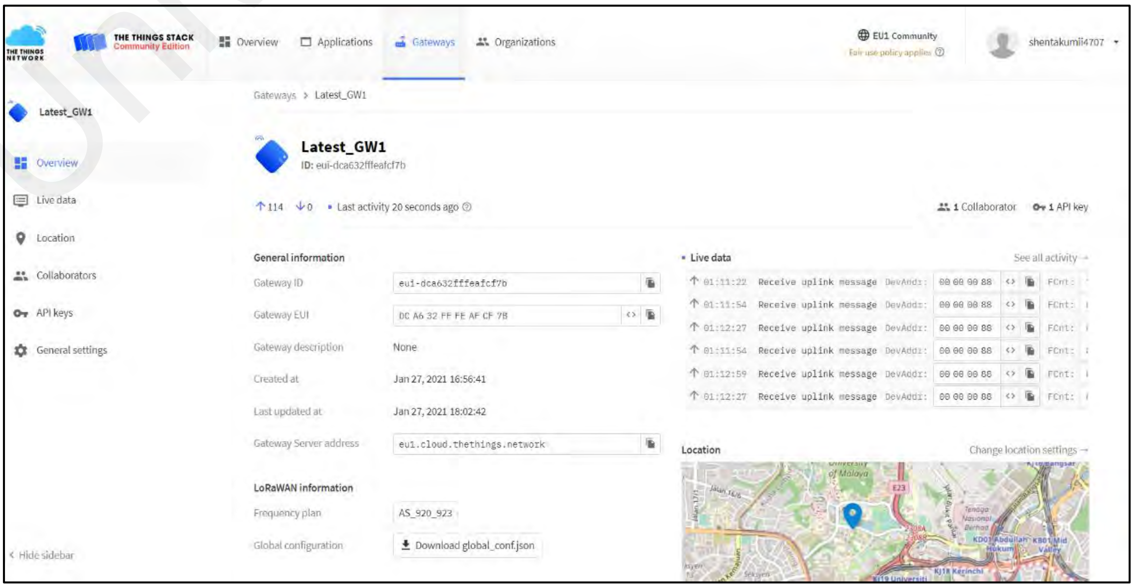

Figure 3.5: The Thing Stack Dashboard

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3.5 Experiment Setting

The experiment was carried out at both river Sungai Anak Air Batu and Sungai Pantai within University Malaya. The gateway located on the top of roof of Block C Faculty of Engineering with height estimation of 25 m from the ground and three water stations embedded with LoRa end nodes located floated in the river as shown in Figure 3.6 and Figure 3.7 respectively.

Figure 3.6: LoRa Gateway on Top of the Roof

Figure 3.7: Floated Water Station in the River

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First water station P1 was located at Sungai Pantai while water station P2 was located at Sungai Anak Air Batu and P3 water station located at end meet of both rivers. The distances of water station from the gateway denoted as in Table 3.3 and illustrated as in Figure 3.8.

Table 3.3: Distance of End Nodes from Gateway

End Node ID	Distance (m)
P1	117
P2	1560
P3	566

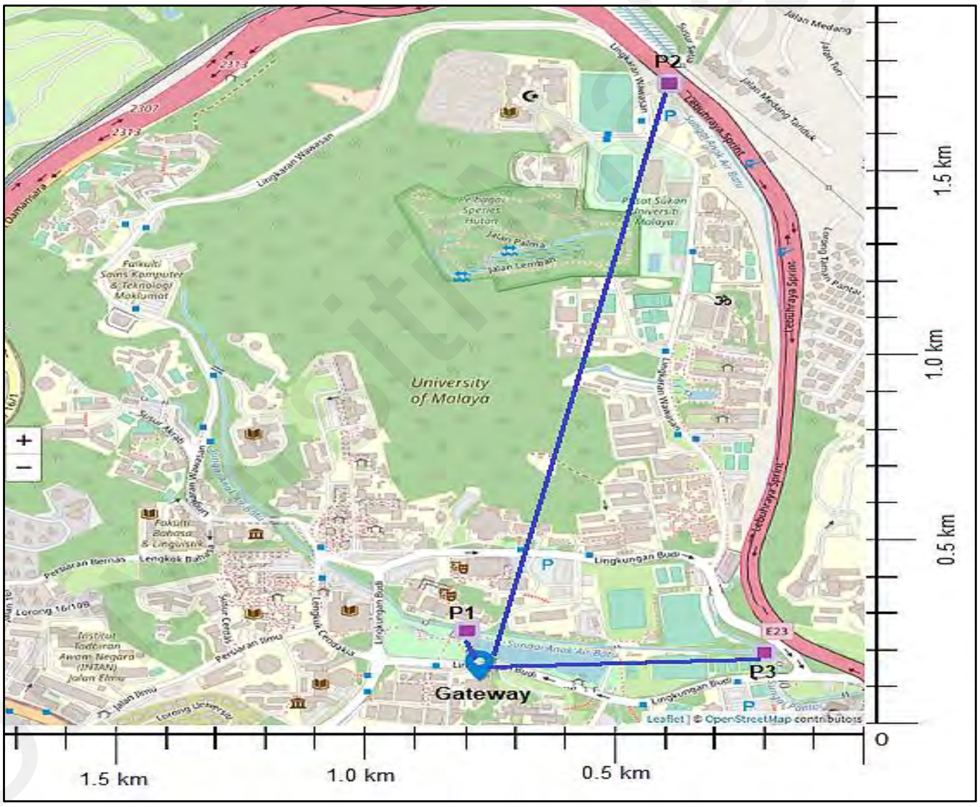

Figure 3.8: Water Station and Gateway Position in Residential Area.

The distance of water stations from gateway were less than 2 km due to estimation area of Universiti Malaya is within 2 km². The accuracy of data is will be probably as the distance is less than 2 km is relatively short for each water station. However, considering the existence of LOS between transmitter and receiver affecting the propagation

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management. Previous testing from previous paper allows the adjustment of lora node, the antenna and gateway configuration as in Table 3.2. However, the measurement technique of distance also affecting the data accuracy hence this distance of this study obtained from the displacement of the nodes from the gateway.

Significant to the quantity of end nodes and gateway in this experiment, star topology was applied as it is simpler and less expensive to be implemented. Furthermore, it not required full time alert for end nodes and allow them to fall into sleep mode. Hence, it minimized power consumption on end nodes and prolonged the life of battery.

3.6 Precaution Step

Reflecting the test will be conducted in outdoor and irregular river environment, a few preventative measures were taken. The floating cage design for water station protect the sensor from contact with the ground when the water level decrease with the determined height of as shown in Figure 3.3. Since the water station can from can be removed the floating cage for maintenance purpose as mentioned previously, the lock kit as shown in Figure 3.9 was used to keep the water station intact with the cage for safety purpose from change of water speed and erratic scenario of in-situ water monitoring.

Figure 3.9: Locking Device for Water Station with Floating Cage

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3.7 Water Quality Monitoring Dashboard

The Things Stack live dashboard that was integrated with LoRaWAN server through version MAC V1.0.2 of LoRaWAN visualized the selected properties of water quality data, RSSI, SNR and packet loss for LoRa performance validation. The Thing Stack server was trained to be integrated with Thing Speak for data preview activity in its dashboard and data storage. The data also will be extracted directly from Things Speak for analysis purposes on water quality status and classification. An alternative mode for obtaining the status of water quality parameters directly through the developed Android APK application named Water_Quality_TestView through MIT Inventor developer. Result in the Android dashboard extracted from data store in Thing Speak obtained through The Thing Stack Server. The developed Android dashboard demonstrated as below figure.

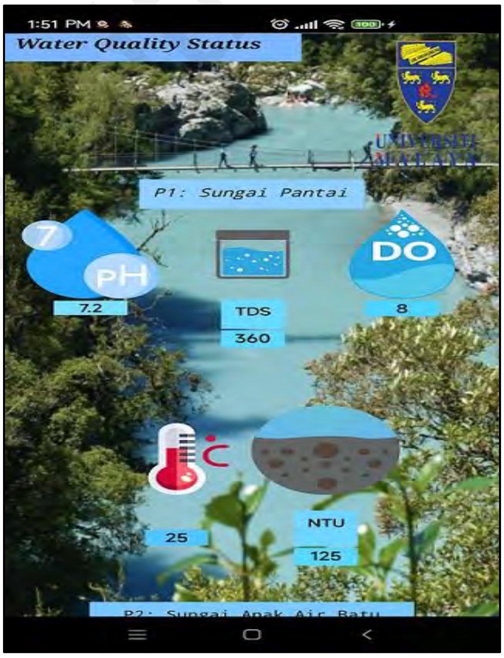

Figure 3.10: Dashboard of Water Quality Status through Android Application.

However, there are few limitations sin MIT App Inventor as it limiting the optimization of underlying code and unflexible. Hence, the output shown in this App

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recording the average of median filter of water quality monitoring data suitable for normal user.

3.8 Water Quality Data Classification

Collected water quality data that was extracted from monitor preview dashboard. As every water quality parameter taken is important for water status classification, every water parameter undergo data pre-processing to be transformed into structure set of data for classification analysis through cluster method that define its group from its statistical features. The result from cluster will pre-classify the water class and drinkable purpose based on WQI information from DOE. Below Figure 3.11 visualizes the flow of water quality data analysis process.

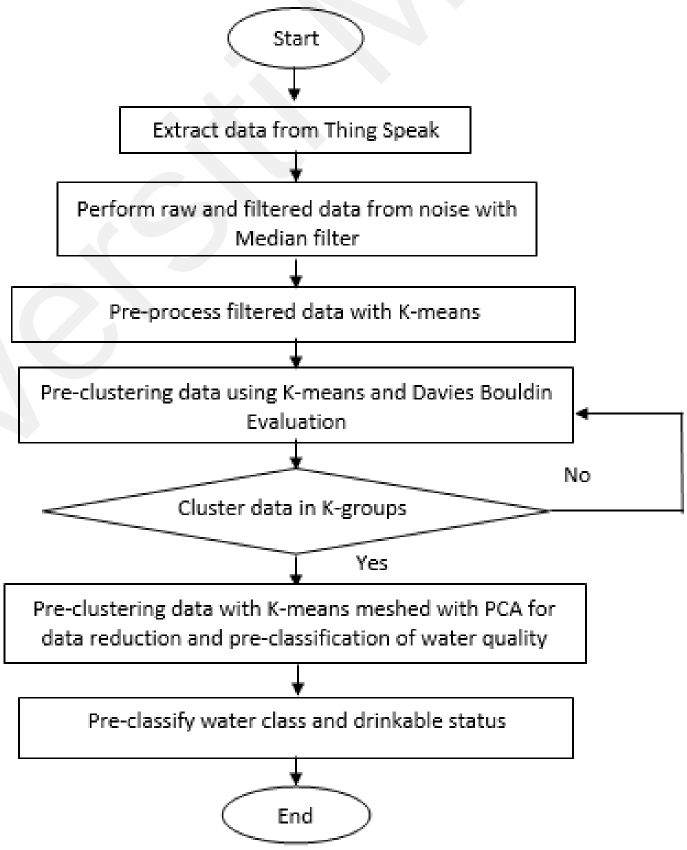

Figure 3.11: Flowchart for Water Classification Process.

K-means algorithm used in this study to approach the point of closest cluster and recognize the centroid of every cluster of water quality level classification. K-means also

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able to identify the patterns in filtered water quality data in its behavior and water sensor type. The results from K-means pre-clustering were meshed with Principal Component Analysis (PCA) to improve the quality of group pre-clustering from K-means by removing unnecessary outliers.

PCA helps to focusing on the most important feature in every type of water quality data thus reduce its complexity. Explained variance is function of ratio of related eigenvalue and sum of eigenvalues of all eigenvectors. The number of N eigenvectors, the explained variance for each eigenvector (principal component) can be expressed the ratio of eigenvalue of related eigenvalue, λ_i and sum of all eigenvalues as in equation (17).

$$\frac{\lambda_i}{\lambda_1+\lambda_2+\cdots+\lambda_N} \tag{17}$$

In the case of principle component analysis (PCA), the covariance matrix is the result of the eigen decomposition of the transformation matrix, which contains a set of eigenvectors and associated eigenvalues. The principal components that comprise the majority of the information conveyed by features are represented by these eigenvectors. The percentage of variance explained from proportion of variance explained and its overall variance estimation explaining the data accuracy. The mesh also used to interpret water quality group for pre-classification its class based on its pattern.

3.9 LoRa Network Performance Evaluation

The changes in LoRa parameter and environment attributes influence its network performance. Hence, network performance evaluation able to validate the implementation of LoRa network to serve its purpose in its application. There were several network

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properties that were analyzed in this experiment to determine the capability of LoRa in continuous water quality monitoring purposes described in this chapter. This chapter describes the importance of network properties selected for observation purposes in this study.

3.9.1 Received Strength Signal Indicator (RSSI)

RSSI is relative received strength signal for wireless environment. It estimated measurement of radio signal strength of receiver during transmission from transmitter. The importance of RSSI measurement is to study the capability of a device on listening signal from the transmitter. The received signal power in milliwatts and commonly in negative value measured in dBm. The higher the value of RSSI near to zero, the better the signal strength.

The value of RSSI depend on the type of location, variable of Line of Sight (LOS) and distance from node to the receiver. Hence, the distance between the transmitter and receiver, affecting the signal strength. Signal strength also affected by the energy of background noise and desired signal that may cause communication errors. RSSI also mainly influenced by location, Line of Sight (LOS) variable, n, distance between the node and receiver, d, and default received power at 1 m distance, A, as shown in equation (17).

$$RSSI = -10n\log_{10} d + A \tag{17}$$

The background noise affecting the signal strength causing error in communication. The impact of noise affect can be eliminated through Expected Signal Power (ESP) equation (18) below.

$$ESP = RSSI + SNR - 10\log_{10}(1 + 10^{0.1SNR}) \tag{18}$$

Metric above also used as indicator to measure the actual received power.

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3.9.2 Signal Noise Ratio (SNR)

SNR is a concept of wireless functionality qualification by distinguishing received signals from impractical background signal within the spectrum. It determined from the ratio of received power signal to the noise floor. SNR usually expressed in decibels (dB) and can be defined through equation (19).

$$SNR = \frac{P_{Sn}}{P_n} \tag{19}$$

Measuring the ratio in watts is defined as in equation (20).

$$SNR\ (dB) = 10 \log_{10} \frac{P_{Sn}}{P_n} \tag{20}$$

Where P_{Sn} is the signal power, and P_n is the noise power. The signal quality enhanced when signal power is higher than noise power allow receiver to demodulate the signal. Signals that below noise floor exposing data to corruption hence required retransmission between the transmitter and receivers. When SNR turn to 0 since it unreadable as it was generated from the equality of P_{Sn} and P_n expressing the signal is contending with the noise level. These frequent errors will reduce the data speed and thus require retransmission of packet data. As retransmitted signal require airtime in wireless environment, it degrade wireless throughput and latency. Hence, it is ideally when P_{Sn} is higher than P_n to minimize the noise interference. Opportunely, LoRa technology offer an ability to demodulate signal below noise floor depend on its spreading factor with its minimum SNR as shown in Table 3.4 below.

Table 3.4: Minimum SNR Value at different Spreading Factor

Spreading Factor (RegModulationCfg)	Spreading Factor (Chips/Symbol)	LoRa Demodulator SNR (dB)
7	128	-7.5
9	512	-12.5
12	4096	-20

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Table 3.4 also show the significant difference SF to adapt the environment based on its ability on SNR as it directly related to data transfer rate. The values of SF can be changed differ to its purpose and advantages. A higher SF means a longer spreading sequence that can provide better resistance to interference and multipath effects. However, it also increases the complexity of the system and reduces the data rate. A lower SF means a shorter spreading sequence, which is faster and more efficient but may be more susceptible to interference. Therefore, testing, analyze and determine the suitable values of the SF can have significant effects on the performance of a Spread Spectrum system, including resistance to interference, transmission rate, power efficiency, security, adaptability to changing channel conditions, and reliability.

3.9.3 Packet Loss

Packet loss produced from inability of transmitted data to reach its destination along the network. Packet data dropped usually influenced by the error from lack of signal strength at receiver, extreme system noise, overload network nodes, network congestion, hardware issues, distances and number of other factors causing packet loss during transmission. Presence of packet loss affects network performance hence reduce the quality of communication from latency and jitter complications. Degradation of communication quality affecting throughput reduction, dropping data packet impacting on incomplete data transmitted and downgrade of security communication that can cause loss in data encryption.

In this study, LoRa is a wireless network that uses the UDP protocol. Although it tolerates packet loss, the sender is unable to determine whether packets have been received. The server, The Thing Stack, uses the Semtech UDP Packet Forwarder. Packet loss was monitored and documented using the gateway log. Equation (21) defines packet loss.

$$PL\ (\%) = \frac{P_{st} - P_{rc}}{P_{st} \times 100} \quad (21)$$

Where PL is the packet loss defined over time with P_{st}, sent packet and P_{rc}, the received packet.

Inspecting the packet loss allow room for improvement modification to handles capacity of network loads though there were no absolute fixed solutions for packet loss. In this study, the analyzation result from packet loss are integrated with the conclusion from time delay to assist in identifying trends in network traffic statistics. This pattern allows for the deduction of a variety of transmission-related variables, including hardware failure, network congestion, and signal interference.

3.9.4 Path Loss

Path loss defined value of energy loss in space over distances between transmitter and receiver. Thus, the further the distances between receiver and transmitter, the higher energy losses. Most cases, the propagation model portrayed the radio signal travel in free space that is not heavily affected by external factor. The general signal path loss formulated as in (23).

$$L_p = P^t + G^r + G^t + P^r \quad (22)$$

Where:
L_p = Path Loss
P^t = Power at Antenna Transmitter
G^r = Power Gain at Receiver
G^t = Power Gain at Transmitter
P^r = RSSI

While the free space path loss usually denoted with terms of wavelength or frequency as follows in equation (23) and equation (24) respectively.

$$L_{fs} = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (23)$$

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$$L_{fs} = 10 \log\left(\frac{\lambda^2}{4\pi^2 d^2}\right) \quad (24)$$

The carrier frequency in this study, 915 MHz, modify the value of λ as in equations (25) and (26).

$$\lambda = \frac{v}{f} \quad (25)$$

$$\lambda = \frac{3\times10^8}{915\times10^6} = 0.3279m \quad (26)$$

Space path loss equation dependent on the impact from spread of energy and the fault of antenna. In free space damping propagation application, the commonly used logarithmic calculation extended from equation (12) from chapter 2 and equation (24) merges with the energy spread and antenna fault, as given by equation (27).

$$L_{fs} = 20 \log_{10} d + 91.67 - G_{tx} - G_{rx} \quad (27)$$

The transmitter antenna gains are denoted by G_{tx} and G_{rx}, respectively, while the antenna receiver gain includes feeder losses. The increase in distance increased the loss in free space by 6 dB. Reflection, refraction, and penetration of radio waves impacted by the attenuation structure have a substantial impact on the budget link's energy losses. According to equation (14) from the preceding section, the Okumura-Hata module is utilized to calculate propagation loss in an urban context.

3.9.5 Received Sensitivity and Received Power

The minimum sensitivity (R_{xs}) is the minimum received power (R_{xp}) level on the receiver node to decode the transmitted bits precisely. R_{xs} which is the value that prompting on the link budget. R_{xs} defined by in equation (28) also tolerance for thermal noise.

$$R_{xs} = -174 + 10 \log_{10} BW + NF + SNR \quad (28)$$

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Where BW is the bandwidth and NF is the noise factor, referring to equation (28). The received power declines as it passes through the channel over a distance and in the environment. The higher the receiver sensitivity show less interference effect from noise factor. The link budget quantifies the link performance by counting all the power received at the receiver. Equation (29) show the calculation of link budget from case of extreme path loss without reflecting on antenna gain and others type of free space attenuation.

$$B_L = Max. R_{xs} - Max. P_{tx} \tag{29}$$

Defining it in received power, R_{xp}, accounting all losses and gains as well as transmission power while travel through air as shown in equation is given by equation (30).

$$R_{xp} = P_{tx} + P_G - P_L \tag{30}$$

Where P_{tx}, the transmitted power, P_G and P_L are power gain and losses respectively.

Establishment of Direct LOS between transmitter and receiver also required as possible to obtain long range and good link budget. The spatial area between LOS in radio transmission known Fresnel Zone. Existence of structure attenuation affects the negative pressure on radio propagation. Figure 3.12 illustrates the Fresnel zone with object between within LOS between transmitter and receiver hence reduce the range and signal level.

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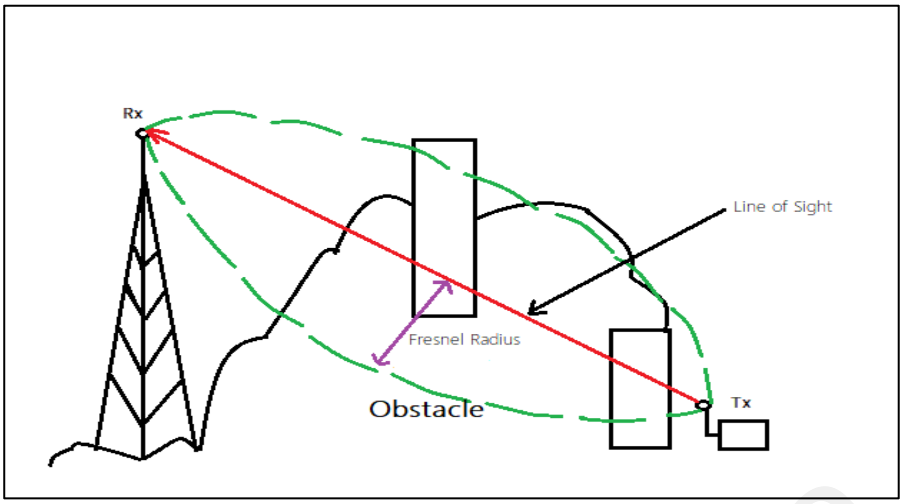

Figure 3.12: Fresnel Zone between Transmitter and Receiver with Obstruction within LOS

The effect of reflection and diffraction from the obstacle causes loss in signal thus revolute the LoRa propagation in Fresnel Zone. The reduction of signal in this situation known as Non-Line-of-Sight (NLOS) phenomenon. The path of NLOS between transmitter and receiver is shown as in Figure 3.13.

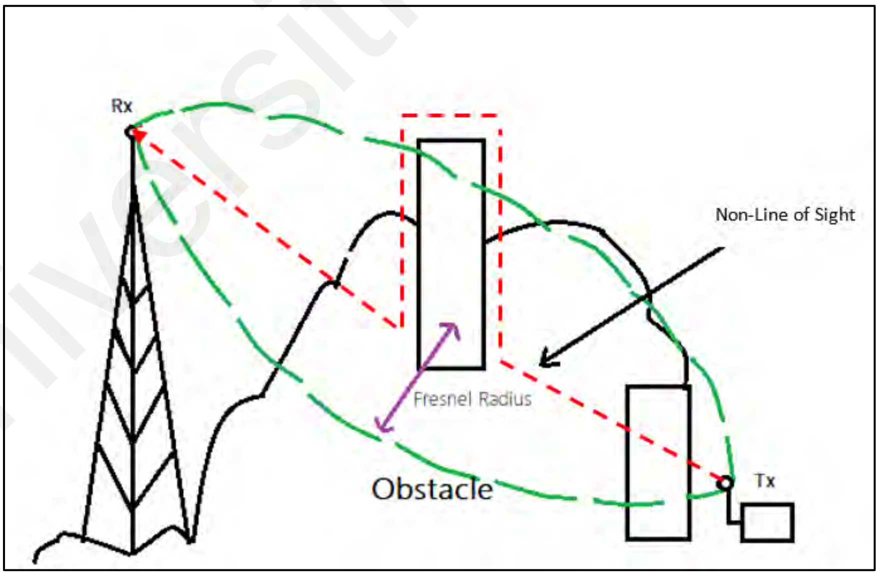

Figure 3.13: NLOS Path between Transmitter and Receiver in Fresnel Zone

The amount of signal loss within the radius of Fresnel Zone can be determined from equation (31). D is the distance between transmitter and receiver measured in km while f is the frequency applied for foliage propagation respectively.

$$R_{Fresnel}(m) = 8.657 \times \frac{\sqrt{D}}{f} \quad (31)$$

The received power diminishes during travel across the channel with the signal dropping over distances and effect of environment. In LoRa study, the received sensitivity can go lower to -130 dBm thus allow interpretation of lower signals.

As LoRaWAN network applied omnidirectional antenna thus it radiated energy distributed on horizontal level where nodes and gateway positioned. Selecting value of SF also important to set the data transfer rate against the range. Besides that, the noise level produced and bandwidth of receiver which is operate at 922 MHz in this study also affecting the level of receiver sensitivity. In summary, a receiver with higher sensitivity will be able to detect weaker signals, which can result in a longer range. However, if the receive power is too low, even a sensitive receiver may not be able to detect signals at a distance.

3.10 Summary

In summary, three water stations embedded with LoRa node were located at different specified places in this study. LoRa gateways were located between water stations at estimated height 25 m from the ground for data accumulation. Thing Speak and Android APK application used for water quality observation preview. The classification of water class based on collected data through mesh of K-means and PCA analysis method. The observation LoRa network performance on RSSI, SNR, packet loss, path loss and received power were verified to study the compatibility of the network with autonomous water quality monitoring system. Figure 3.13 summarizes the process of this study.

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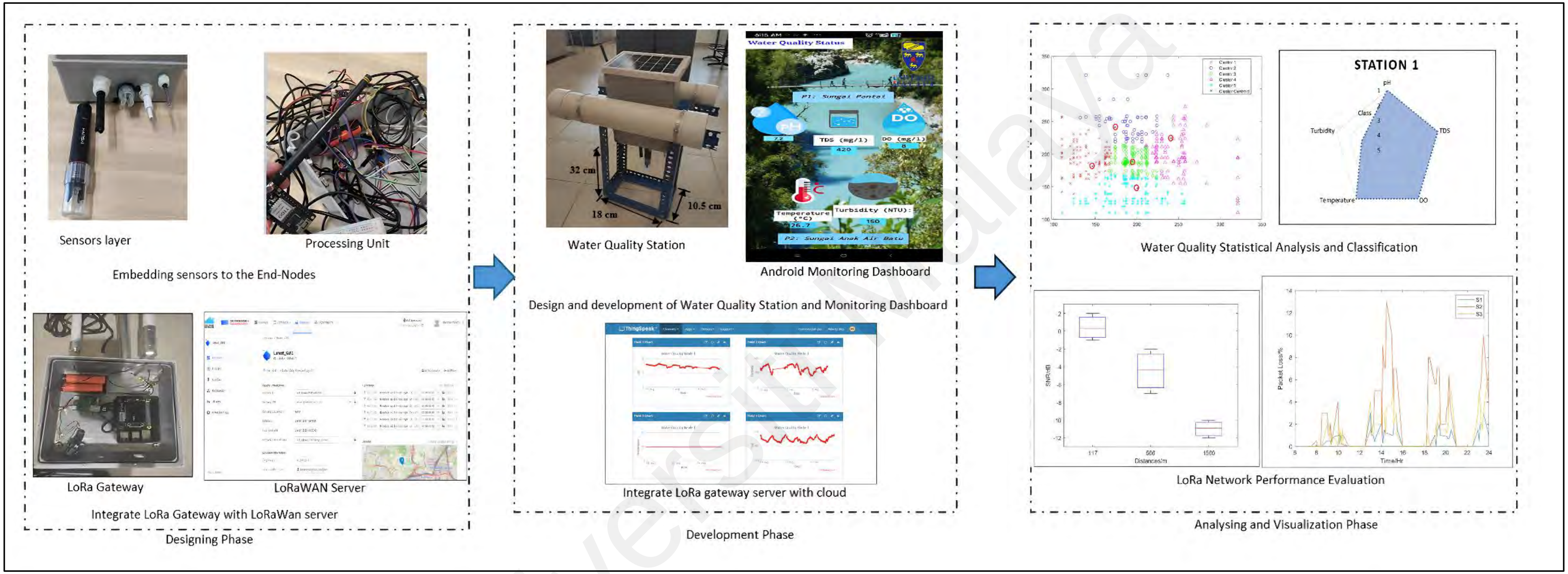

Figure 3.14: Summary of Developing a LoRa-Integrated Water Quality Monitoring System

CHAPTER 4: RESULT AND DISCUSSION

4.1 Overview

This chapter observed and analyzed the compatibility of LoRa to be implemented in the real time water quality monitoring system. In this study, the collected water quality data were analyzed as decision maker for water environmentalists. Collecting data of water quality in this study aim to verify the reliability of LoRa network as a bridge for monitoring status of water quality in outdoor realm at low cost and low energy utilization. Whilst collecting data for water quality, the performance of LoRa network were examined through The Thing Stack window for RSSI, SNR and lost packet. Besides, path loss and receiver power were determined applying equation made from Free Space Propagation and Okumura-Hata model on equation (14), (15), (28) and (31) in Chapter 2 and Chapter 3. The trend of LoRa network performances during data transmission were analyzed using Matlab through Machine Learning Algorithm approach. The verified result from analysis of LoRa network performances able to processing the information on LoRa capabilities for future research.

4.2 Water Quality Data

ThingSpeak is deployed as cloud in this study to store the data. Behavior of raw water quality data were observed from ThingSpeak that were integrated with The Thing Stack server live data as shown in Figure 4.1 for station 1, P1. ThingSpeak dashboard for station P2 and P3 can be referred in Appendix A(i) and A(ii) respectively. Additionally, data can be directly extracted from this data preview monitor.

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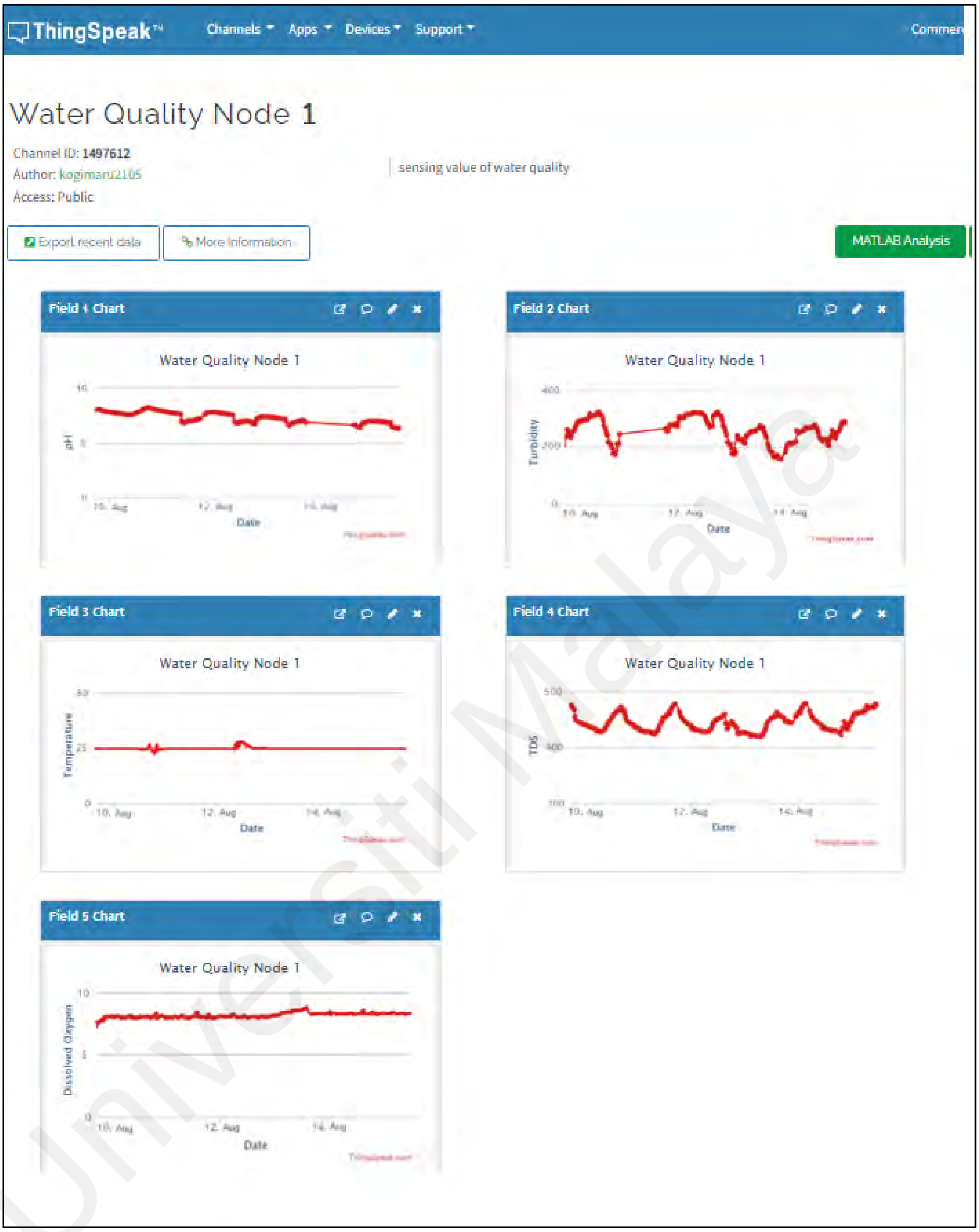

Figure 4.1: Thing Speak Dashboard for Station 1, P1

The extracted raw data obtained from ThingSpeak were filtered with median filter to reduce the noise, outlier and improve the accuracy before the classification of water quality. The duration of observation was taken for 14 days in August 2022. Below Figure 4.2, 4.3 and 4.4 demonstrate the pre-processing of water quality filter data.

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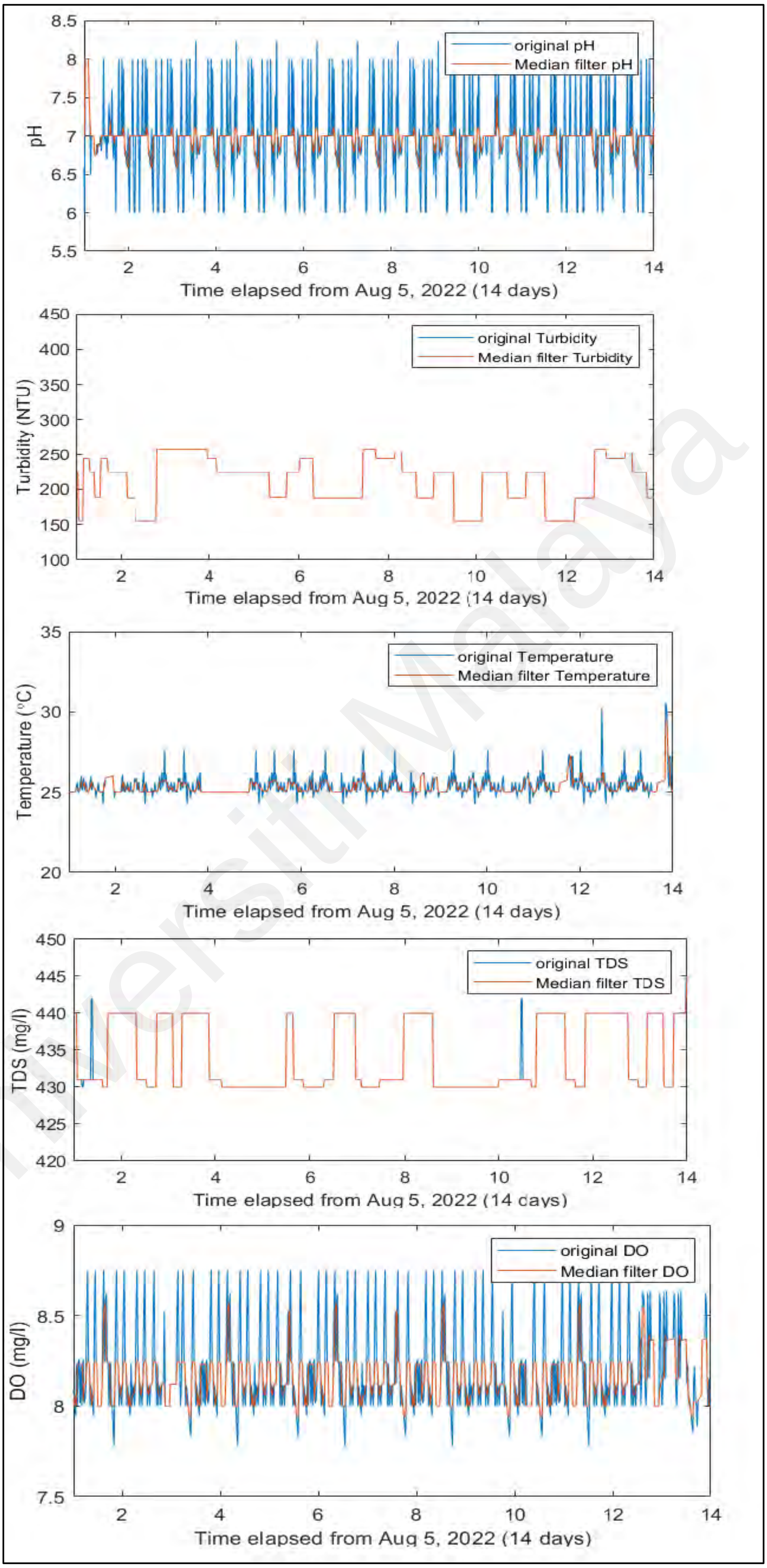

Figure 4.2: Water Sensors Response at Station 1, P1

Based on Figure 4.2, station 1 raw and filtered pH was constantly fluctuated but it were still within the ideal range between Class II and based on Table 2.2 in Chapter 2. Value of turbidity fluctuated at undesired value for higher water quality class which is limited to 50 NTU based on WQI standard. The value may be affected by water speed and human activity generating particles and solids in water but it still within acceptable value for raw water resources. Though temperature was not included in WQI, it is an important element in WQMS as it significantly affecting all three properties of water including biological, chemical and physical. Thus, it is important to observe the change in water temperature. While temperature and dissolved oxygen value fluctuated but still within its managed value at ideal range for living aquatic organism based in higher class. TDS value fluctuated within Class I but inadvisable for drinking purposes based on its turbidity value.

While for station 2 in Figure 4.3, dissolved oxygen at station 2 falls at ideal range for first class water quality continuously similar with previous station. Value of pH also gained at desirable value whether for drinkable or raw water standard value. Though the temperature filtered data constantly remained at desire for Class I, there were a lot of outlier falls at 30°C that show the rise of temperature more than +2°C than normal level. According to the raw data, the value of TDS at this station reached as low as estimated at 350 mg/l at particular time. However, the clarity of water at this station had bigger fluctuation based on its turbidity value at undesirable value compared to the previous station make it unsuitable for drinking purposes.

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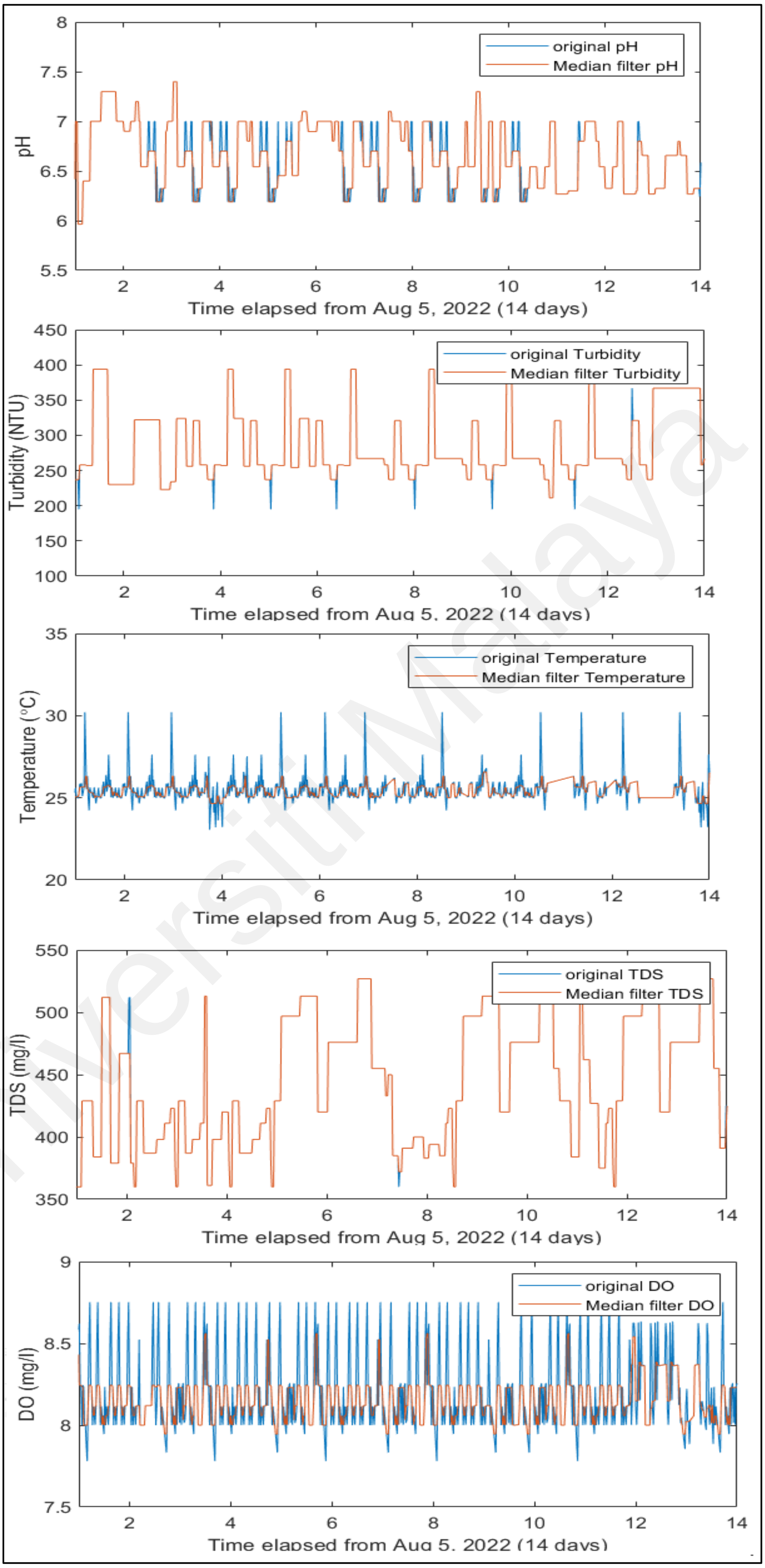

Figure 4.3: Water Sensors Response at Station 2, P2.

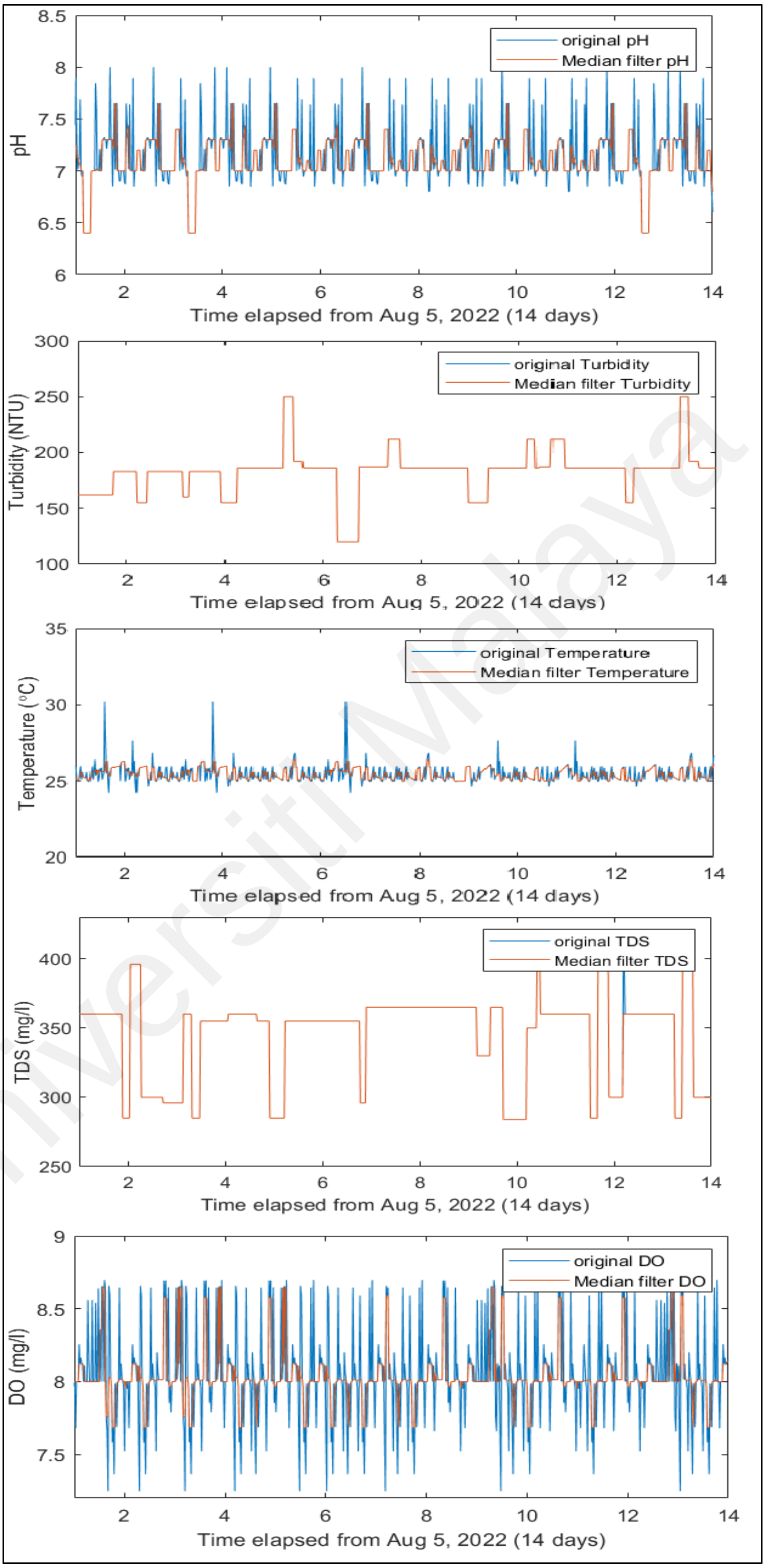

Figure 4.4: Water Sensors Response at Station 3, P3

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Referring to Figure 4.4, The value of pH, temperature and dissolved oxygen remain constant for its fluctuation even for its filtered data within the good water class based on standard of WQI at Station 3. TDS value had slightly varied from lowest and highest but within desirable range, 500 mg/l for clean water. Furthermore, the value of turbidity at this area also in good condition for recommended raw water and recreation purposes.

This stage able to foresight the water class for this river. However, further data processing and analysis is required to conclude final water quality classification by its trends and patterns.

4.2.1 Water Quality Classification

The result from the raw data can pre-determined characteristic of water quality. The constant state of dissolved oxygen and temperature expressing the all the water under observation are within tolerable state as a habitat for aquatic creatures but not suitable for drinking. The result collected continued to data pre-processing with K-means measurement to distinguish the cluster into k-groups that functioned as the observed points for cluster predefinition.

Table 4.1: K-means result of Obtained Water Quality Properties

Water Station	pH	Turbidity (NTU)	Temperature (°C)	Total Dissolved Solid (mg/l)	Dissolved Oxygen (mg/l)
P1	6.9591	213.21	25.3197	434.0368	8.1437
P2	6.6507	285.8137	28.4855	439.488	8.15
P3	7.0998	183.075	25.4387	346.1062	8.0396

The cluster group for each water quality properties with K-means were demonstrated as in Appendix B. The result from K-means were compared to previous study by UM Water Warrior team that concluded this study area had moderate level of pollution. Standardization data from K-means was clustered with PCA method to improve its accuracy on classification and removing the outliers by reduce the dimension. Below

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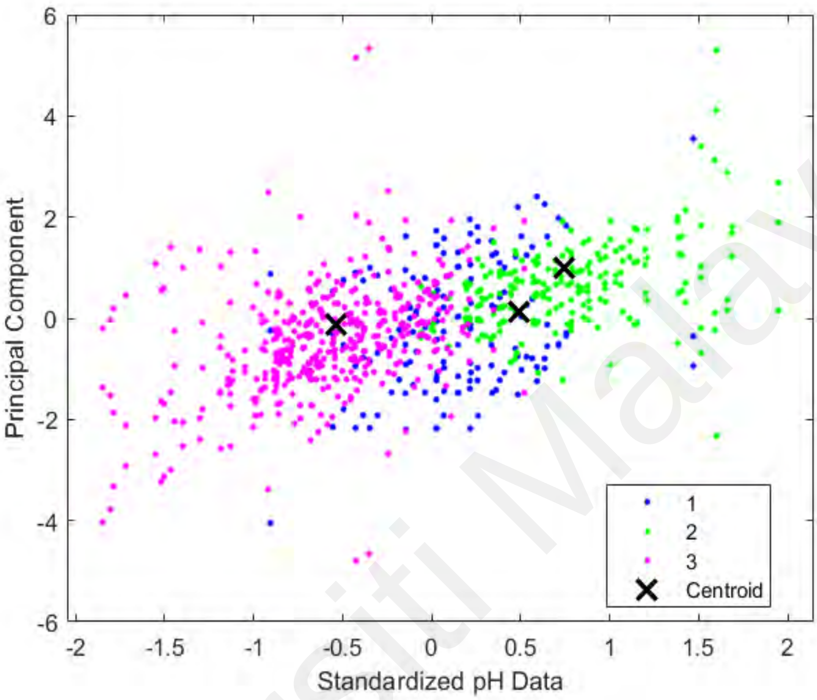
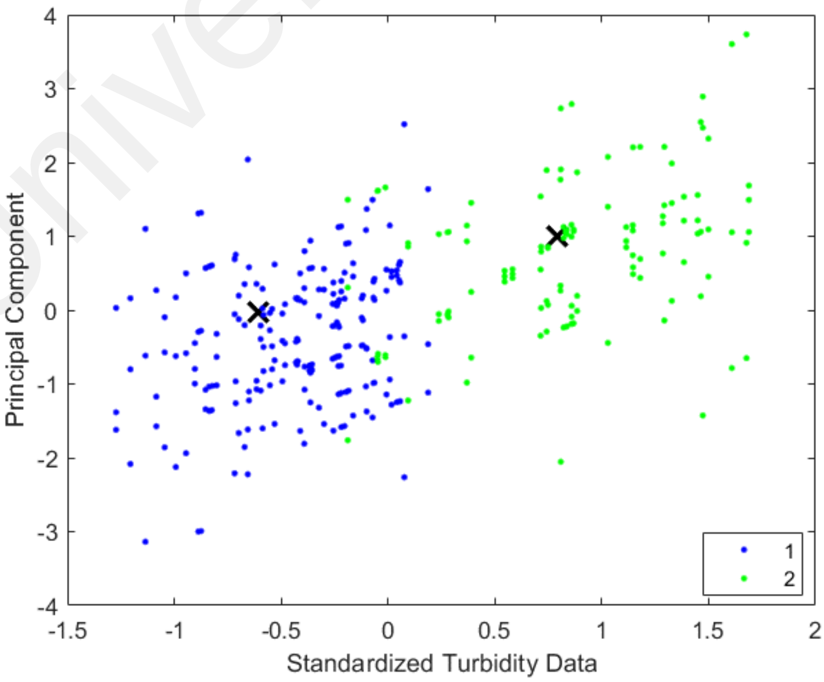
Table 4.2 demonstrates the clustering of through PCA from K-means output for all water quality properties.

Table 4.2: Mesh of PCA and K-means on Water Quality Properties

Water Quality Properties	Accuracy
	96.7%
	93.12%

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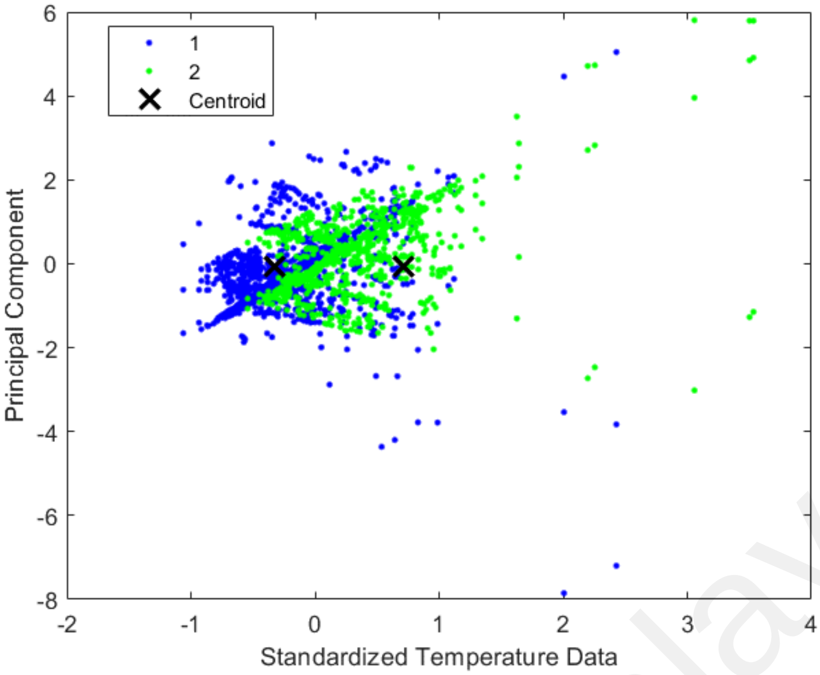
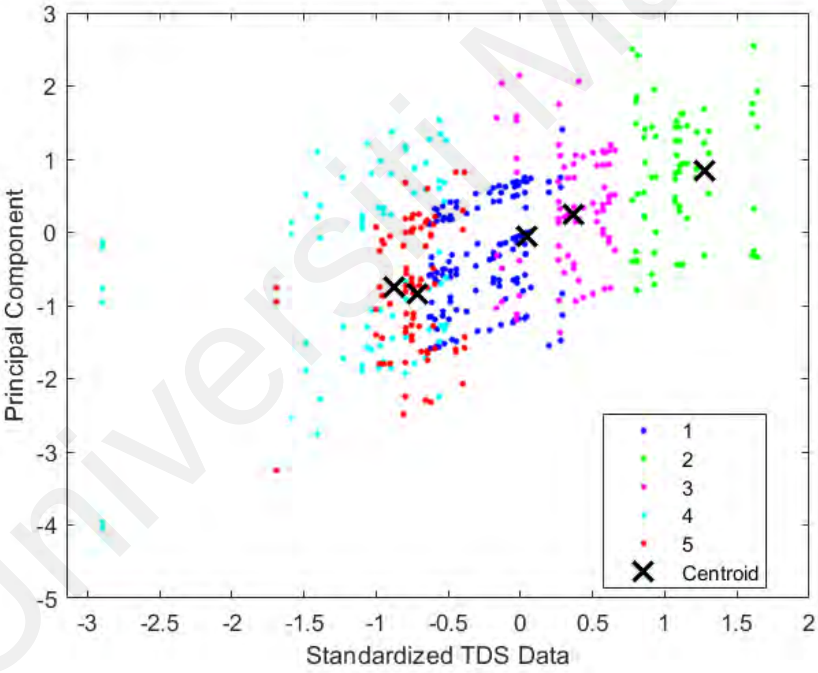
	99.94%
	94.15%

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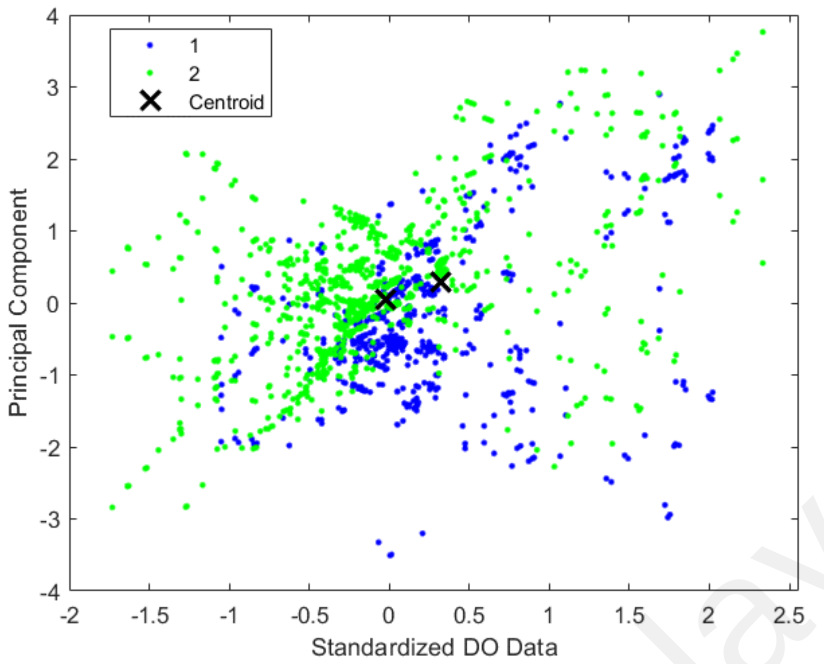	97.5%

Based on mesh cluster class from K-means and PCA obtained for each water qualities for every station, the accuracy reach nearly 100%. The result from the cluster allow the determination of pre-classification on water quality class based on the dimension reduction.

The dimension reduction from PCA method show that the three cluster group in pH show that pH fell within the same group and based on value of K-means obtained, pH was classified as Class I. While turbidity had bigger outliers and large distance of centroids compared to other water quality properties, it show that turbidity fell within low class and based on its K-means and WQI standards. Though temperature had an estimation similar centroid between two cluster, the K-means value show the difference value of temperature at Station 2, P2 had rise more than 2°C compared to other station hence temperature of Station 2 can be pre-classified as Class IIA. Based on TDS properties, the cluster was divided into 5 groups based on K-means. However, this mesh method show the relationship of all the cluster group fell below large range of TDS standard WQI in Class I as the centroid of its group were not far from each other. DO

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relationship between its cluster was the most stable compared to other water quality properties thus the group of this cluster appeared within the similar group. Based on it K-means, the value of DO was categorized in Class I referring to standard WQI.

The conclusion from mesh product of K-means and PCA for water quality properties able predict the early water quality status. The status of water qualities was visualized in pentagon shape as five types of parameters were investigated in this study. The finalize shape of pentagon able to portrayed the condition of water quality at every station as refer to the previous researcher that uses heart shape to describe the status of water quality to the science citizen. The complete shape of pentagon portrays the highest status of water quality for all water properties while the least incomplete shape of pentagon capable to notified the early detection of water deterioration affected from substances contained in water bodies.

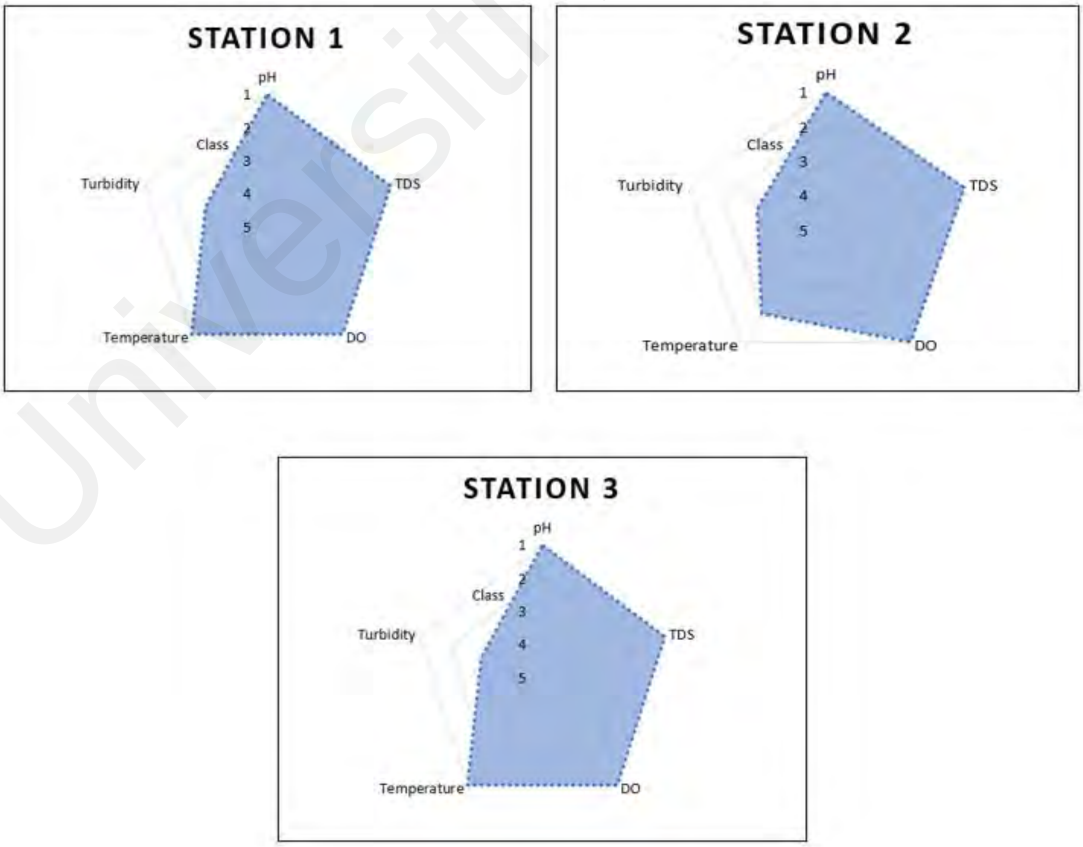

Figure 4.5: Pentagonal Summarization of Water Quality Status

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Based on the summary pentagonal shape illustrated in Figure 4.5, the water bodies at all locations followed a similar pattern. The water body is classified as Class Ⅰ based on its entire pentagonal shape. However, the water trend in the figures above for all stations had an unsatisfactory shape due to turbidity. The temperature and turbidity class influenced the water bodies at Station 2. In conclusion, the water bodies in Sungai Pantai and Sungai Anak Air Batu at Universiti Malaya are rated as class ⅡB, which are suitable for recreational purposes but not drinkable. In addition, normal treatments are required for water supply.

Although the result of water cannot determine the precise status of water quality index since there were important parameter not included in this experiment such as Ammoniacal Nitrogen, Biochemical Oxygen Demand and Chemical Oxygen Demand based on DOE water quality index from equation (1) in Chapter 2 due to limitation for real-time measurement. However, the pre-determined result from continuous monitoring method benefiting hydrologist for daily observation and support decision system.

4.3 LoRa Network Evaluation

Evaluating the network performance during transmission of water quality data significant to compatibility of LoRa as the communicator of the system. The large amount of loss data and low performance of network quality below the Key Performance of Indicator (KPI) of LoRa important factors for ideal radio range in monitoring purpose.

The experiment was executed within dual indoor and outdoor space due to unsuitability of the gateway antenna fragile structured to be stationed at alfresco environment. The total of payload transmitted to gateway from LoRa nodes at all water stations tracked the received frequency, RSSI, SNR and packet loss that can be viewed uniformly with water quality parameters data at The Thing Stack dashboard. The output

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of network properties from The Things Stack were recorded for LoRa performance analysis.

4.3.1 RSSI and SNR

Reference value of RSSI for each station were calculated from equation (18). The behavior recorded average of daily RSSI generated by every SF for every station in The Thing Stack were show as in 4.6, 4.7 and 4.8 for all stations respectively.

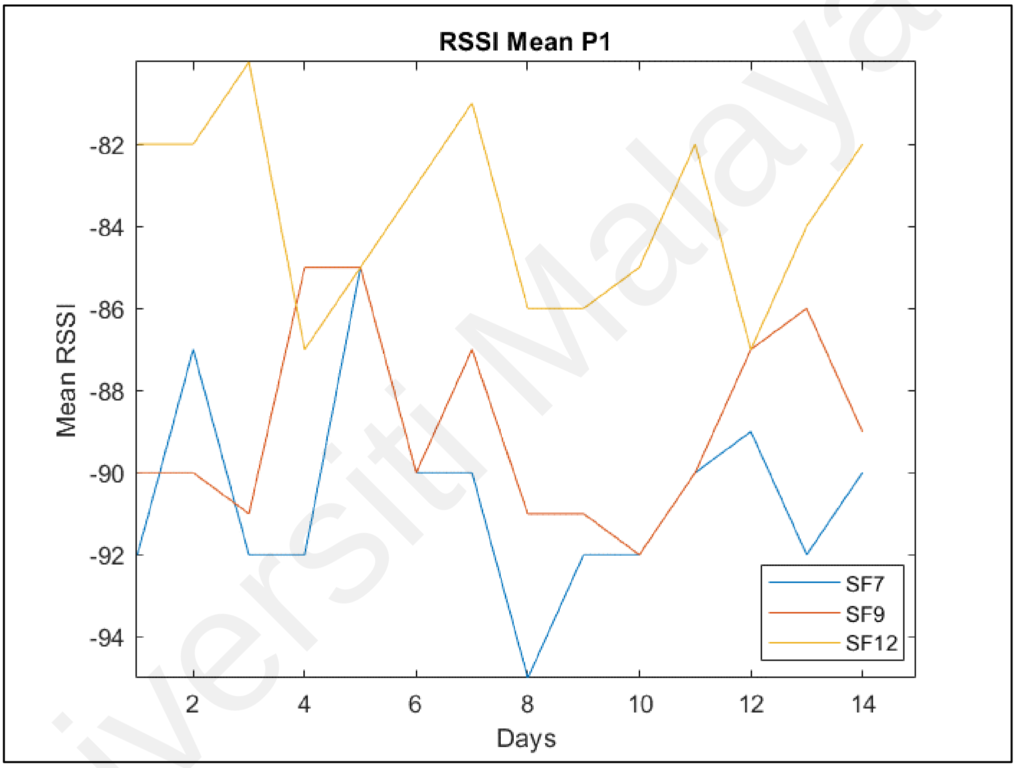

Figure 4.6: Daily Average RSSI P1

P1 was the node nearest to the gateway with distance of 117 m. Expected of RSSI based on the equation (18) from this Station 1 is -59.08 dBm. Though, its Fresnel Zone for the antenna is at disadvantage due to large height differences that affects the spatial area within NLOS. Hence, it affecting the actual value of recorded RSSI compared to its reference on calculated RSSI. The highest SF used also unable to achieve the value calculated RSSI. However, the trend of RSSI from this distance performed within desirable value for every SF based on Figure 4.6.

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While node P2 had largest distance from the gateway, the signal strength able to overcome the NLOS factor within its Fresnel Zone based on Figure 4.7. The calculated RSSI obtained from this distance is -81.58 dBm. Though it had largest difference from calculated RSSI, the daily average of RSSI were still within acceptable value of for LoRa even for SF 7 with its lowest at -118 dBm.

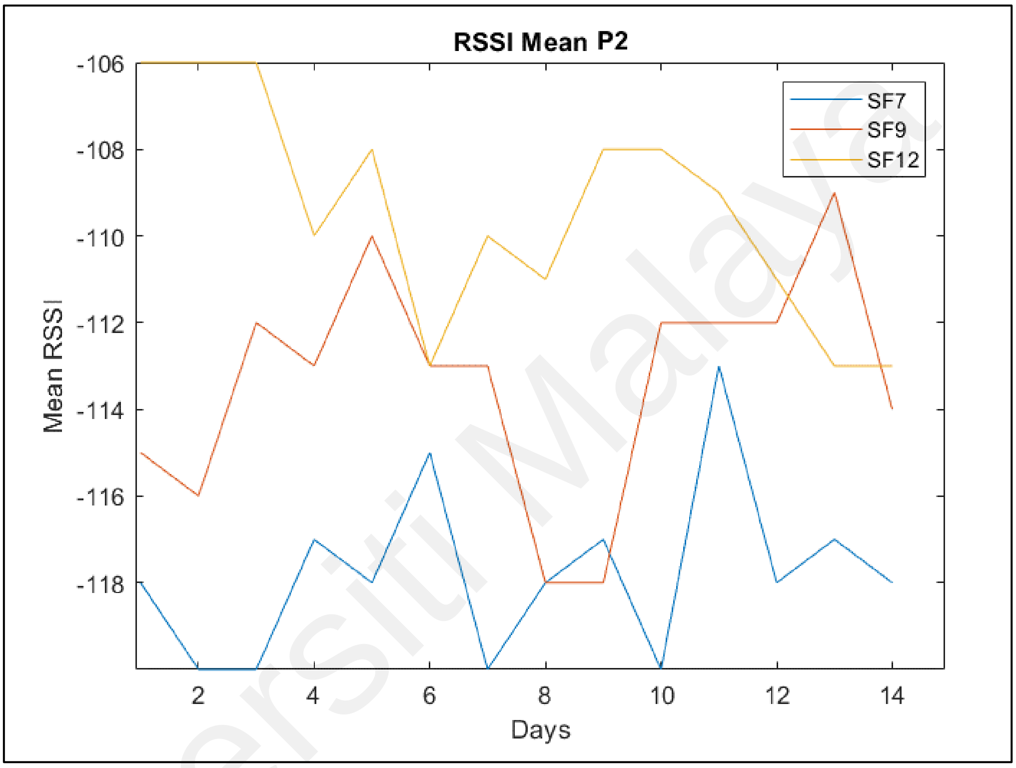

Figure 4.7: Daily Average RSSI P2

Based on Figure 4.8, daily average RSSI from station 3, P3 also operate within desirable value for LoRa. The highest RSSI from this distance is -85 dBm reached through SF 12 and it is the nearest to the reference of RSSI value which is -73.23. However, there were large differences between SF12 to SF9 and SF7 respectively. It shows that the higher SF impacting the signal to a better performance.

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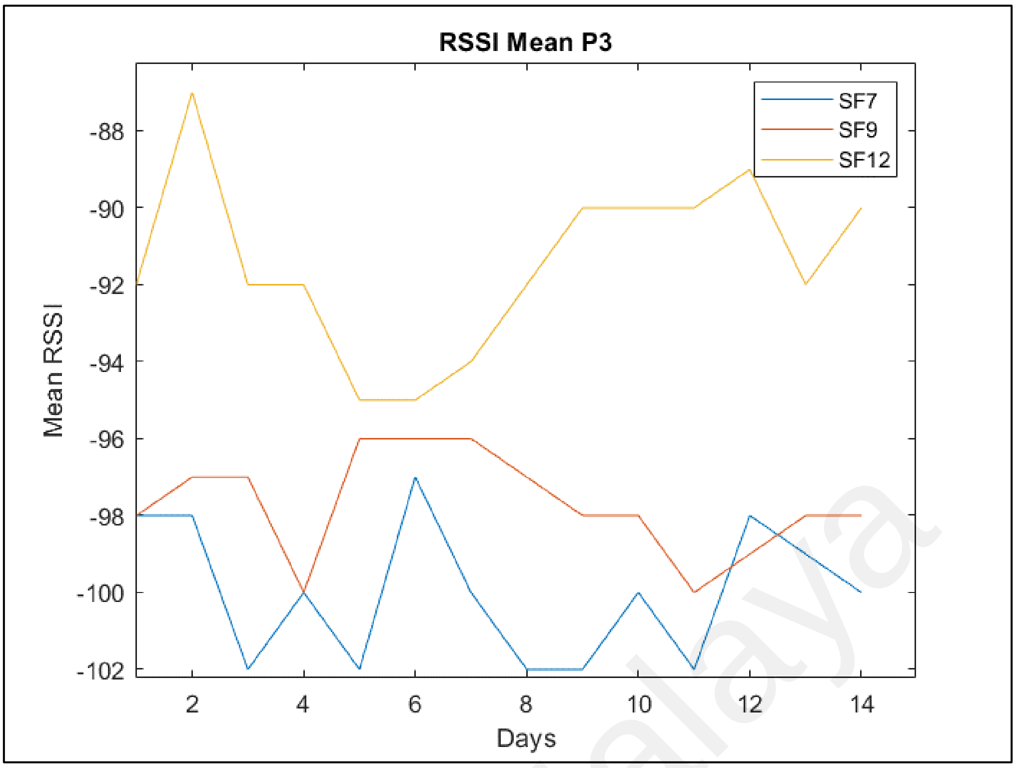

Figure 4.8: Daily Average RSSI P3

Distance between node and gateway also plays a good impact on the strength signal which include the NLOS factor. Henceforth, it causes the difference between expected RSSI through calculation and actual recorded RSSI. Furthermore, the variety of RSSI value effected by distances, environment influences, weather, interruption of other radio frequencies and other variables. However, the signal strength indicator requires other factors to show the ability of a network. Hence, the daily noise ratio was observed through The Thing Stack and recorded as in Figure 4.9, 4.10 and 4.11 for all the nodes from water station P1, P2 and P3 respectively.

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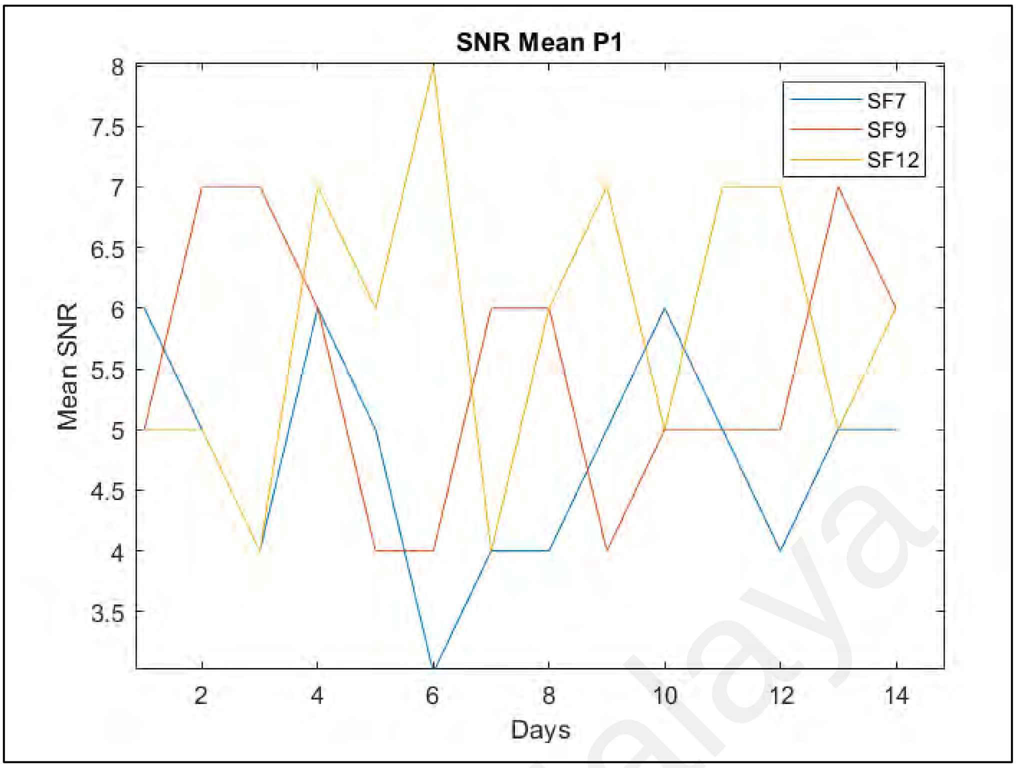

Figure 4.9: Daily Average SNR P1

SNR at P1 based on Figure 4.9 demonstrated a good range for every SF. The range difference of SNR also not vary from each other when different SF was implemented at this distance. The recorded SNR also passing the benchmark for LoRa demodulator for each SF. Though, the use of higher SF12 able to reach the highest SNR at 8 dB.

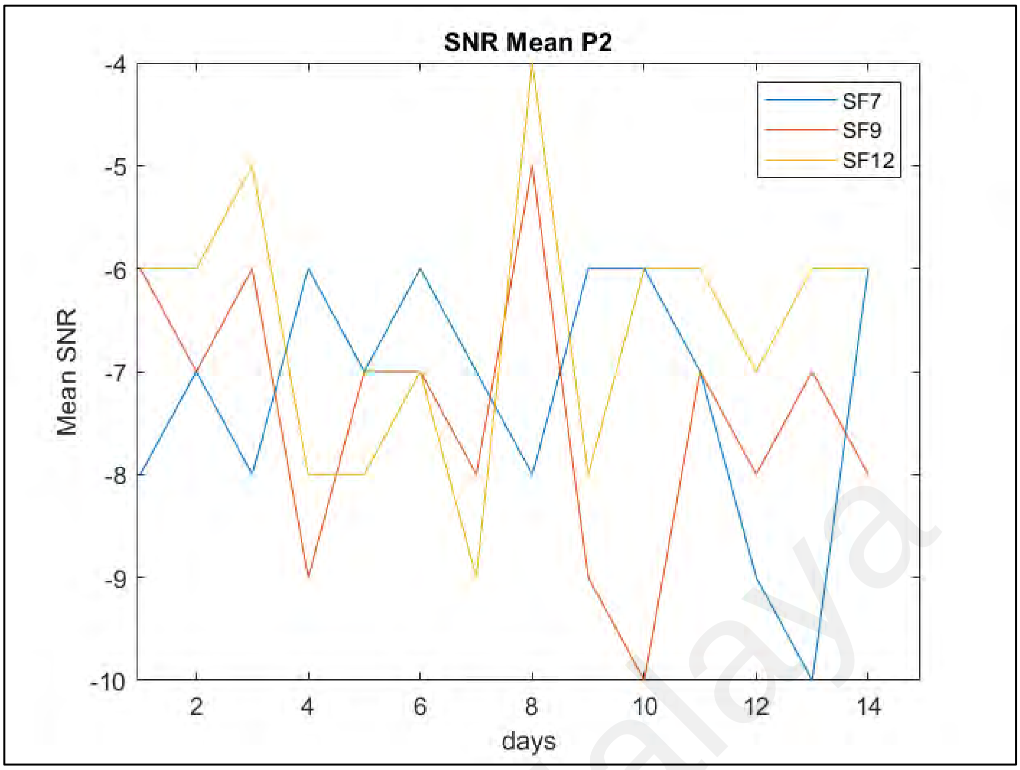

Figure 4.10: Daily Average SNR P2

While SNR at P2 also able to perform within acceptable range for LoRa technology as it able to demodulate signal below noise floor at -20 dB. The lowest daily average SNR achieved by both SF7 and SF9 were -10 dB. Lowest SNR by SF 7 fail to pass the benchmark for LoRa demodulator. The lower SNR might affect other network properties and data accumulation as it will increase the latency. Further observation on SF uses at this station, P2 will be analyzed with further network properties.

Referring to Figure 4.11, the daily average SNR from P3 continuously perform within desirable range for every SF. Uses of SF7 from this node also able to achieve higher signal ratio than noise with estimation of 3.5 dB. It shows that the SF uses do not impact the average of SNR but it allows the demodulation of low signal to adapt the environment for data transmission.

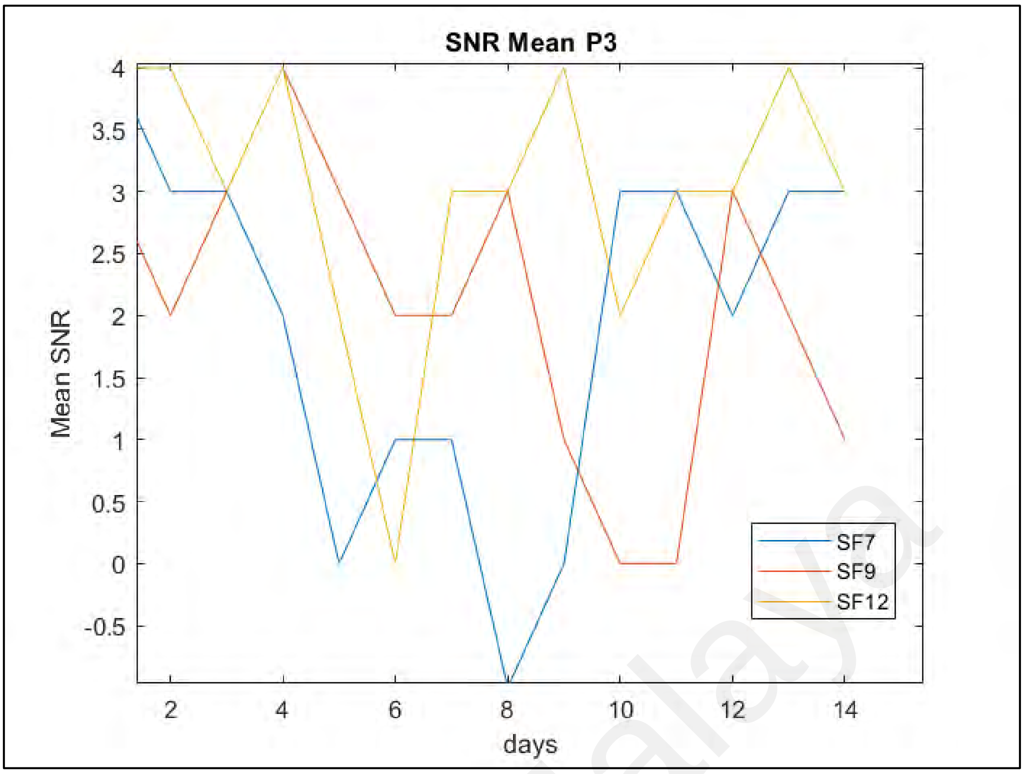

Figure 4.11: Daily Average SNR P3

This study unable to compared it with the calculation SNR based on equation (19) and (20) as it is difficult to measure the actual noise floor without proper equipment. However, the SNR achieved a conclusion that LoRa able to perceive signal below noise floor as it impacted from NLOS factor in urban environment while distances factor barely influencing the SNR value.

4.3.2 Packet Loss

The effect of the RSSI and SNR corresponds to the dropped packet data. The occurrence of high packet loss was heavily influenced by a low SNR that could not be demodulated by the receiver, as well as the NLOS impact in an urban setting. Packet loss require retransmission hence led to latency and increase in time delay. The Thing Stack output recording the sent packet and received packet for each data allow the calculation packet loss based on equation (21). Figures 4.12, 4.13 and 4.14 display the daily average of packet loss with its time delay.

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P1 had the smallest range of packet loss for all SF. The ranges obtained were within desirable wireless network range, below 3%. However, there were highest delay at 10 s when SF12 was implemented though no packet loss was recorded.

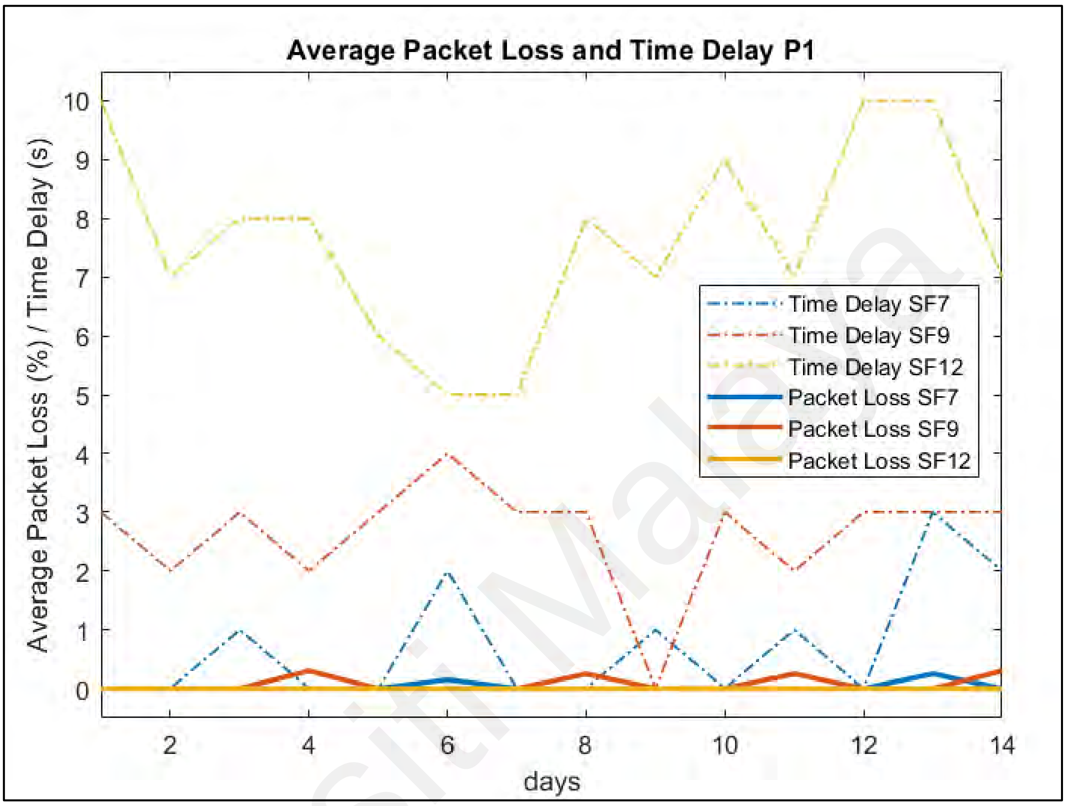

Figure 4.12: Daily Average of Packet Loss and Time Delay P1

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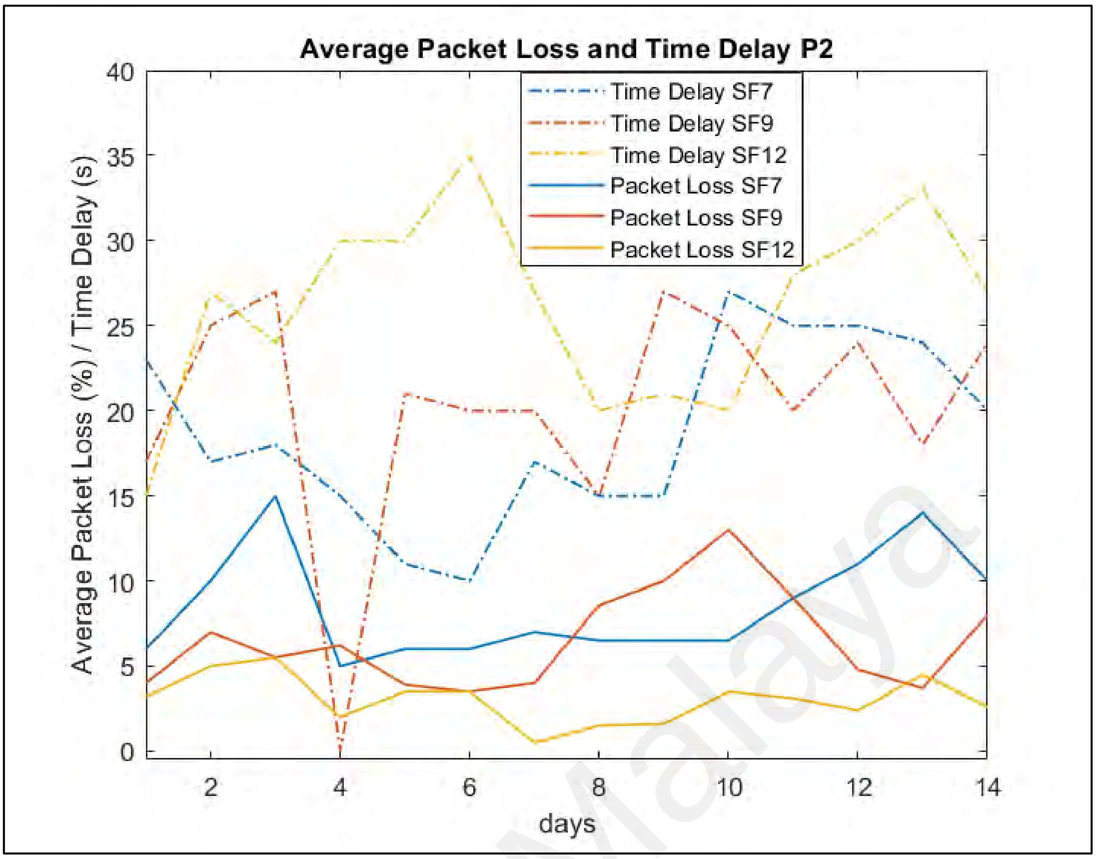

Figure 4.13: Daily Average of Packet Loss and Time Delay P2

Monitoring packet loss at Station 2, P2, the average packet loss reaches highest as 15% for SF7. While the delay for SF7 is not high as SF12 that reach 35 s due to transfer rate factor in SF, higher SF able to reduce the loss packet occurred in this study. The higher packet loss impacting the accumulation data that can lead to inaccuracy for water quality observation.

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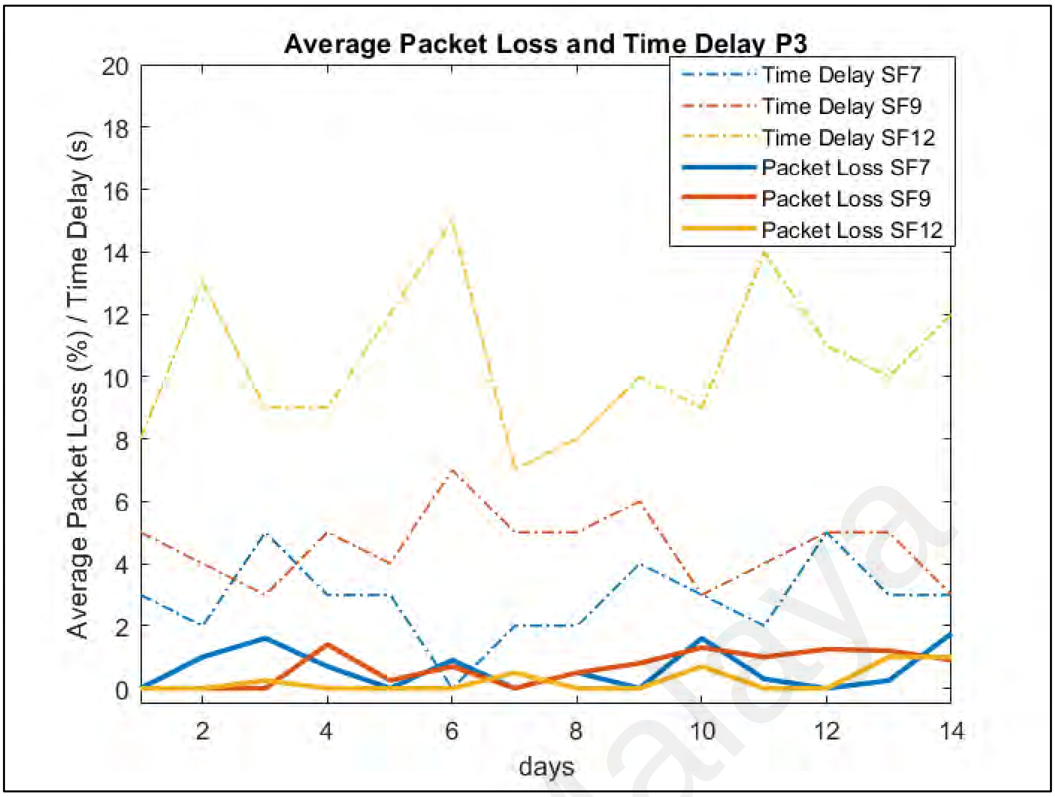

Figure 4.14: Daily Average of Packet Loss and Time Delay P3

Based on Figure 4.14, the packet loss for each SF from P3 were still within acceptable range. Nonetheless, there were highest time delay at estimation of 15 s when SF12 was implemented.

High packet loss affects network speed and increases latency, reducing the collected data and lowering the accuracy of water quality measurements. Furthermore, depending on the density of the environment, increasing SF may increase latency, resulting in more time delays and packet loss. Nonetheless, perfect prevention of packet loss in any network scenario is unattainable; nonetheless, it can be reduced through preventive measures. Sudden changes in data packets can predict network issues. The selection of SF for each station is important to improve the transmission of packet data while optimize the time delays as long as it do not affect water quality monitoring data.

4.3.3 Path Loss

Identifying path loss for wireless network applications in urban environments with possible power attenuation is important for defining the budget link. The path losses in this study were analyzed using the propagation of free space (FSDP), referring to (26), and the Okumura-Hata (Oku-Hata) model, referring to (14). The path losses are presented in Table 4.3.

Table 4.3: The Difference of Path Loss based on FSDP and Okumura-Hata model

Antenna Gain (dBi)	Water Station	Distances (m)	Path Loss FSDP (dB)	Path Loss Oku-Hata (dB)
3	P1	117	64.41	88.21
	P2	1560	82.71	127.34
	P3	566	73.91	112.03

Because the FSDP approach accounts for antenna gain and feeder losses, the path loss from each end node benefited from the antenna gain of 3 dBi. The Oku-Hata model evaluate the height of the transmitter and receiver, frequency, and distances based on equation (15). Furthermore, the Oku-Hata technique has a higher route loss than the FSDP method since it takes into consideration the effects of diffraction, penetration, and reflection of various barriers in the outer realm. The resulting FSDP for distance with a 1 km estimate in this investigation was substantial.

Furthermore, transmitted signal varies randomly from its regular average value as it adjusts to the difference in the heap environment. As a result, the attenuation signal power due to reflection, refraction, penetration and diffusion from the various obstacles in the Fresnel Zone at the Line of Sight (LOS) between transmitter and receiver diminishing the signal intensity. Nevertheless, the average value of route loss can be adjusted by changing the transmission power and antenna gain values.

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4.3.4 Received Power

The calculation of transmission power, gains, and losses that affect the amount of received power has a significant impact on the overall budget link. In terms of the link budget, the results of received power and received sensitivity are important in calculating the value of the fading margin. The fading margin produces a design specification that ensures performance level of the system.

The sensitivity of signal detection is determined by energy detection threshold of the receiver. The energy detection also including noise floor, modulation type and SF. The actual comparison of the R_{xs} from the calculation is done through the experiment measuring of its sensitivity by transmitting a known signal at specific power level while measuring its minimum power.

This metric was not generally discussed in prior research of the LoRa monitoring system, despite the fact that receiver sensitivity of LoRa can reach -130 dBm. As a result, it allows for the interpretation of weaker signals; however, it is necessary to specify the minimum strength that must be identified and processed for transmission quality assurance.

Table 4.4: Total of Received Power and Received Sensitivity

Antenna Gain (dBi)	Station	Distances (m)	Received Sensitivity (dBm)	Received Power (dBm)
3	P1	117	-118.58	-108.34
	P2	1560	-129.1	-118.02
	P3	566	-122.98	-112.44

The gateway can detect an increase in received power from any location because the received sensitivity is spread with a minimum of -129.1 dBm. The received power measured in all locations remained below the received sensitivity values. The faulty receiver sensitivity in this study allowed the receiver to decipher the feeble signals sent by the LoRa nodes at each water station. This design solution employs a higher antenna gain to ensure a fading margin of at least 10 dB at all distances.

4.4 Summary

From this chapter, proposed method on classification of water bodies through mesh clustering of K-means and PCA on the filtered and raw data of water quality able to pre-conclude the class of water bodies in real-time manner indicated the effectiveness of the method. Furthermore, the summarization of water class through pentagon shape based on standard WQI able to provide simple but informative deduction on water quality condition in early phase.

The result from evaluation on LoRa network performance on strength signal and noise ratio allow the study on receiver sensitivity and power. The distribution of RSSI spread also did not drop exceed the weakest signal strength of -120 dBm. Besides that, the ability of LoRa to demodulate signals below floor till -20 dB showed the SNR obtained able to be adapted. Though the packet loss reached the undesirable value for wireless network which is more than 3% but the type of water quality data is low data rate hence the monitoring analysis on water quality still able to be accomplish in real-time manner. The path loss for urban environment also able to be calculated with Okumura-Hata that considering the effect of reflection, diffraction and penetration within NLOS setting. LoRa also able to interpret the weak signal of received power resultant from all station due to it sensitivity as lowest as -129.1 dBm.

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CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Overview

This chapter concluded the overall outcome from this research on achieving its objectives. The limitations and drawbacks found from this research also recorded in conclusion section for future reference. Finally, the possible recommendations were listed in this chapter for further research in water quality monitoring with WSN.

5.2 Conclusion

As has been demonstrated from this study in previous chapter, developed water station embedded with LoRa and water quality sensor signified to the first objective of this study on designing independent water quality monitoring station using LoRa. Referring to the analysis of LoRa network performance in this study for all settings, it can be concluded that the design of water station able to operate independently send data of water quality from selected sensor to the monitor platform in real time. Selecting the reliable and durable elements for LoRa on its hardware benefiting the network efficiency. The RSSI, SNR and packet data analyzed from collected data presented in The Thing Stack indicate that LoRa operated at stable phase despite the high range of path loss due to the distances and attenuation formed from obstacle within its Fresnel zone. Furthermore, LoRa able to decode noise below floor level and allow the receiver sensitivity manage lower power signals. Hence, the gateway able to perceive the transmitted signal from each water station. Differences of SF uses from each node also provide the information on monitoring its effectiveness on RSSI, SNR and packet loss considering the effect in NLOS setting in urban environments.

Next, the built GUI on Android and Thing Speak monitor view exhibited the execution of second objective that aimed at monitor and provide real time water quality condition to support water environmentalist in decision making. The collected water qualities

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sensor data were evaluated based on WQI and NWQS Malaysia standard as the benchmark. The analyzation of water quality data from the mesh of K-means and PCA method able to categorize the water class at early stage that were summarized in deployed pentagon shape influencing the focused action decision for water environmentalist.

In final analysis, LoRa is applicable for water quality monitoring in-situ system as water quality data is small packet type of data. Furthermore, it proved its ability to provide early decision for water environmentalists to make pre-deduction on water bodies condition.

5.3 Recommendations

Water quality monitoring study is continuously progressing to reach target of SDG 6.3 on water quality improvement, wastewater treatment and safe reuse of clean water. Consequently, there few things that can be improved after this research was concluded for future study. Firstly, the design of water stations can be modified into more robust structures that can function through increment of water speed and rough environment for a longer period. Moreover, the design also must consider the most appropriate power input rate for sensor and wireless network to reduce amount of maintenance required.

Besides that, a combination of in-situ water quality monitoring and laboratory analysis in one board monitor view that able to deduce precise WQI value for further action in avoiding scarcity of clean water. The method of statistical analysis on water quality sensor data also can be explored further with the aim of achieve better accuracy on classification of water for each characteristic.

Finally, LoRa capability in Industry 4.0 for Smart Earth objective can be enhanced by study on each of its properties. Exploring and understanding the advantage of its properties allow better design and implementation of LoRa network in any application.

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Understanding the factor of SF for objective of a study also important to manipulate it based on its advantages. Also, select suitable antenna for transmitter and receiver depends on the objectives and environment as it is one of the major mechanisms that influencing the operation of LoRa network. The location of gateway also generates better optical visibility between antennas by considering the Fresnel Zone factor. Deciding the connection material and cable also important to reduce the loss at transmitter and receiver to improve the receiver sensitivity so it can receive the power level of transmitted bits clearly.

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