SHORT MESSAGE SERVICE (SMS) BASED SYSTEM FOR MONITORING FREE CHLORINE CONCENTRATION AND PH IN THE WATER RESERVOIRS

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A Project Report Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Chlorine is the most common and affordable chemical reagent used for killing harmful micro-organisms in the water to eliminate the spread of waterborne diseases such as cholera and diarrhoea. According to World Health Organization, a free chlorine level within 0.5~1 mg/l and a pH level within 6.5~8.5 is recommended for human consumption. It is essential to monitor water quality parameters such as free chlorine in the water since a lower value will not disinfect water efficiently while extreme values of free chlorine may affect the community's health. Zanzibar Water Authority (ZAWA) employs colorimetric approach to manually measure free chlorine in the water reservoirs and submit the results into the kobocollect mobile application. However, this approach is prone to human errors, ineffective and time consuming. The objective of this current project was to develop a SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs. Extreme Programming (XP) agile development methodology accompanied with V-Model were employed for developing and testing of the proposed system. The developed system consists of hardware device and dashboard for remote monitoring of water quality parameters such as free chlorine concentration and pH. The hardware device sends sensor data and notification alerts as SMS. The device is energy efficient since it uses SMS to send sensor data. The device can be deployed in a noisy environment since it uses RS485 communication protocol to communicate with the free chlorine sensor. The developed dashboard is used for remote monitoring of the sensor data. The dashboard is user friendly and practical since it was designed with the end users. The system was tested and validated by the end users to ensure all requirements were met. The developed system has a potential capability to improve management of water reservoirs by enhancing transparency, cooperation, and accountability among stakeholders.

DECLARATION

I, Edson Samwel Mwambe, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this project report is my original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

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The above declaration is confirmed by:

Dr. Elizabeth Mkoba		25/08/2023
Name of Supervisor 1	**Signature**	**Date**

Dr. Mussa Ally		01/09/2023
Name of Supervisor 2	**Signature**	**Date**

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Nelson Mandela African Institution of Science and Technology, a project report titled ***"Short Message Service (SMS) based system for monitoring free chlorine concentration and pH in the water reservoirs"*** in partial fulfillment of the requirements for the degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology.

Dr. Elizabeth Mkoba		25/08/2023
Name of Supervisor 1	**Signature**	**Date**

Dr. Mussa Ally		01/09/2023
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Lastly, Many thanks to my classmate, comrades, friends and instructors for their encouragement and emotional support throughout the project especially in the most challenging times.

DEDICATION

I dedicate this work to my family; particularly my parents Samwel Mwambe and Victoria Katembo, my sisters Happiness Mwambe and Luiza Mwambe, as well as my younger brother Jovin Mwambe for their emotional support, prayers, and encouragement throughout the project. I also dedicate this work to the memory of my late relatives; my aunts Victoria Mwambe and Beatrice Musiba, as well as my cousin Celia Mwambe.

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LIST OF ABBREVIATIONS

CSS	Cascading Style Sheets
DC	Direct Current
DPD	N,N-diethyl-p-phenylenediamine
FRC	Free Residual Chlorine
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HTML	Hypertext Markup Language
IDE	Integrated Development Environment
IoT	Internet of Things
JST	Japan Solderless Terminal
LCD	Liquid Crystal Display
PCB	Printed Circuit Board
pH	Potential of Hydrogen
PHP	Hypertext Preprocessor
RS485	Recommended Standard 485
SMS	Short Message Service
SPST	Single Pole, Single Throw
TCO	Tanzania Country Office
TTL	Transistor-to-Transistor Logic
UART	Universal Asynchronous Receiver-Transmitter
UML	Unified Modelling Language
UNICEF	United Nations Children’s Fund
WASH	Water, Sanitation and Hygiene
WHO	World Health Organization

Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Network
XAMPP	Cross Platform Apache MySQL PHP and Perl
XML	Extensible Markup Language
ZAWA	Zanzibar Water Authority

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Accessible, safe, and adequate water supply is crucial for the health and well-being of the community. Tangible benefits to community's health can be achieved by constantly improving access to safe and clean water supply. Coordinated efforts of several stakeholders should be made to achieve high quality (clean and safe) water supply. Poor quality water supply to the community can result in outbreaks of waterborne diseases including cholera. Waterborne diseases, particularly, should be avoided because they spread quickly and affect a significant number of people in a community (WHO, 2017).

Water quality monitoring is crucial for preserving the safety of water sources and protecting public health. Water quality is largely damaged by the interdependent physical, chemical, and microbiological parameters, such as temperature, pH, free chlorine concentration, organic carbon, dissolved oxygen, turbidity, conductivity, and microbes. Among these parameters, the concentration of free chlorine and pH are crucial for the natural environment and our health (Qin *et al.*, 2015).

Potential of Hydrogen (pH) of the solution is calculated by the negative logarithm of the concentration of hydronium ions ($H3O^{+}$), expressed as $pH = -\log [H3O^{+}]$. Zero to fouthen (0-14) is the range of pH, neutral value is when pH =7, acidic value is when pH less than 7 and basic value is when pH greater than 7. According to the World Health Organization, pH recommended range for drinking water to be within 6.5 to 8.5 (WHO, 2017). The process of water treatment might be affected if pH is outside the recommended range, and eventually it might also affect the community's health.

Water disinfection is unquestionably crucial for killing harmful micro-organisms to eliminate the spread of waterborne diseases such as cholera and diarrhoea. Chlorine is the most popular and affordable chemical reagent utilized for water disinfection. Free Chlorine is the sum concentration of the hypochlorite ion (OCl^{-}) and hypochlorous acid ($HOCl$). According to WHO, the free chlorine of at least 0.5 mg/l is recommended in the water reservoirs and the recommended free residual chlorine of at least 0.2 mg/l at the point of use (WHO, 2017). Extreme values of free residual chlorine may affect the community's health. excessive concentration of free residual chlorine can cause irritation and unpleasant odor or taste in the water. Conversely, insufficient concentration of free chlorine may not effectively disinfect the water, allowing harmful microorganisms to survive and potentially cause waterborne diseases. The free chlorine and pH are interdependent, the pH of the water affects the effectiveness of the free chlorine. The effectiveness of free chlorine as a disinfectant is influenced by the pH of water. The range of pH for the free chlorine to be most effective is typically 6.5 and 7.5 (McFadden *et al.,* 2017). Therefore, pH and free chlorine must be regularly monitored to protect the public health.

Zanzibar Water Authority (ZAWA) and Zanzibar Ministry of the Environment are currently running a program in Zanzibar to measure the amount of free residual chlorine in the water. The Ministry of Environment tests free chlorine in the private water supply (community bulk monitoring) and ZAWA tests free chlorine in the ZAWA water supply. The test of each sampling point is done at least once a week for ZAWA and private water supply.

Zanzibar Water Authority (ZAWA) measures the free chlorine concentrations of the water sample based on colorimetric approach. Colorimetry is the most familiar and economical method for determining the amount of free chlorine and pH in water. Indicating reagents are substances that are introduced to water and whose reaction with free chlorine in the water changes the color of the water, indicating reagents such as diethyl-p-phenylenediamine (DPD), toluidine groups, potassium iodide (KI) solution, starch, and o-toluidine for chlorine and phenol red for pH. comparing with naked eyes the amount of free chlorine and pH in the water are determined by the water's color when compared to a set of standard colors (Sumriddetchkajorn *et al.*, 2013). The instrument used by ZAWA for measuring the free chlorine and pH in the water is the pooltester as shown in Fig. 1.

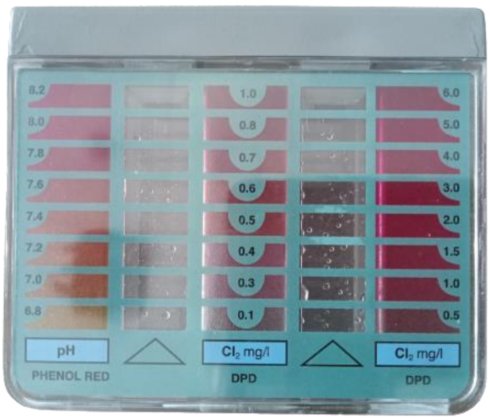


Figure 1: Pooltester

The proposed system for monitoring of free chlorine and pH is composed of the embedded system and web application. The system has been integrated with the GSM technology. Global System for Mobile Communication (GSM) technology has been deployed in the system for sending notification alerts and data as SMS. Notification alerts are sent when the values are extreme, and data are sent twice a day to the remote server for monitoring. The system composed of the web application for visualizing the pH and free chlorine of the water reservoirs on the map. The main objective of the current project was to develop a Short Message Service (SMS)-based system for monitoring free residual chlorine and pH in the water reservoirs.

1.2 Statement of the Problem

Chlorination is the most popular and economical method used for water treatment to eliminate bacteria and viruses. Chlorine has been used by public and private water suppliers to protect the public health against waterborne outbreaks such as cholera. However, chlorine should be used in a regulated manner to disinfect water safely and effectively without affecting human health. Free chlorine and pH are interdependent factors of water therefore it is necessary to regularly monitor the amount of free chlorine and pH in the water reservoirs for public health.

Zanzibar Water Authority (ZAWA) staff currently performs manual measurements of the free chlorine concentrations of the water sample locations at least once in a week. They use a colorimetric approach to measure free chlorine by utilizing pooltester or hach instruments. Additionally, they manually submit the results of the free chlorine of the sample locations using the Kobocollect application. This approach is prone to human errors, ineffective and time consuming for ZAWA staff. Additionally, because there are only a small number of ZAWA staff (about 4 staff) and roughly 45 ZAWA water reservoirs (27 in Unguja and 18 in Pemba), scattered across Zanzibar. It is exceedingly difficult for ZAWA staff to constantly examine the pH and free chlorine of the water reservoirs. Therefore, this current project intends to develop a digital system for simplifying the process of monitoring free chlorine and pH in the water reservoirs to match the limited resources of ZAWA.

1.3 Rationale of the Study

Cholera epidemics frequently affect Zanzibar, having a significant negative impact on the region's health, economic, and social activities. Cholera is still a threat to public health and economy of Zanzibar, cholera continues to kill and sicken people in Zanzibar, despite the fight. Zanzibar has recorded over 17 cholera outbreaks since 1978, totaling 14 364 cholera cases and

210 deaths. Since 2017, the government of Zanzibar has been working with partners to implement the Zanzibar Comprehensive Cholera Elimination Plan (ZCCEP), a 10-year plan to eliminate cholera by enhancing access to clean water and public facilities' sanitation (Bi *et al.*, 2018).

The developed system for monitoring amount of free chlorine and pH in the water enables mapping out the water reservoirs with their free chlorine concentrations and pH values. It aligns with the government's plan to eliminate cholera by ensuring public water reservoirs are always chlorinated.

The procedure currently used by ZAWA to manually measure the levels of free chlorine in water points and manually publish the results on the Kobocollect application is prone to human errors including missing dates and values, is ineffective and is time consuming for ZAWA staff because they must physically go to water reservoirs.

The developed system is accurate, cost effective and effective for monitoring amount of free chlorine and pH in the water reservoirs.

1.4 Objectives of the Study

1.4.1 General Objective

The main objective of the project is to develop a SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs.

1.4.2 Specific Objectives

The study aimed to achieve the following specific objectives:

(i) To gather requirements for developing SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs.

(ii) To develop SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs.

(iii) To validate the developed system.

1.5 Research Questions

The study intended to answer the following questions:

(i) What are the requirements for developing SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs?

(ii) How to develop SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs?

(iii) Does the developed system meet the requirements?

1.6 Significance of the Study

Through the project, the community will have access to safe and clean water that complies with the standards. By improving access to chlorinated water, the current project will eradicate waterborne outbreaks including cholera. The developed system will ensure the community have access to water supply that is within the recommended ranges of pH and free residual chlorine. The system will ensure early detection of unacceptable levels of pH and free chlorine, additionally, it will make pH and free chlorine monitoring a simple activity that can be carried out with limited resources, including staff.

The system is not prone to human errors since it is automated in monitoring and reporting pH and free chlorine concentration in the water reservoirs. The system is based on GMS technology which has a wide coverage and cost-effective.

1.7 Delineation of the Study

This current project is comprised of an embedded system and web application. The embedded system is based on ESP32, GMS module, pH sensor and free chlorine sensor all embedded together. The system is based on the GSM technology because it has a wide coverage and cost-effective. The embedded system measures the pH and free chlorine values and sends the data as SMS to the RapidPro. RapidPro is a SMS gateway platform used for data collection. On the other hand, web-based application fetches pH and free chlorine data from the RapidPro for visualization. Both qualitative and quantitative methods were used in this current project for data collection regarding the field of water quality.

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of the Key Terms

2.1.1 Short Message Service (SMS)

Short Message Service (SMS) technology is one of the stable, flexible, and ubiquitous wireless technologies for data exchange between subscribers. Global System for Mobile Communications (GSM) standard is the foundation of the SMS technology. The developed system uses GSM module to provide SMS services for remotely monitoring (ElKamchouchi & ElShafee, 2012).

2.1.2 Potential of Hydrogen (pH)

Potential of Hydrogen (pH) of a solution is calculated by the negative logarithm of the concentration of hydronium ions ($H3O +$); pH = -log [$H3O +$]. Zero to foutheen (0-14) is the range of pH, neutral value is when pH =7, acidic value is when pH less than 7 and basic value is when pH greater than 7 (WHO, 2017).

2.1.3 Free Residual Chlorine

Free Chlorine is the sum concentration of the hypochlorite ion (OCl^-) and hypochlorous acid (HOCl) (Waters & Hung, 2013). When chlorine is added into water, part of it reacts with microorganisms and some of it is left behind, known as free chlorine. Free chlorine will disappear when reacted with micro-organisms or lost to the outside world (WHO, 2017).

2.2 Related Works

Currently, ZAWA uses colorimetric approach to manually measure free chlorine in the water. This method involves adding an indicating reagent such as DPD to a sample of water in a pool tester, after some seconds the water color changes. Free chlorine concentration is approximated by visually comparing the water color after being mixed with DPD to the set of standard colors on the pooltester (WHO, 2017). The results of free chlorine concentrations are then manually recorded in the kobocollect android app. However, this method is ineffective, time consuming and prone to human errors due to lack of staff and long distances between water reservoirs.

Several studies have been conducted in the field of monitoring water quality parameters including temperature, free chlorine, and pH. They have led to the development of several systems for monitoring water quality parameters. The following are the reviews on the existing systems developed based on the past related studies.

2.2.1 System for Monitoring Residual Chlorine, pH, Temperature, and Bisphenol

Alam *et al.* (2021) developed an embedded system for monitoring water quality parameters such as residual chlorine, pH, temperature, and bisphenol. The system composed of carbon-based residual chlorine sensor, pd/pd-O based pH sensor, β-cyclodextrin bisphenol sensor, and temperature sensor, all these sensors were embedded on the glass slide. The system measures temperature and pH in real-time, residual chlorine in every 50s, and BPA in every half an hour. The system is portable, user friendly and monitors multi-parameters. However, the system has high capital and maintenance costs, consumes high power and it requires smartphone to capture the sensor data and upload the data to the cloud for monitoring.

2.2.2 Chemiresistor for Monitoring Residual Chlorine

Yen *et al.* (2020) developed a nanohybrid conductive paper based chemiresistor for monitoring residual chlorine. The sensed data are captured, processed by the circuit, and sent wireless to the smartphone via Bluetooth for monitoring. The system is small, user friendly and measures wide range of chlorine concentrations (0.1 ~ 500 ppm). However, the monitoring is limited locally, and it consumes high power when sending data to the smartphone via Bluetooth.

2.2.3 Colorimetric Device for Analyzing Free Chlorine in the Field

Dou *et al.* (2019) developed a self-calibration colorimetric device for the determining the level of free chlorine in the water samples based on smartphone. The colorimetric device was used to estimate the amount of free chlorine in the water samples in the field. The device consists of a light source, flow tube, an optical flitter array and a smartphone with a light illumination detector. The colorimetric reagent used in this study is N, N-diethyl-p-phenylenediamine (DPD). The colorimetric device is low-cost, accurate and sensitive. However, the device requires smart phone for it to operate and cannot be used for continuous monitoring of free chlorine in the water reservoirs.

2.2.4 Internet of Things Based System for Monitoring and Controlling Water Chlorination

Zidan *et al.* (2018) developed system for remotely monitoring and controlling of water chlorination based on the Internet of Things technologies. The system consists of Arduino based hardware and dashboard for remote monitoring. The system automatically monitors the amount of free chlorine and controls the chlorine dosing pump to maintain the amount of chlorine in the recommended range. Also, the system monitors the level of chlorine liquid in the tanks and sends the notification alerts to the person responsible when chlorine in the tanks runs out. The dashboard receives data from Arduino through Wi-Fi connection. The developed system is practical in the real-world settings. However, may not work in a low resource settings environment where internet is unavailable.

2.2.5 System for Monitoring Residual Chlorine, Temperature, and pH

Qin *et al.* (2018) developed a system for monitoring water quality parameters including residual chlorine, temperature, and pH. The system is composed of temperature, pH, and residual chlorine sensors embedded into a single system. The inkjet-printed temperature and pH sensors were integrated into a single sensing probe, and the residual chlorine sensor was electrochemically modified. The system is low-cost, easy to use, hypersensitive, accurate (accuracy >82%), and smaller (25 mm x 30 mm). However, the system measurements of the water quality parameters are limited locally and not sent to the cloud/central server for monitoring.

2.2.6 Real Time Water Quality Monitoring System Based on Internet of Things

Geetha and Gouthami (2017) developed an IoT based system for monitoring water quality in real time. The key parameters monitored in this study are pH, turbidity, water level and conductivity. The system consists of a microcontroller integrated with sensors for monitoring all parameters. The microcontroller uploads sensor data to the Ubidots cloud for remote monitoring. The cloud sends alert SMS messages when the parameters monitored have exceeded the threshold value. The system monitors five water quality parameters. However, the system does not monitor free residual chlorine.

2.2.7 Water Quality Monitoring and Control System based on WSN

Faustine, *et al.* (2014) developed a prototype system for monitoring and controlling water quality based on wireless sensor network within Lake Victoria Basin. The system comprised of three main blocks, dashboard, Wireless Sensor Network (WSN) sensor nodes and gateway nodes. The system is composed of Arduino microcontroller connected with water quality sensors and wireless module for network connection. Also, the system consists of a dashboard for remotely water quality parameters visualization. The system sense in real time the water quality parameters including pH, dissolved oxygen, electrical conductivity, and water temperature. The sensor data are sent to the web page and mobile application for visualization. The system has been put into use, to ensure that it works properly in the real-world settings. However, the system does not detect free chlorine concentration in the water.

2.3 Technical Research Gap

The related works in the field of water quality employ sophisticated technologies including internet to upload sensor data to the cloud. However, these technologies consume more power and will not work in the low resource settings real world environment where internet might not be available. Other related works determine the free chlorine concentration in the water sample locally, this approach is time consuming and not effective since monitoring of free chlorine cannot be done remotely.

The current project is set to address the technical gap by developing a system which consists of a device (embedded system) and companion dashboard (web application). The device detects the free residual chlorine concentration and pH in the water reservoirs and sends the sensor data to the dashboard via SMS for remote monitoring. The device sends SMS/Instant Messaging notification alerts to the human operator when pH or free chlorine concentration exceeds the threshold value. The dashboard will be used for monitoring and visualization of free chlorine and pH values of the water reservoirs to enable corrective, longer-term action. The proposed system is illustrated in Fig. 2.

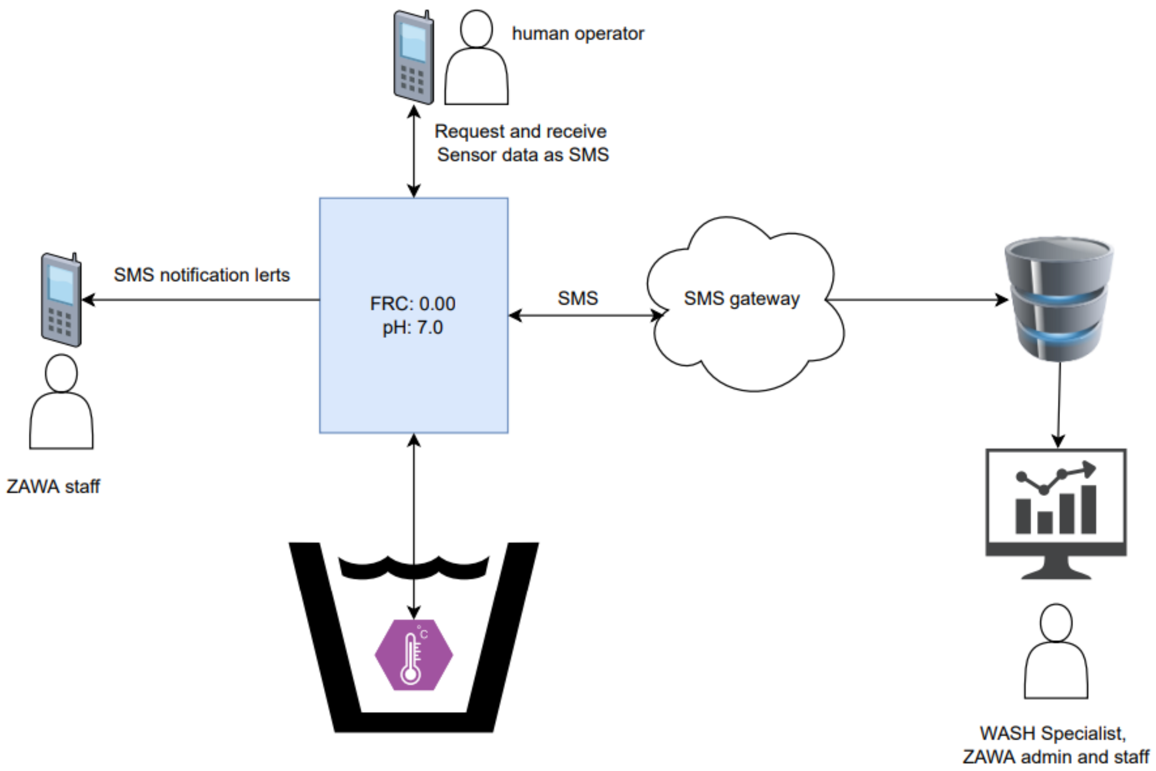


Figure 2: Proposed system

CHAPTER THREE

MATERIALS AND METHODS

3.1 Project Case Study

The current project was carried out at UNICEF Tanzania and ZAWA. Zanzibar Water Authority (ZAWA) is the authority that manages and supplies water direct to the community in Zanzibar. The current project was based in Zanzibar region because Zanzibar has had the most cholera outbreaks in Tanzania. Since 1978 to 2018, Zanzibar has reported over 17 outbreaks of cholera and reported a total of 14 364 cholera cases and 210 deaths (Bi *et al.*, 2018). Zanzibar Island is shown in Fig. 3.

Figure 3: Map showing Zanzibar Island

3.2 Research Methods

Both qualitative and quantitative methods were used in this current project for data collection regarding the water quality at Zanzibar. The data collection methods were employed to gain a clear understanding of the existing challenges and develop a solution that offers a significant value to the community in Zanzibar.

3.3 Target Population

This current project targeted ZAWA staff, Zanzibar's Ministry of Environment and UNICEF-Tanzania WASH specialists.

3.4 Sampling Technique and Sample Size

Snowballing combined with purposive sampling technique were employed in this current project to reach a total of 8 participants. Snowballing was used since it is versatile, fast, and the most common sampling technique used in qualitative research (Knott *et al.,* 2022). Snowballing was employed to obtain more participants from water quality field including ZAWA, Ministry of Environment and UNICEF Tanzania based on referrals and networking. Purposive sampling techniques was used since it is fast and cost-effective technique (Taherdoost, 2016). Purposely sampling techniques was utilized to reach more participants based on their expertise in the field of water quality. Both sampling techniques were employed to reach 8 participants; 3 ZAWA staff, 1 environmental officer, 4 WASH specialists.

3.5 System Requirements

The following are the tools employed in this current project to develop requirements for system development.

3.5.1 Data Collection Methods

Secondary data was collected from several sources including books, journals, websites, reports. These sources provide valuable background information, historical data, and research findings that were relevant. Primary data was collected through interviews and observation. Primary data were collected from UNICEF WASH specialists, environmental officer and ZAWA staff who were dealing with chlorination program in Zanzibar. These interviews and observation methods were used to obtain firsthand information, insights, and experience from the individuals who had a practical knowledge and experience in the field.

3.5.2 Data Analysis

The system was tested and validated by the system users including WASH specialist and ZAWA staff to ensure it met their requirements. Data from the validation was then analyzed by using Microsoft excel software application. The analysis primarily involved visualizing the data to extract additional insights and gain a deeper understanding of the information it contained.

3.6 System Development Approach

Extreme Programming (XP) agile development methodology was employed in the development of SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs. This methodology has been selected due to its ability to deliver product quickly even under time constraints and its ability to quickly respond to the changes in the requirements to meet user satisfaction (Tabassum *et al.,* 2017). Extreme Programming (XP) method is shown in Fig. 4.

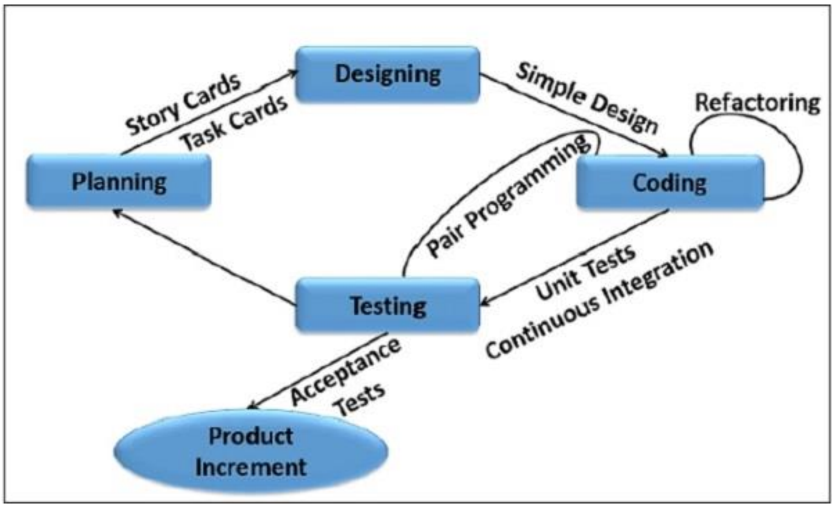


Figure 4: Extreme Programming (XP) agile development System Design

The conceptual design, block design, circuit diagram, use case diagram, flow chart diagrams, data flow diagram and database design diagram are presented in this section.

3.6.1 Conceptual Design

The system consists of a device (hardware) and a dashboard for remote monitoring. The device consists of microcontroller directed connected to free residual sensor, pH sensor, LCD and GMS for sending sensor data to the dashboard. The dashboard was used for monitoring and visualization of free chlorine concentration and pH by the ZAWA staff. The conceptual design is shown in Fig. 5.

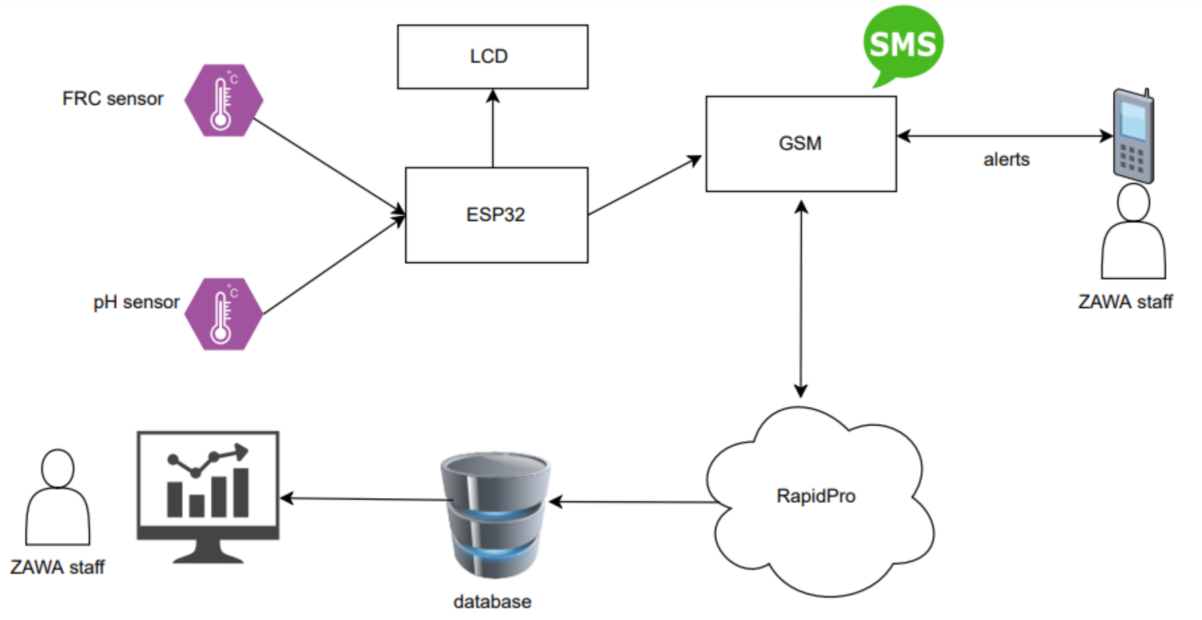


Figure 5: Conceptual design

3.6.2 Block Diagram

The device consists main five blocks, ESP32 microcontroller, liquid crystal display (LCD), FRC sensor, pH sensor and GSM module. The software part consists of three main blocks, SMS gateway, database and dashboard as shown in Fig. 6.

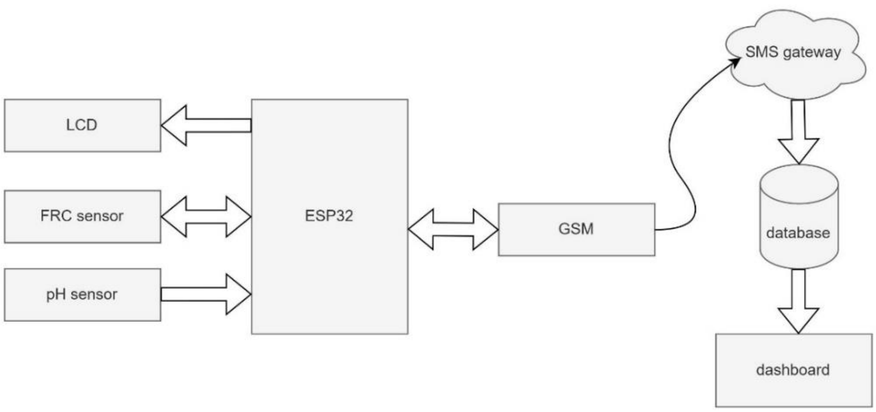


Figure 6: Block diagram of the system

3.6.3 Circuit Diagram

The system's circuit diagram consists of input of 5 VDC from either solar panel or adapter to charge 3.7 V lithium rechargeable battery through TP4056 battery charger. The voltage output of the TP4056 is boosted by the XL6009E1 boost voltage converter to 12 VDC for the free residual chlorine sensor and GSM module before being stepped down to 5 VDC by LM7805 to power the remaining components of the system including ESP32, pH meter and TTL to RS485 converter as shown in Fig. 7.

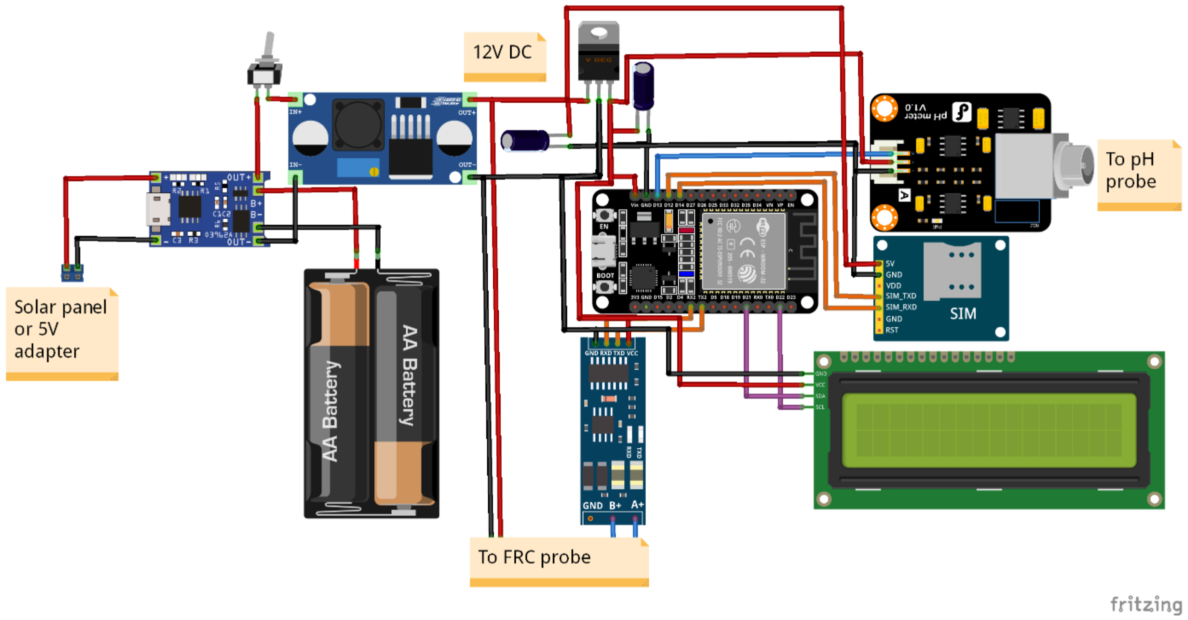


Figure 7: Circuit design of the system

The circuit diagram of the automatic switching power supply consists of the solar panel, LM2596 step down regulator, 5 VDC SONGLE relay, 1N4007 diode and 5 VDC adapter power jack. The LM2596 steps down the power from the solar panel to 5 VDC before being directly connected to the normally closed (NC) input of the relay. The adapter power jack powers the relay and is also connected to the normally open (NO) input of the relay as shown in Fig. 8. The relay automatically switches between solar panel and adapter power supply.

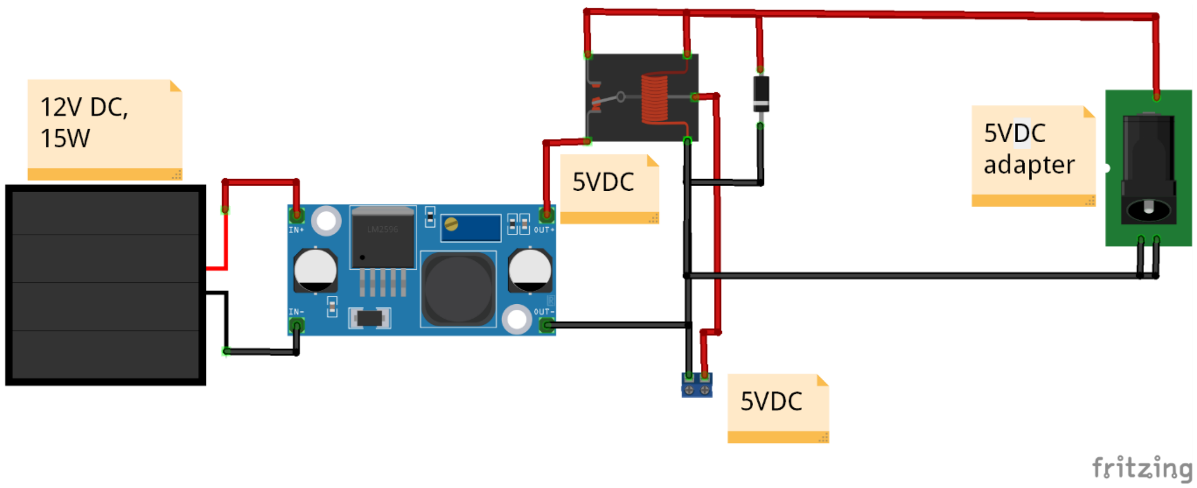


Figure 8: Circuit design for the automatic switching of power supply

The system's schematic PCB design consists of power jack, LM2596 step down voltage regulator, 5 VDC SONGLE relay, 1N4007 diode, TP4056 charger for 3.7 V lithium battery, XL6009E1 boost converter, LM7805 voltage regulator, 10 uF capacitor, 0.1 uF capacitor, terminal blocks for solar panel, switch, battery and free chlorine sensor 12 VDC power supply, and JST connectors for pH meter, GSM module, XY-K485 module and I2C 1602 LCD as shown in Fig. 9.

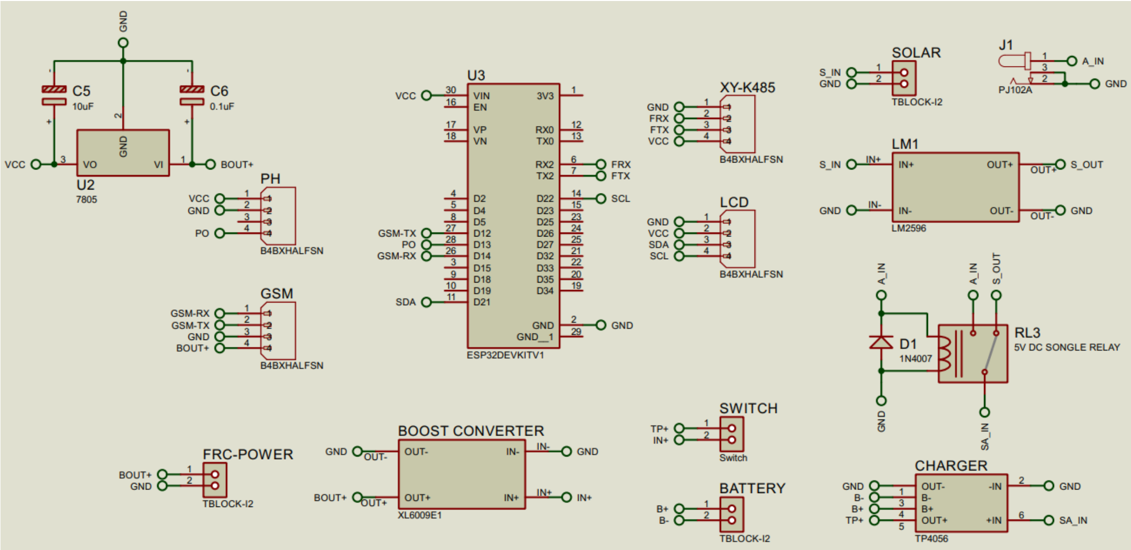


Figure 9: **Schematic capture for PCB design**

After designing the schematic for the PCB, all component's PCB packages were created and installed. Components' PCB packages were manually placed and routed on the bottom layer of the PCB layout as illustrated in Fig. 10.

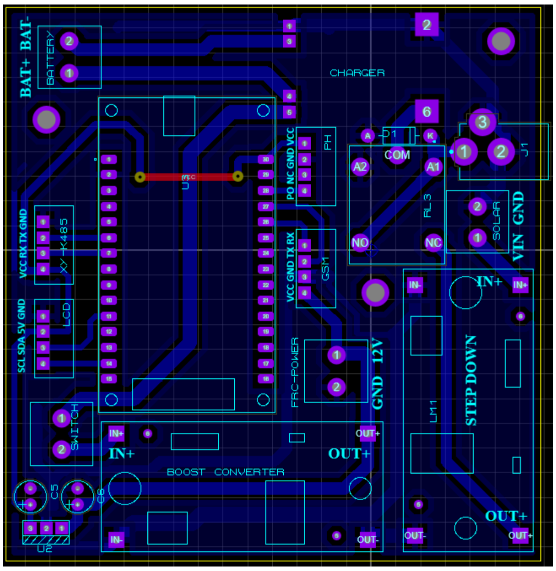


Figure 10: **Printed circuit board (PCB) layout**

To position the components on the PCB board more effectively, a Proteus 3D model was employed, as illustrated in Fig. 11.

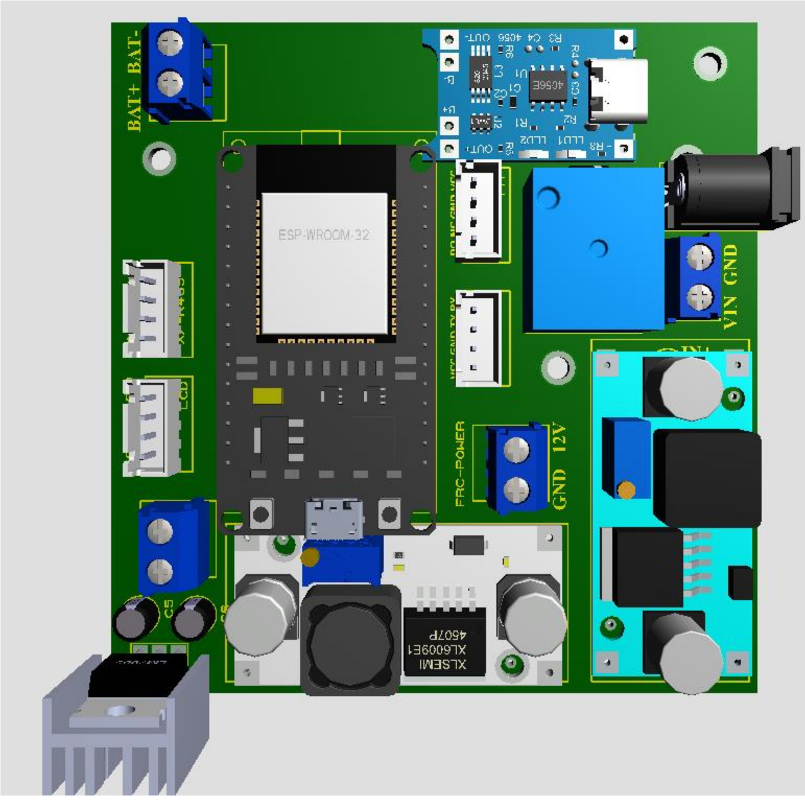


Figure 11: The 3D model of the system

3.6.4 Use Case Diagram

The system consists of three main actors, sensor module, WASH specialist (super admin), vendor admin and vendor staff. The sensor module sends the free chlorine concentration and pH in the water to the dashboard and sends the SMS notification alerts to human operator when the sensor data exceed the threshold value. The WASH specialist can perform all operations in the system including manage vendors, reservoirs, users, reports and sensor data. Vendor staff manages the vendor's data assigned to them including reservoirs, reports and sensor data, and Vendor admin manages vendor's staff and all the vendor's data such as reservoirs, reports and sensor data. The use case diagram of the system is illustrated in Fig. 12.

Figure 12: Use case diagram of the system

3.6.5 Flow Chart Diagram

A user needs to be registered and given credentials to login to the system for security purpose. The system requires users to enter their email and password, if the credentials provided are valid a user can be allowed to access the dashboard and be able to perform all authorized functionality according to their access level as shown in Fig. 13.

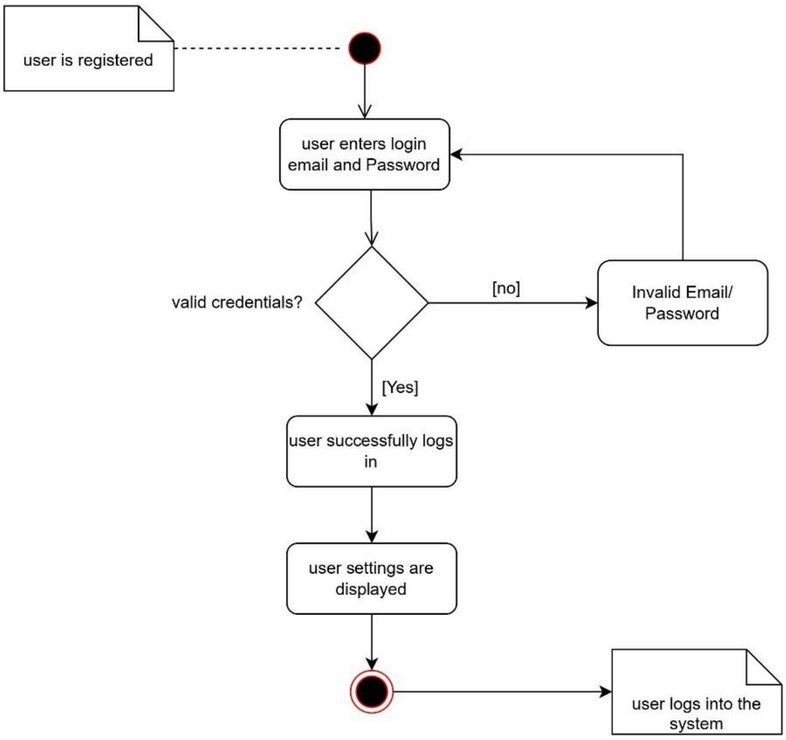


Figure 13: User authentication flowchart diagram

For the hardware device, GSM searches for network connection and the ESP32 microcontroller sets the baud rate for UART communication with GMS and XY-K485 module when the device is switched on. After the initial set up, the device reads the sensor data and display it on the LCD. The device sends the sensor data as SMS when sensor value exceeds the threshold value or when the device receives text either “niambie” (which means tell me) or “ripoti” (which means report) as illustrated in Fig. 14.

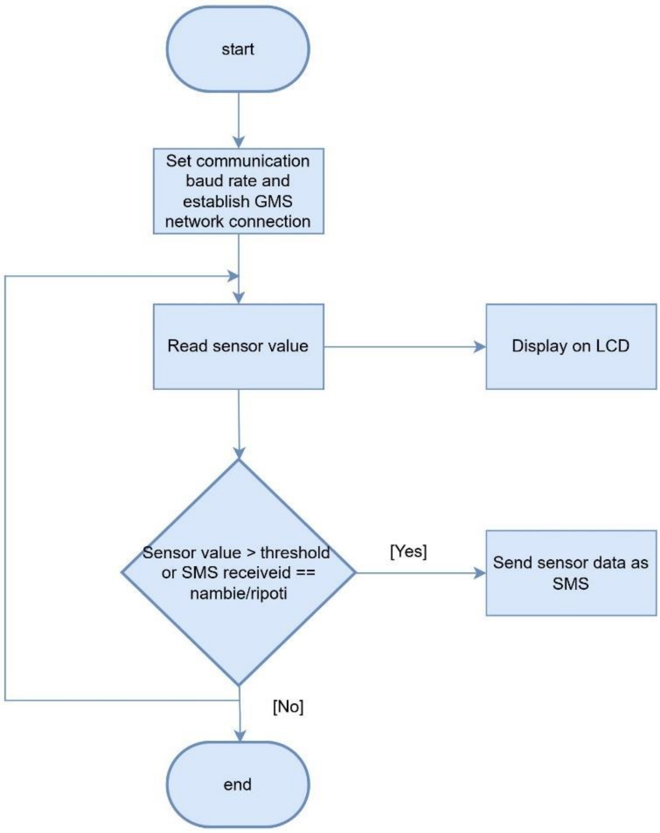


Figure 14: Flowchart of the hardware device

3.6.6 Data Flow Diagram

The system validates the credentials provided by the WASH specialist if they are valid, the system authorizes the WASH specialist to manage several modules including vendors, users, reservoirs and manage reports as illustrated in Fig. 15. Water, Sanitation and Hygiene (WASH) specialist can add, edit or delete vendors including ZAWA, users and reservoirs. Water, Sanitation and Hygiene (WASH) specialist can also visualize the free chlorine concentration and pH levels of the reservoirs.

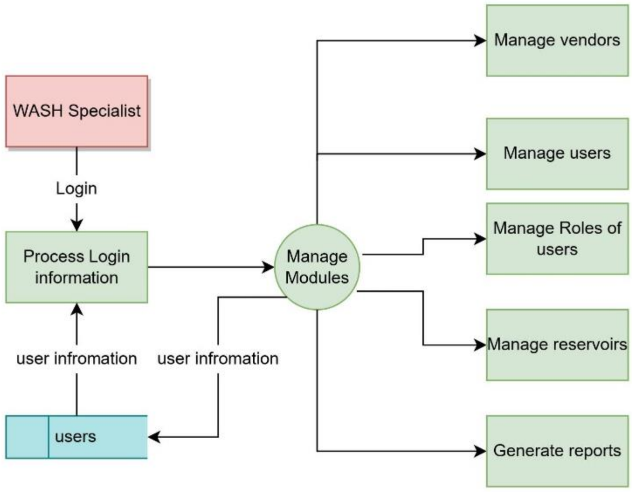


Figure 15: Water, Sanitation and Hygiene (WASH) specialist data flow diagram

The system validates the credentials provided by the vendor administrator. If they are valid, the system authorizes the vendor administrator to manage several vendor's modules, including users, reservoirs and generate reports as illustrated in Fig. 16. The vendor administrator can add, edit, or delete users and reservoirs. Furthermore, the vendor administrator can visualize the free chlorine concentration and pH levels of the reservoirs. The vendor administrator belongs to specific vendor including ZAWA or private vendor.

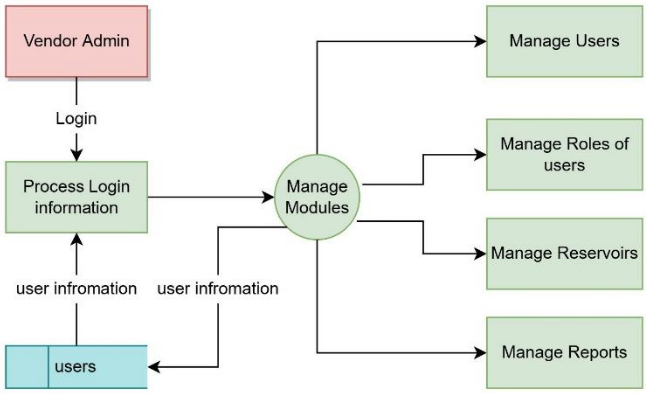


Figure 16: Vendor administrator data flow diagram

The system validates the credentials provided by the vendor staff if they are valid, the system authorizes the vendor staff to manage several modules including reservoirs and reports. Vendor staff can also monitor free chlorine concentration and pH levels of the reservoirs assigned by the vendor administrator as shown in Fig. 17. The vendor staff belongs to specific vendor including ZAWA or private vendor.

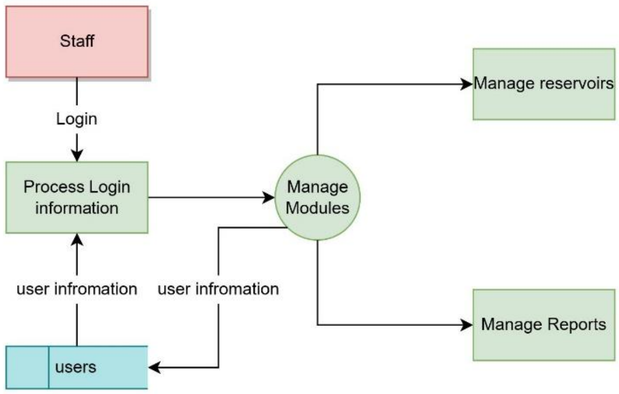


Figure 17: Vendor staff data flow diagram

3.6.7 Database Design

The database was named as frc_dashboard, which it consists six of tables; reservoir, junction, user, company, results and role. Database design is illustrated in Fig. 18.

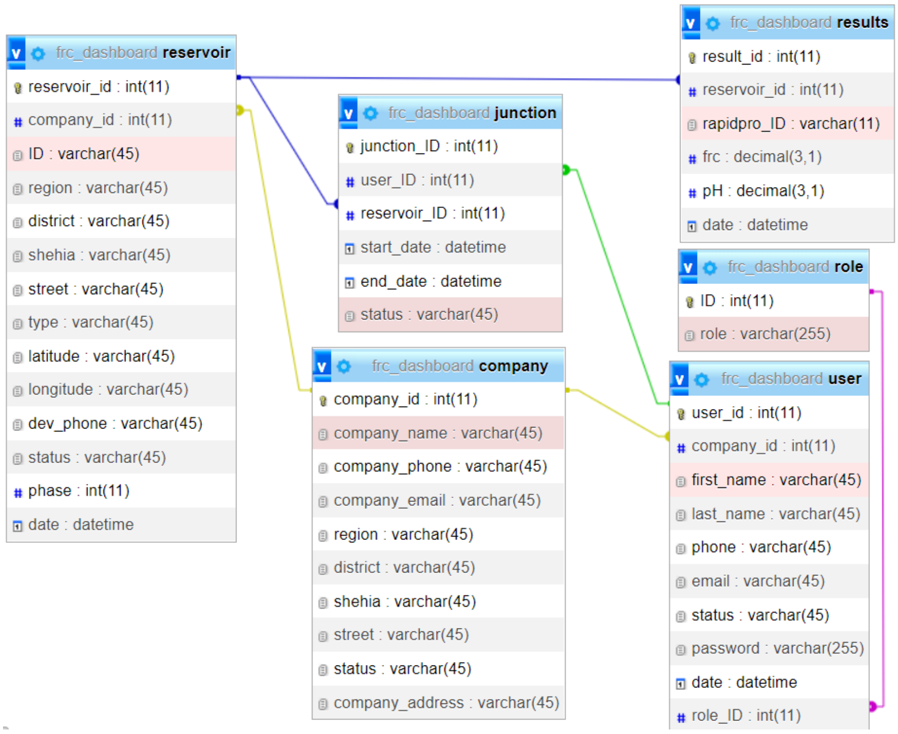


Figure 18: Database design

3.7 System Development

This section presents the hardware requirements and software requirements used during the system development.

3.7.1 Hardware Requirements

The hardware requirements used during the system development are presented in the Table 1.

Table 1: Hardware requirements for system development

Item	Specification
Microcontroller Board	ESP32
Liquid Crystal Display	1602 LCD Display
I2C Display interface adapter	PCF8574
pH sensor	Industrial grade pH sensor
Free chlorine sensor	BH-485-CL
TTL to RS485 Converter	XY-K485
GMS Module	GSM SIM800C
Batteries	3.7V 4200mAh lithium rechargeable batteries
Step Down converters	DC-DC Buck converters LM2596, LM7805
Step up DC-DC boost converter	XL6009E1
Electrolytic capacitors	10uF, 0.1uF
Battery charger	TP4056
Relay	SRD-05VDC-SL-C
Diode	1N4007
connectors and wires	JST, Screw terminal blocks
Solar panel	12V, 15W
Power jack	DC Power jack 5.5mm x 2.1mm (2.54mm Pitch)
Switch	SPST switch
Enclosure box	CE IP55 200x155x80mm outdoor waterproof power box
power adapter	5VDC/2A power adapter

(i) The ESP32

ESP32 is robust, low-power, and low-cost microcontroller with built in Wi-Fi 802.11 b/g/n, dual mode Bluetooth version 4.2, and dual core-processor. The ESP32 is the ESP8266's improved successor and comes with a number of new and sophisticated functions. Espressif Systems, a firm, designed the ESP32 chip (Babiuch *et al.*, 2019). In this current project, ESP32 has been used to read pH and free chorine sensor data and sends the data to the LCD display. In addition, ESP32 uses UART protocol to communicate with GSM module to send and receive SMS. The model of ESP32 used in this current project was ESP32-WROON-32 as shown in Fig. 19.

Figure 19: The ESP32-WROOM-32 development board

(ii) Liquid Crystal Display

The LCD display was used in this current project to display the pH and free chlorine concentration sensor. The LCD was used in this current project because they are power efficient, robust in harsh environments and portable. The LCD display used in this current project is a 16x02 LCD display as illustrated in Fig. 20. The LCD display was used with I2C Display interface adapter to be connected to the ESP32 microcontroller so as to reduce number of wires from 16 to 4 wires only including SCL, SDA, VCC and GND.

Figure 20: The 16 x 2 LCD display and I2C interface adapter

(iii) Potential of Hydrogen (pH) sensor

Industrial grade pH sensor was used in this current project to measure the pH of water and determine degree of alkalinity or acidity. This model was used since it is more accurate and respond fast than its previous model. Industrial grade pH sensor consists of pH electrode and pH meter board for voltage conversion interfaced by BNC connector. It can measure pH range of 0~14. The pH meter board can be powered by voltage in the range of 3.3~ 5V to be compatible with several microcontroller board. The pH probe is equipped with 5-meter-long cable, enables it to measure a water sample from a distance, as illustrated in Fig. 21.

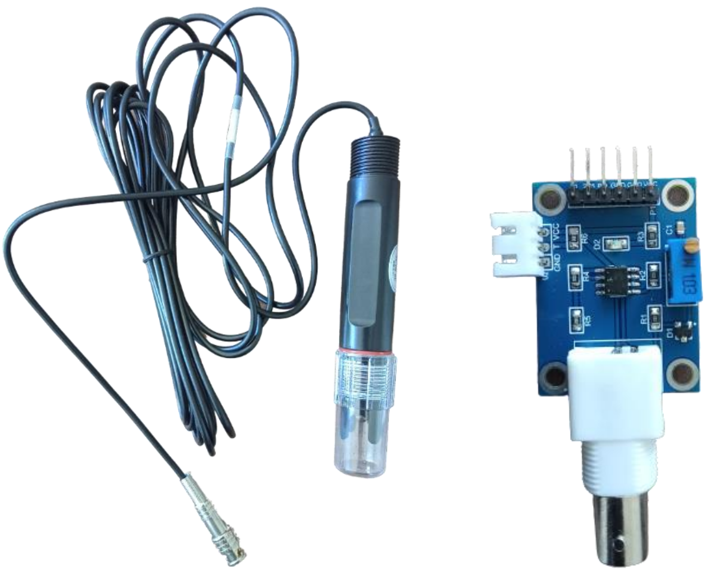


Figure 21: Industrial grade pH sensor

(iv) Free chlorine sensor

The model of the free chlorine sensor used in this current project was BH-485-CL digital residual chlorine sensor as shown in Fig. 22. It is advanced digital sensor for intelligently detecting water quality and it was independently developed by BOQU Instrument company. This sensor uses the RS485 communication protocol and comes with a 5 m long wire. It was selected to be used in this current project since it has several qualities such as fast response, high stability, accurate measurement, and high sensitivity (Shanghai BOQU Instrument Co., 2019). The measuring range of free chlorine is 0-20.00 mg/L.

Figure 22: The BH-485-CL digital residual chlorine sensor

(v) The TTL to RS485 Converter

This is the module which converts the communication protocol from TTL to RS485 communication and vice versa. The model used in this current project for TTL to RS485 converter was XY-K485 module as shown in Fig. 23. The free chlorine sensor used in this current project output RS485 signal which is then converted by XY-K485 to TTL standard for ESP32 microcontroller to understand. The RS485 communication standard is used since it has immunity to noise and can transmit data for a long distance.

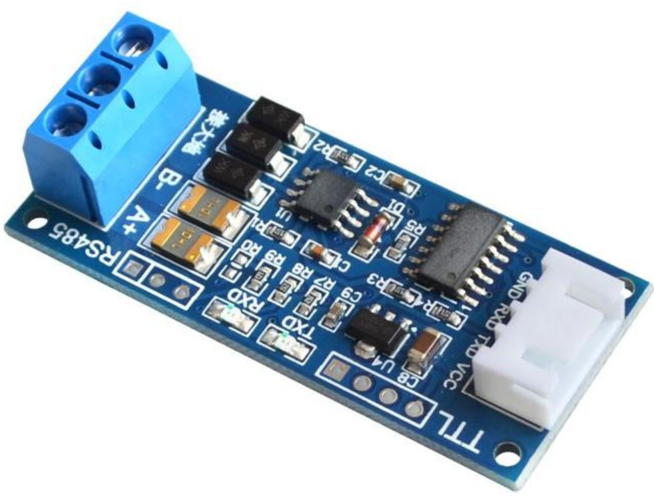


Figure 23: The XY-K485 module

(vi) Global System for Module Communication

Global System for Mobile Communication is the 2G wireless protocol used for mobile communication to transfer text, voice, and data. The GSM module employed in this current project is GMS SIM800C as shown in Fig. 24. The module requires Sim card to establish network connection. The GSM module is commanded by ESP32 microcontroller to receive and send texts through AT commands (Kanani & Padole, 2020). Communication protocol used was TTL which is compatible with the ESP32 microcontroller.

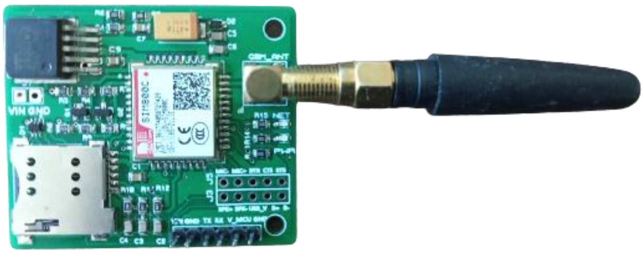


Figure 24: The GSM SIM800C module

(vii) Batteries

The batteries employed in this current project were 3.7 V 4200 mAh lithium (Li) battery as shown in Fig. 25. The system was powered by two batteries connected in parallel to increase capacity. These batteries are charged by either solar panel or 5 VDC adapter through TP4056 charger.

Figure 25: The 3.7V 4200 mAh lithium battery

(viii) Step Down converters

The step-down converters used in this current project were LM2596 and LM7805. The LM2596 buck converter is the DC-DC adjustable step-down converter with input voltage up to 40 V and output voltage range from 1.2 V~37 V as shown in Fig. 26. The LM2596 module was used to regulate solar panel output voltage to 5 VDC as shown in Fig. 27. The LM7805 module is the 5 VDC fixed voltage regulator. The LM7805 was used to regulate output voltage of the boost converter from 12 VDC to 5 VDC to power ESP32, pH meter, XY-K485 and LCD.

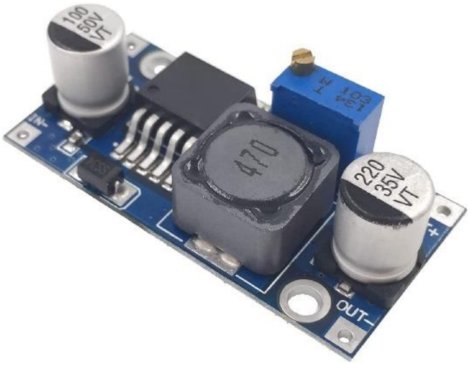


Figure 26: The LM2596 step down module

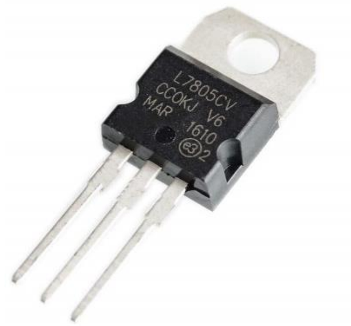


Figure 27: The LM7805

(ix) Electrolytic Capacitors

The electrolytic capacitors used in this current project are 10 uF and 0.1 uF as shown in Fig. 28. A 10 uF electrolytic capacitor was the input capacitor and a 0.1 uF electrolytic capacitor was the output capacitor connected to the LM7805 regulator. The primary function of input and output capacitors when used with LM7805 is to eliminate the AC noise ripple and produce pure DC voltage.

Figure 28: Electrolytic capacitor

(x) Battery charger

The battery charger employed in this current project was TP4056 standalone linear lithium battery charger as shown in Fig. 29. The TP4056 was used to charge two 3.7 V lithium batteries connected in parallel. The charging voltage for the TP4056 charger is fixed at 4.2 V. A red

LED on the TP4056 indicates that the batteries are charging, and a blue LED indicates that the batteries are fully charged. The TP4056 charger was selected since it can automatically recharge the batteries and prevents them from being overcharged.

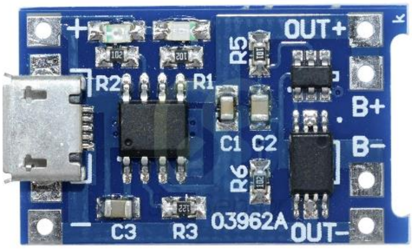


Figure 29: TP4056 standalone lithium battery charger

(xi) Relay

The specification of the relay employed in this current project was SRD-05VDC-SL-C as shown in Fig. 30. The model of the relay is SRD and the nominal coil voltage is 5 VDC. The relay was used in this current project for automatic switching between the solar panel and 5 VDC adaptor power supply for charging the lithium batteries. The relay was powered by a 5 VDC adaptor and it was also wired to normally open (NO) input of the relay. The solar panel voltage output was wired to normally closed terminal of the relay. The common output of the relay was connected to normally closed, allowing electricity from the solar panel when the 5 VDC adaptor was not providing power. The common output of the relay was switched to normally open when powered by the 5 VDC adapter, allowing 5 VDC adapter power supply.

Figure 30: The SRD-05VDC-SL-C relay

(xii) Diode

The specification of the diode used in this current project was 1N4007 as illustrated in Fig. 31. The diode was connected in forward bias to the VCC and GND terminals of the relay. The diode was connected with the relay to prevent the voltage spikes in the coil so as to protect the components around the relay.

Figure 31: The 1N4007 diode

(xiii) Solar panel

The specification of the solar panel used in this current project was 12 V, 15 W solar panel as shown in Fig. 32. Solar panel output voltage was stepped down by LM2578 buck converter from 12 V to 5 V. The 5 VDC voltage output was connected to TP4056 charger through the relay to charge lithium batteries.

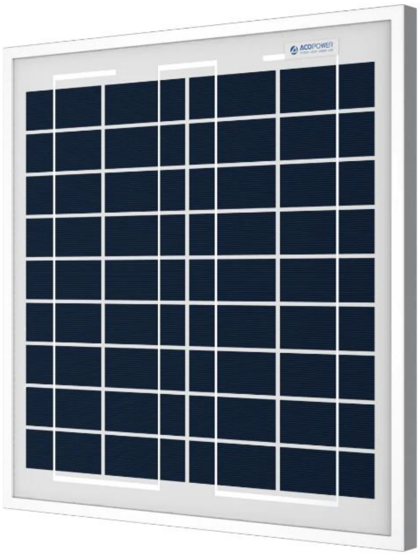


Figure 32: Solar panel

(xiv) Power jack and adapter

The power adaptor employed in this current project was 5 VDC power adapter as shown in Fig. 33 and the power jack used was DC female power jack 5.5 mm x 2.1 mm (2.54 mm Pitch) as shown in Fig. 34. The power adapter was used to charge batteries when connected to the power jack.

Figure 33: The 5VDC power adapter

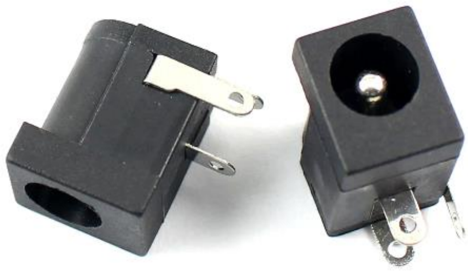


Figure 34: Direct Current female power jack

(xv) Switch

The specification of the switch employed in this current project was SPST switch as shown in Fig. 35. The switch consists of two bidirectional terminals. One terminal of the switch was interfaced to the TP4056 charger, and the other terminal was interfaced to the XL6009E1 boost converter. The switch was used to switch ON or OFF the system.

Figure 35: The SPST switch

(xvi) Enclosure Box

The specification of the enclosure box used in this current project was CE IP55 200x155x80 mm outdoor waterproof power box as shown in Fig. 36. The enclosure box was used as the case for the system and offers protection for the circuit and its components.

Figure 36: CE IP55 200x155x80mm outdoor waterproof power box

3.7.2 Software Requirements

This section presents the software requirements that were used during the system designing and development as illustrated in Table 2.

Table 2: Software requirements for system development

Software	Purpose
Draw.io	Modeling the UML diagrams for the system.
Proteus	Designing circuit and PCB.
Fritzing	Designing circuit
Arduino IDE	Writing sketches for the ESP32 Microcontroller.
Apache	Hosting and testing web application locally
MySQL	Database
PHP	Programming the web application
RapidPro	Collecting data via SMS
Visual Studio Code	Writing PHP, HTML, CSS and JavaScript code.

(i) Draw io

The draw io was employed in this current project to model UML diagrams for the system design. The case diagram, flowchart diagram, block diagram, conceptual design and system architecture were the UML diagrams developed. The draw io software is shown in Fig. 37.

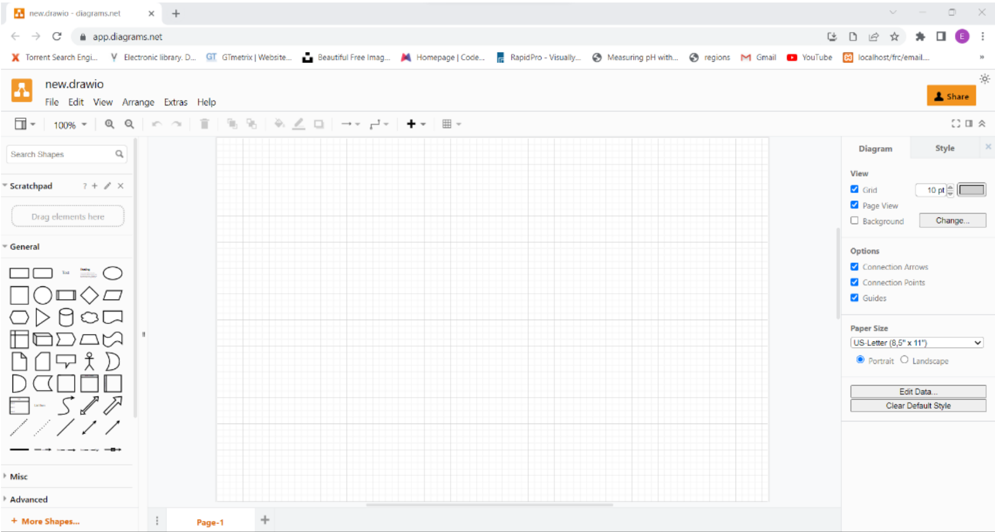


Figure 37: Draw io software

(ii) Proteus

Proteus was used in this current project for circuit and PCB designing for the proposed system. The proteus schematic capture section was used for designing the circuit. The PCB layout of the proteus was used for placing and routing all components in the PCB board and then was visualized in three dimensions on the 3D visualizer. The proteus software is illustrated in Fig. 38.

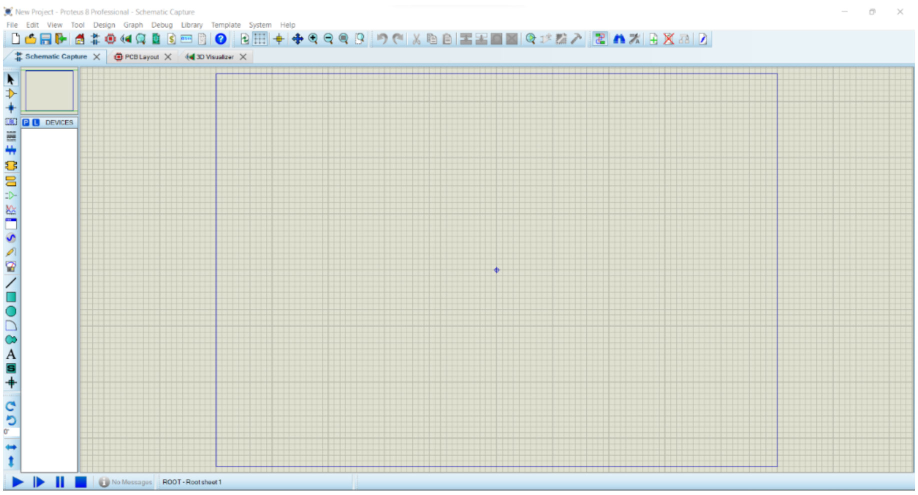


Figure 38: Proteus software

(iii) Fritzing

Fritzing was employed in this current project for circuit designing. The power supply circuit was designed separately. The other circuit consists of ESP32 microcontroller, sensors and the remaining components. Fritzing software is illustrated in Fig. 39.

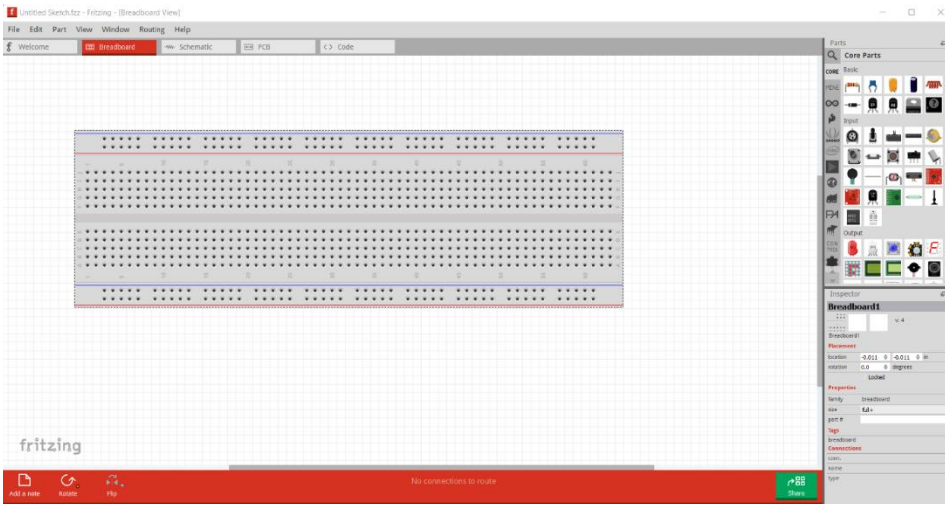


Figure 39: Fritzing software

(iv) Arduino IDE

Arduino IDE was used in this current project to write and compile sketches for the ESP32 microcontroller. To enable Arduino IDE to upload sketches to ESP32, first ESP32 boards is installed in Arduino IDE by using Arduino IDE Board manager. Arduino was selected to be used since it is very familiar IDE compared to others. Arduino IDE is shown in Fig. 40.

Figure 40: Arduino IDE

(v) Apache, MySQL, and PHP

Apache was used to host and test the web application locally before being deployed to the remote server. The MySQL was used as the database to store information required by the web application. The PHP was used to program the web application on the server side and connect it to the database.

(vi) RapidPro

RapidPro is a platform used to collect data via SMS, social media, and voice. It is an open source, open standards, and collaboration. It was used in this current project for data collection using SMS.

(vii) Visual Studio Code

Visual studio code was used in this current project for editing codes for dashboard development. Visual studio code was used to edit PHP, HTML, CSS and JavaScript codes.

3.8 System Testing

The V-Model was employed in this current project for system testing. Testing was involved in every stage of the development to deliver robust and error free system. Initially, unit testing was performed, whereby each module was tested separately independent of all the other modules. Thereafter, integration test was performed, whereby, separate modules were integrated and tested. Followed by system testing where the entire system was tested end to end, looking out for errors and correcting them. Finally, user acceptance testing was performed where user tested system functionality to ensure user requirements were met. The V-Model is illustrated in Fig. 41.

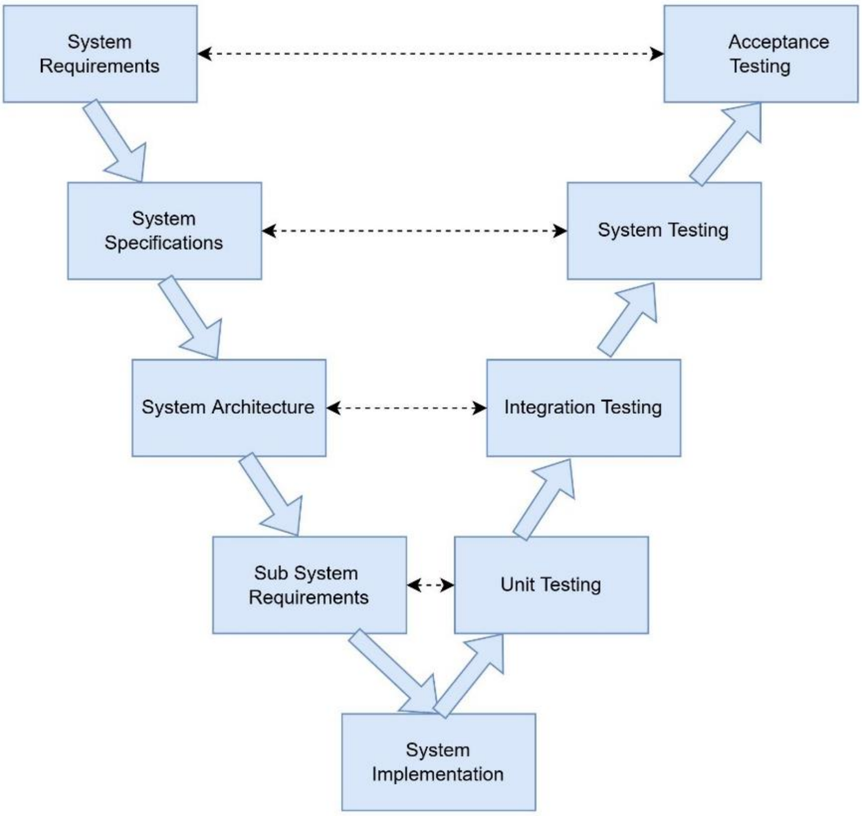


Figure 41: V-Model system testing

3.9 System Validation

Validation is a crucial step in ensuring that the developed system meets the user requirements. The system was used by the users and a user experience survey was issued to validate the developed system. All the actors including WASH specialist, vendor admin and staff were provided with access to the developed system and allowed them to use the system within their normal operations. They were then requested to fill in the user experience surveys for evaluation and validation of the system. The results from the survey enabled the validation of the system.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results from Interviews and Observations

Methods including interviews and observations were utilized for data collection during the field visit in Zanzibar. The interview guide used to interview ZAWA staff and environmental officer is shown in Appendix 3 and that for WASH specialist is shown in Appendix 2. During the field visit there were several key findings that were observed as discussed below.

4.1.1 Test Kit Used for Measuring Free Chlorine

Pooltester, hach, and an electronic sensor are the test kit used to measure free residual chlorine, as shown in Fig. 42. Pooltester is easy to use and produce results fast but not accurate compared to hach. Currently, electronic sensor for free chlorine is not typically utilized since they are not field-portable and takes longer to produce results than pooltester and hach.

(a) (b) (c)

Figure 42: Pooltester (a), hach (b), and electronic sensor (c)

Test results are manually submitted to the android application called Kobocollect application. The application sends data to the dashboard where they can be exported in XML format for analysis. Data analysis is done manually once in every week.

4.1.2 Zanzibar Water Authority (ZAWA) Sampling Points Visited

During a field visit, a total of 12 ZAWA sampling points across Mjini, Magharibi A and Magharibi B districts were visited accompanied by ZAWA data collector. Pooltester test kit was used to detect free chlorine in the water. The results for the ZAWA sampling points visited are shown in Table 3.

Table 3: Results of the visited sampling points

Id	District	Shehia	Location	FRC (mg/l)
MJSP03	Mjini	Gulioni	Kituo cha polish makadara/Gulioni	0.3
MJSP04	Mjini	Makadara	Mitiulaya/Makadara	0.0
MJSP06	Mjini	M/Shauri	Msikiti mdogo/Malofa	0.4
	Mjini		Malindi-Malindi	0.4
MJSP05	Mjini	Mikunguni	Ng'ambo	No water
MJSP22	Mjini	Kilimani	Mnara wa mbao	0.0
MJSP10	Mjini		Sateni (chlorination plant)	1.0
MASP04	Magharibi A	Dole	Dole tank (chlorinantion plant, not always guarded)	FRC couldn’t be tested, there was no access to water sample)
MASP05	Magharibi A		Bububu-polisi	No water
MASP07	Magharibi A		Dole-Kidichi	0.3
MASP11	Magharibi A		Welezo (chlorination plant, 4 guards)	0.0 chlorination plant was not working
MBST01	Magharibi B	Kinuni	Kinuni water tank (chlorination plant)	0.0 chlorination plant was not working

Table 3 illustrate the results of the sampling points visited during the field visit in Zanzibar. Every sampling point has been assigned a unique ID to distinguish it from others. The sampling points visited were in three districts in Zanzibar; Mjini, Magharibi A and Magharibi. Very few sampling points are guarded, most of them are not guarded.

The images of field visits to several sampling points are shown in Fig. 43. The water reservoir for ZAWA where chlorination takes place is shown on the left, while the sampling point close to consumers is shown on the right.

Figure 43: Sampling points field visit

4.1.3 Chlorination Process

Chlorination is done either manually or automatically by the chlorination plants. The flow rate of water entering the tank is estimated and the corresponding flow rate of chlorine entering into the tank is set for automatic chlorination. The chlorination process is shown in the Fig. 44.

(a) (b)

Figure 44: Chlorination plant (a) and water chlorination (b)

4.1.4 Mapping For ZAWA Sampling Points

The water reservoirs to be monitored are registered into the kobocollect android application and assigned a unique ID. The activity of mapping ZAWA water reservoirs is done by ZAWA data collectors. The mapped water reservoirs are then assigned to ZAWA data collectors for monitoring.

The following parameters are used when mapping ZAWA sampling points:

(i) Date

(ii) District

(iii) Shehia

(iv) Village/street

(v) Name of the data collector

(vi) Location type? (Treatment plant, distribution tank, water truck filling point, piped network sampling point or water extraction)

(vii) Location

(viii) Name of the responsible person

(ix) Phone number of the responsible person

(x) Was this location previously included in ZAWA piped network sampling? (yes/no)

(xi) Collect GPS coordinates of the tank? (Latitude, longitude, altitude, and accuracy (within 5 meters))

(xii) Comments?

4.1.5 Free Chlorine Monitoring

Monitoring of free residual chlorine in the water reservoirs is done weekly by the ZAWA data collectors. The following parameters are filled when recording results into the kobocollect application.

(i) Date

(ii) District

(iii) Shehia

(iv) Village/street

(v) Name of the evaluator

(vi) Location type? (Treatment plant, distribution tank, truck filling point, piped network, sampling point, storage tank or water extraction)

(vii) Name of the sampling point (piped network)

(viii) Type of the tap stand (private household tap/community tap stand)

(ix) Water available at the time of visit?

(x) Free residual chlorine?

(xi) Type of the test kit used.

(xii) Collect GPS coordinates of the tank? (Latitude, longitude, altitude, and accuracy (within 5 meters))

(xiii) Comments?

4.1.6 Data Analysis

Data analysis is done manually by the ZAWA data analysist once in every week. Zanzibar Water Authority data analyst is trained by WASH specialist on the data analysis procedures. Data to be analysed is exported in XML format from the kobocollect dashboard. Data analysis is time-consuming and requires good technical expertise of XML files, making it prone to human errors. The parameters include in the data analysis report are the district, number of sampling points visited, number of sampling points with water availability, free chlorine concertation and type of the test kit used to detect free chlorine. The result for data analysis during week 38 (May 9-15) is illustrated in Fig. 45.

ZAWA Monitoring

Piped Network and Treatment Tank Sampling points

Week 38 (May09-15)	Number of points visited	Number of points with water availiable for sampling	Number of Samples n(%)	Number of Samples n(%)	Number of Samples n(%)	Number of Samples n(%)	Number of Samples n(%)
			< 0.1 mg/L	0.1 - < 0.2 mg/L	0.2 - < 0.5 mg/L	0.5 - 1.0 mg/L	>1.0 mg/L
Total	**43**	**34**	**2(6%)**	**0 (0%)**	**0 (0%)**	**32 (94%)**	**0(0%)**
Magaharabi A	8	6	0(0%)	0 (0%)	0 (0%)	6 (100%)	0 (0%)
Magaharabi B	0	-	-	-	-	-	-
Micheweni	5	5	0(0%)	0 (0%)	0 (0%)	5(100%)	0 (0%)
Mjini	17	10	2(20%)	0(0%)	0(0%)	8(80%)	0 (0%)
Wete	13	13	0(0%)	0 (0%)	0 (0%)	13(100%)	0 (0%)
	43	34					

Type of Test kit used

HACH CN 66	18
Pooltester	16

	Total number of sampling points	Number of points visited	Number of sampling points missed
Unguja	41	17	24
Pemba	18	18	0
		35	

Figure 45: Results for ZAWA data analysis

4.2 Identified Requirements

This section is divided into two subsections, functional requirements and non-functional requirements of the proposed system.

4.2.1 Functional Requirements

Functional requirements entail the desired input and output behavior of the system regardless of the physical constraint. The behavior may be described as functions, tasks, or services the system is intended to accomplish. The functional requirements of the proposed system are shown in the Table 4.

Table 4: Functional requirements of the system

S/N	Functional requirement	Description
1.	Detect free chlorine and pH in the water.	The system shall automatically capture free chlorine concentration and pH in the water.
2.	Display free chlorine concentration and pH on the LCD.	The LCD shall continuously display free chlorine concentration and pH values.
3.	Send free chlorine concentration and pH values as SMS.	The system shall send the values of free chlorine concentration and pH as SMS twice a day to the SMS gateway.
4.	Send SMS notification alert.	The system shall send SMS notification alert to human operator when free chlorine concentration and pH values exceeds the threshold value.
5.	Two source of power supply to recharge the batteries.	A system's batteries shall be charged by solar panel or 5 VDC adapter from mains.
6.	Visualize free chlorine and pH of the water reservoirs.	A system shall visualize the free chlorine and pH of the water reservoirs for immediate action.
7.	Manage users, sampling points and sensor data.	A system shall manage users, sampling points and sensor data.
8.	Generate reports.	A system shall generate users, reservoirs and sensor data reports.

4.2.2 Non-functional Requirements

Non-functional requirements describe the quality property of a system in terms of security, reliability, performance as well as usability attributes. The non-functional requirements of the developed system are shown in Table 5.

Table 5: Non-functional requirements of the system

S/N	Non-Functional Requirement	Description
1.	Security	Authentication of the users before they access the system, and the device will be guarded 24 hrs.
2.	Accessibility and availability	The system is accessible and available at any time whenever needed.
3.	Usability	The system is user friendly.
4.	Reliability	The system is reliable without facing major issues during the operation.
5.	Portability and Maintainability	The system is portable and easily maintained.
6.	Scalability	The system is easily scalable.

4.3 System Design Results

The system consists of a device (embedded system) and companion dashboard (web application). The device consists of ESP32 microcontroller, GSM, LCD, pH sensor and free chlorine sensor. The ESP32 reads the sensor data and displays it on the LCD display. The sensor data are sent to the SMS gateway by GSM for remote monitoring. The API transfer the sensor data from the SMS gateway to the intermediate database. The dashboard is used for visualizing the sensor data in a graphical and tabular format. The system architecture is illustrated in Fig. 46.

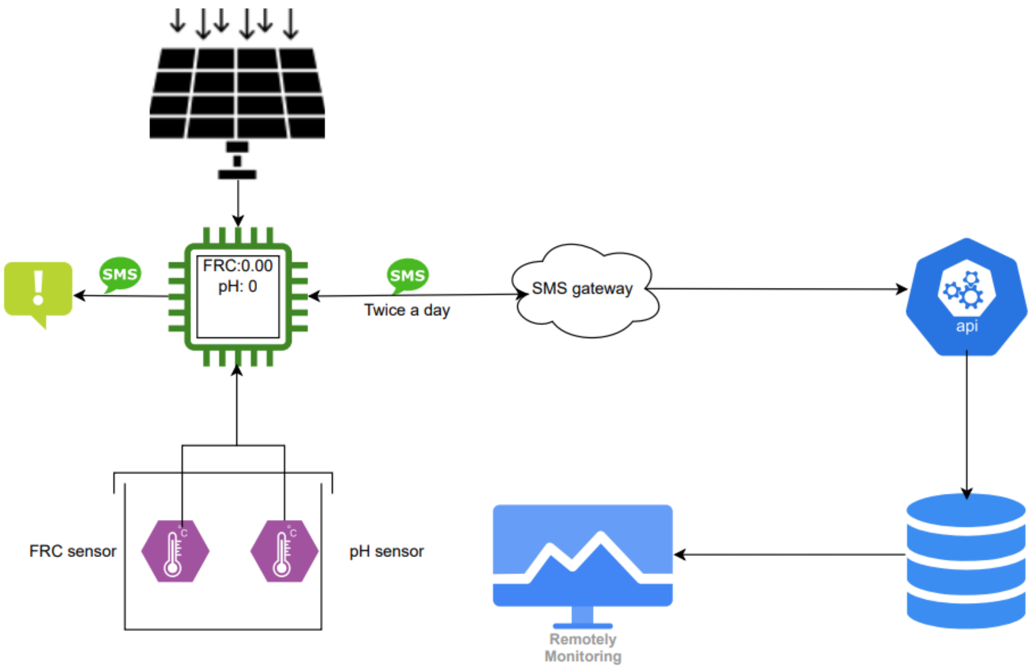


Figure 46: System architecture

4.4 System Development Results

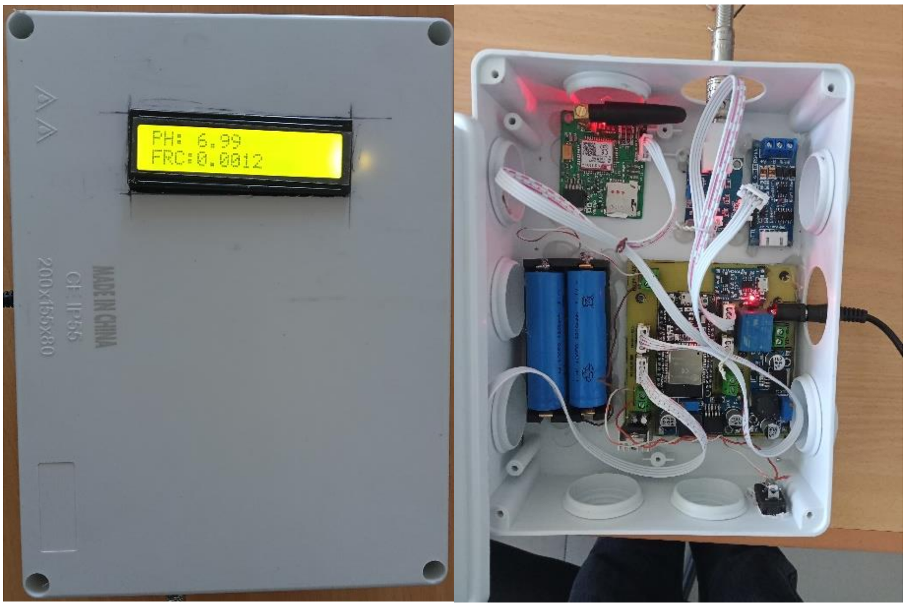
This section involves the results of the development of hardware device and web application.

4.4.1 Hardware Device Results

The hardware device for monitoring pH and free chlorine in the water was developed. The device consists of two sensors submerged into the water; pH and free chlorine sensors. The sensor data are displayed on the LCD display. The device is powered by Lithium batteries which can be recharged by 12V, 15W solar panel or 5V adapter. The hardware device is shown in the Fig. 47.

Figure 47: Prototype of the system

Top view and internal view of the hardware device are shown in Fig. 48. The top view shows the pH and free concentration values on the LCD display.



(a) (b)

Figure 48: Top view (a) and internal view (b) of the hardware device

4.4.2 Web Application System Results

This section presents the results for the development of the web-based application for monitoring pH and free chlorine in the water reservoirs.

(i) Login

This section presents the login page for all the system users; WASH specialist, vendor admin and vendor staff. Users must be signed up to log in into the system. The login page requires users to enter their credentials such as email and password. When the credentials are valid, the system will authenticate the user to access the system based on their access level. The login page is shown in Fig. 49.

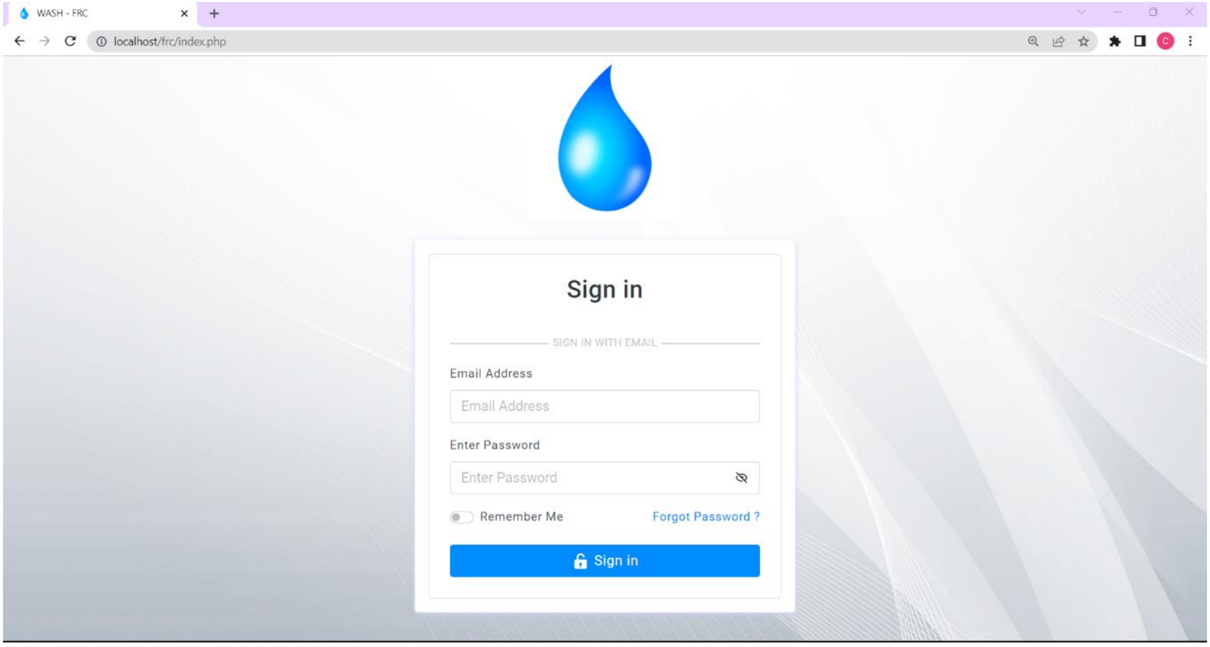


Figure 49: Login page for system users

(ii) Vendor Registration

Vendor registration can be done by WASH specialist only. Water, Sanitation and Hygiene (WASH) specialist creates an account for the new vendor into the system by filling several details including name, email, phone number, region, district, shehia, street and address. Vendor registration page is shown in Fig. 50.

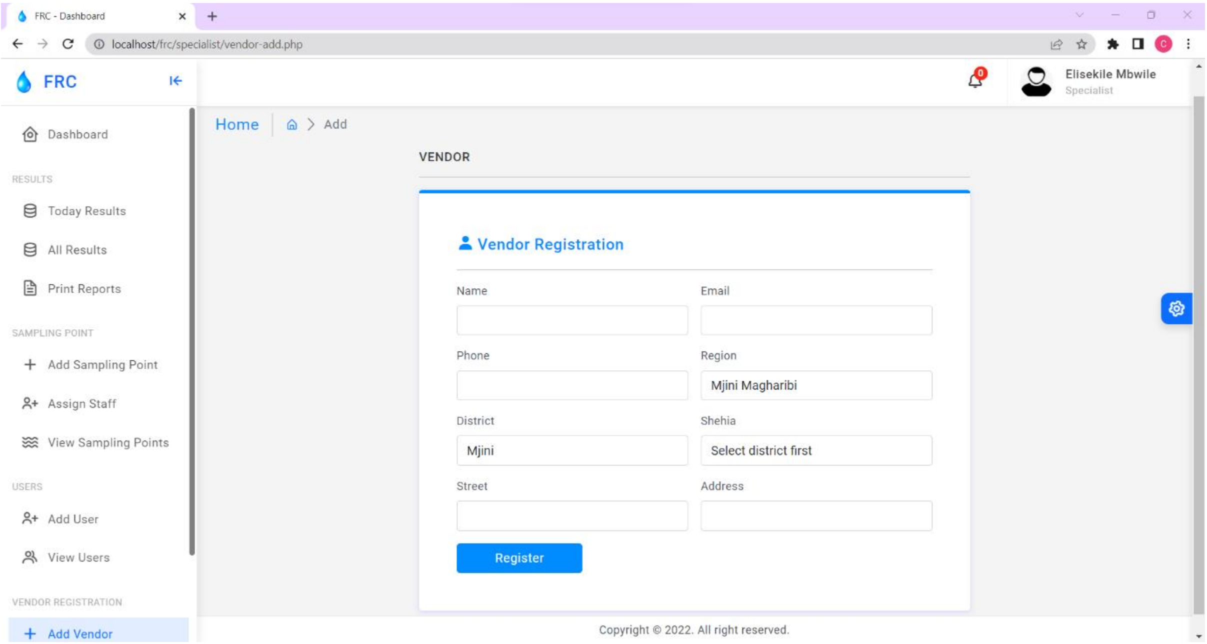


Figure 50: A page for registering a new vendor

(iii) View Vendor Section

The page of the dashboard that displays the list of all vendors registered into the system was developed. This page can only be accessed by WASH specialist. The page displays vendors' details including name, email, phone number, region, district, shehia, street, address, number of sampling points and status. The view vendor page is shown in Fig. 51.

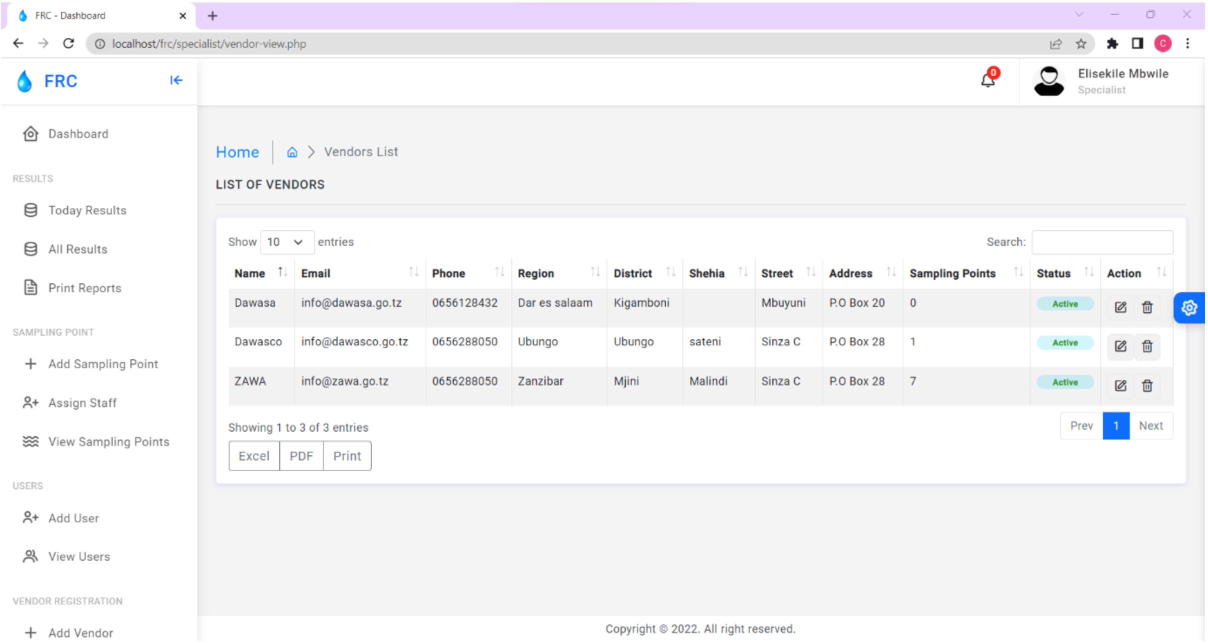


Figure 51: Page for viewing all registered vendors

Water, sanitation and hygiene (WASH) specialist can perform two actions; delete or edit vendor's details. A page for editing specific vendor's details pops up when the edit icon is clicked. A pop-up page for editing vendor's details is shown in Fig. 52.

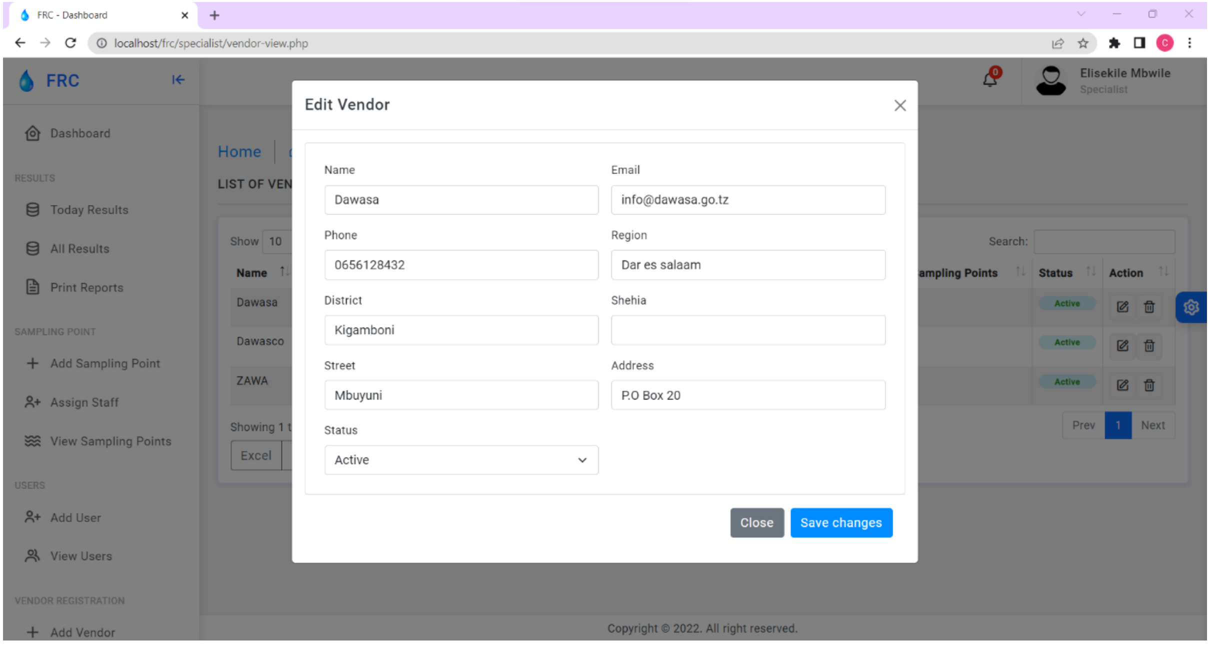


Figure 52: A pop up page for editing vendor's details

A delete vendor alert pop-up page shows up when a delete icon of a specific vendor is clicked. A vendor will be deleted permanently from the database after confirming the vendor and click the delete button on the delete pop-up page. A pop-up alert for deleting a vendor is shown in Fig. 53.

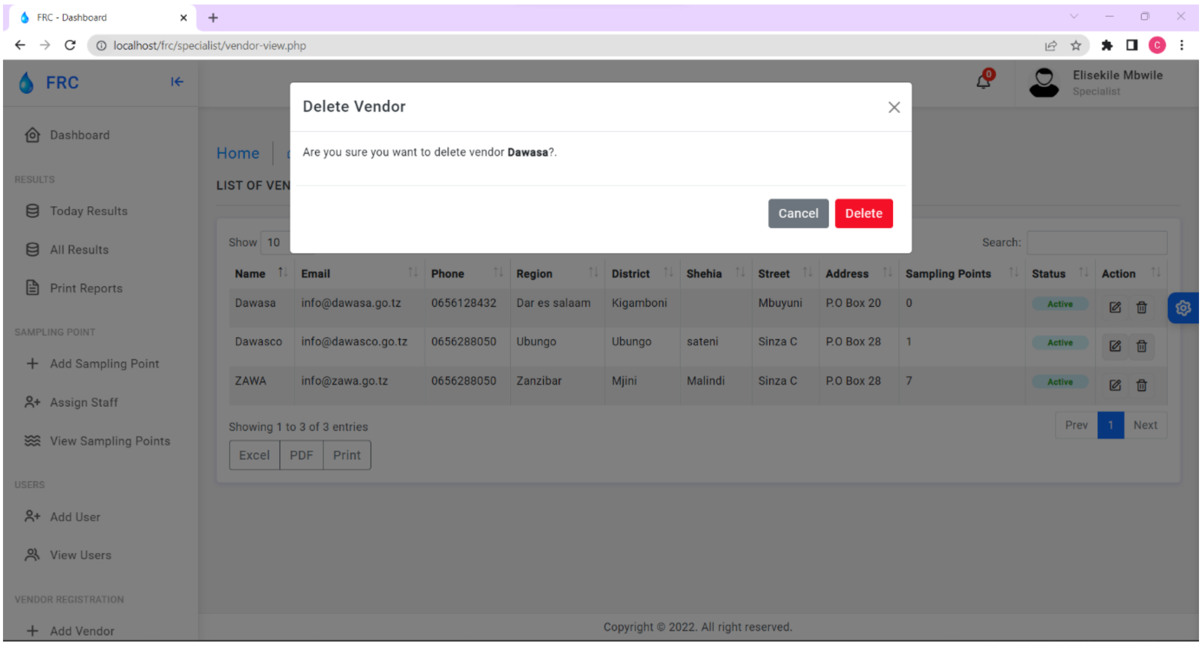


Figure 53: A pop up alert page for deleting a specific vendor

(iv) User Registration

User registration can be performed by two system actors; WASH specialist and vendor admin. Water, sanitation and hygiene (WASH) specialist can add users (specialist, staff or admin) of any vendor while vendor admin can add users (admins or staff) of their own vendor. User's account is created by filling several details including first name, last name, email, phone, vendor, role, and initial password. User password is encrypted by using password-hash algorithm since it is strong and most secure hashing algorithm. User registration page is shown in Fig. 54.

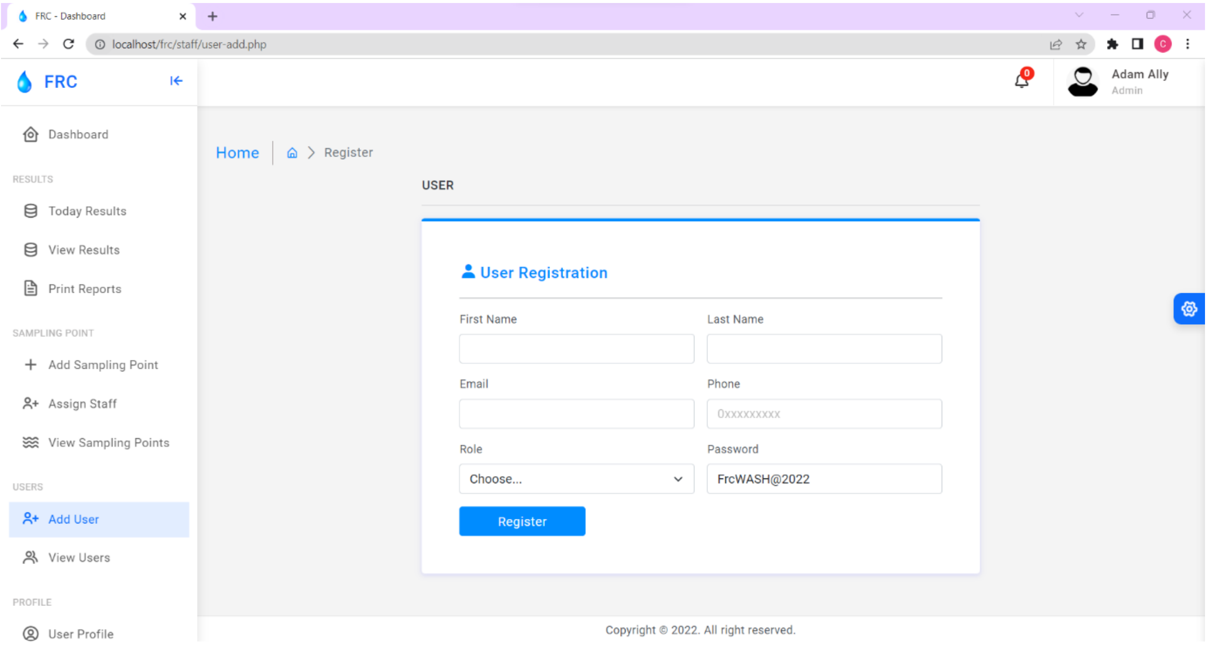


Figure 54: User registration page

(v) View System Users

The page for viewing all the users after they have been registered into the system was developed. This page shows users' details including name, email, phone, role, number of assigned sampling points and status. The user view page is shown in Fig. 55.

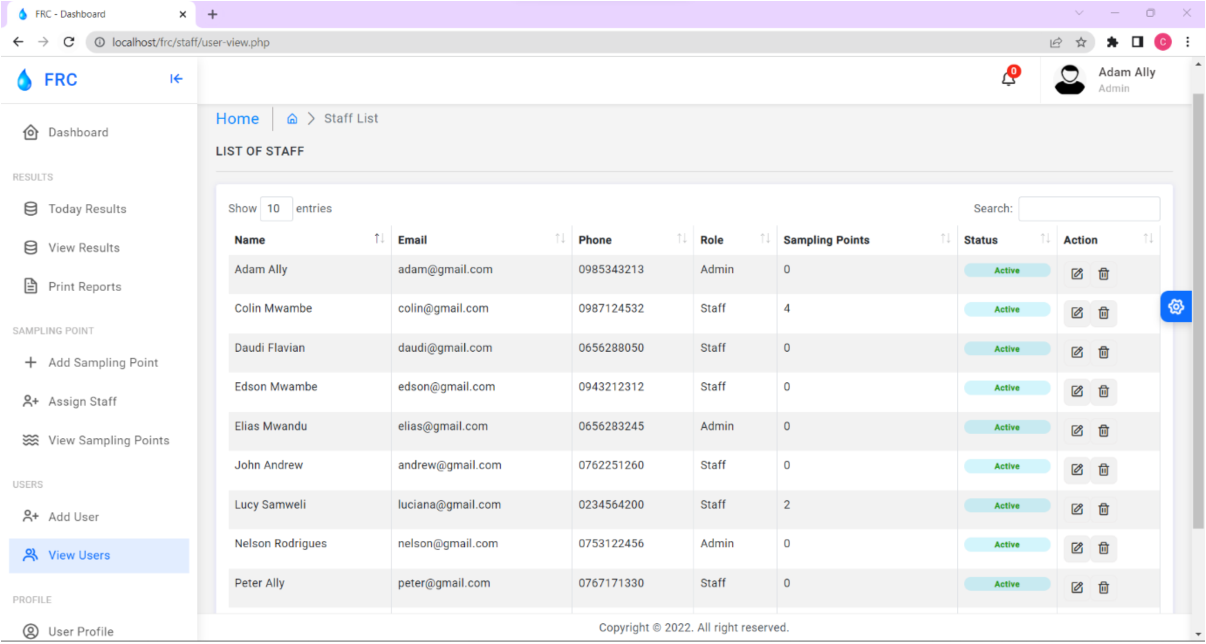


Figure 55: A page for viewing system users

Deleting or editing user's details can be performed in this page. A page for editing specific user's details pops up when the edit icon is clicked. A pop-up page for editing user's details is shown in Fig. 56.

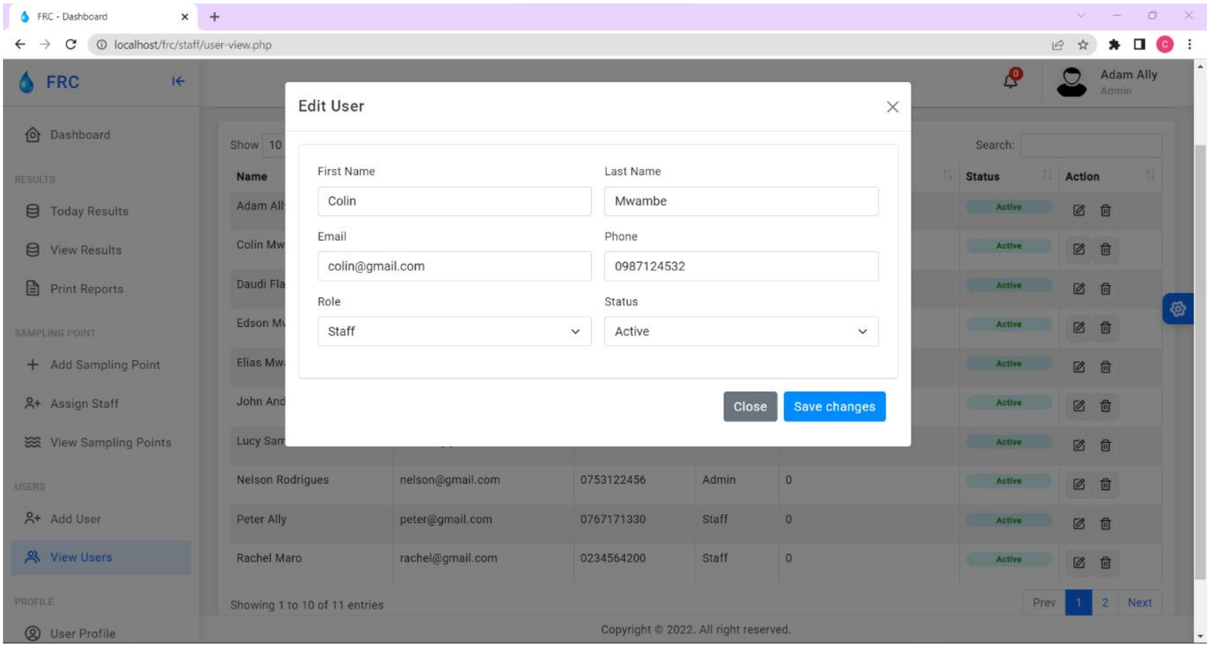


Figure 56: A pop up page for editing user's details

A delete user alert pop-up page shows up when a delete icon of a specific user is clicked. A user will be permanently deleted from the database after confirming the user and click the delete button on the delete pop-up page. A pop-up alert for deleting a user is shown in Fig. 57.

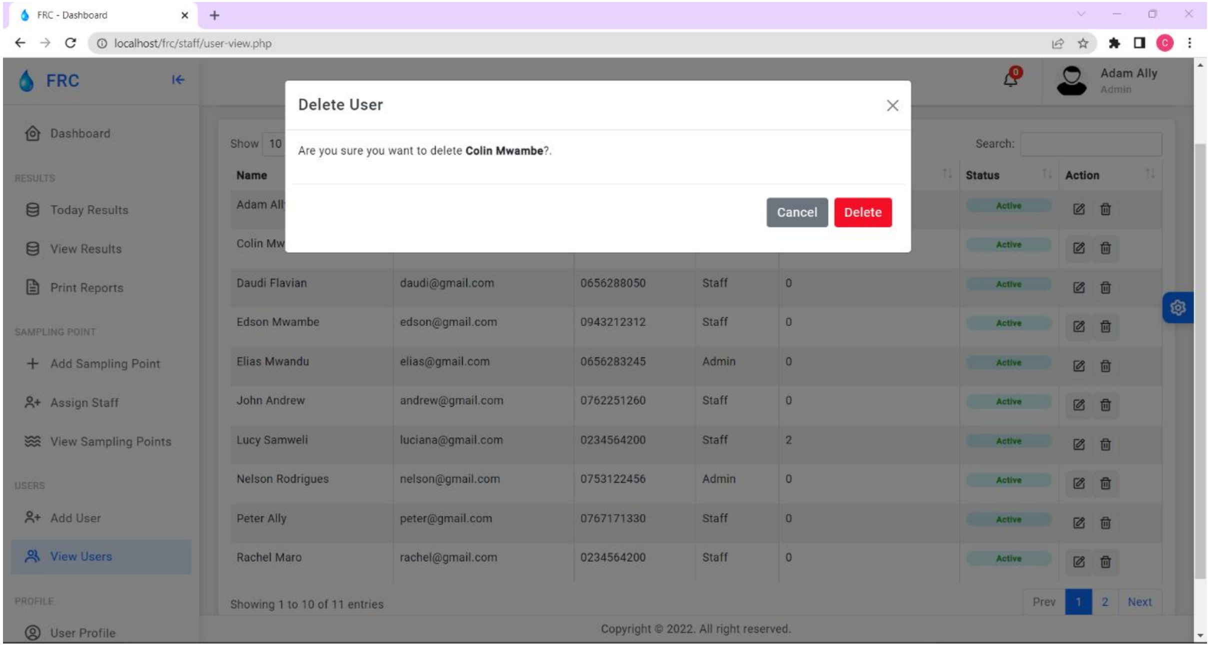


Figure 57: A pop up alert page for deleting a specific user

(vi) Mapping New Sampling Point

The page for registering a new sampling point into the system was developed. This functionality can be done by all system users including WASH specialist, vendor admin and staff. The page will automatically fill the captured GPS coordinates; latitude and longitude of the water reservoir sampling point. Other fields including ID, vendor name, region, district, shehia, street, type, hardware device phone number, phase and status will be manually filled. A page for mapping of the sampling point is shown in Fig. 58.

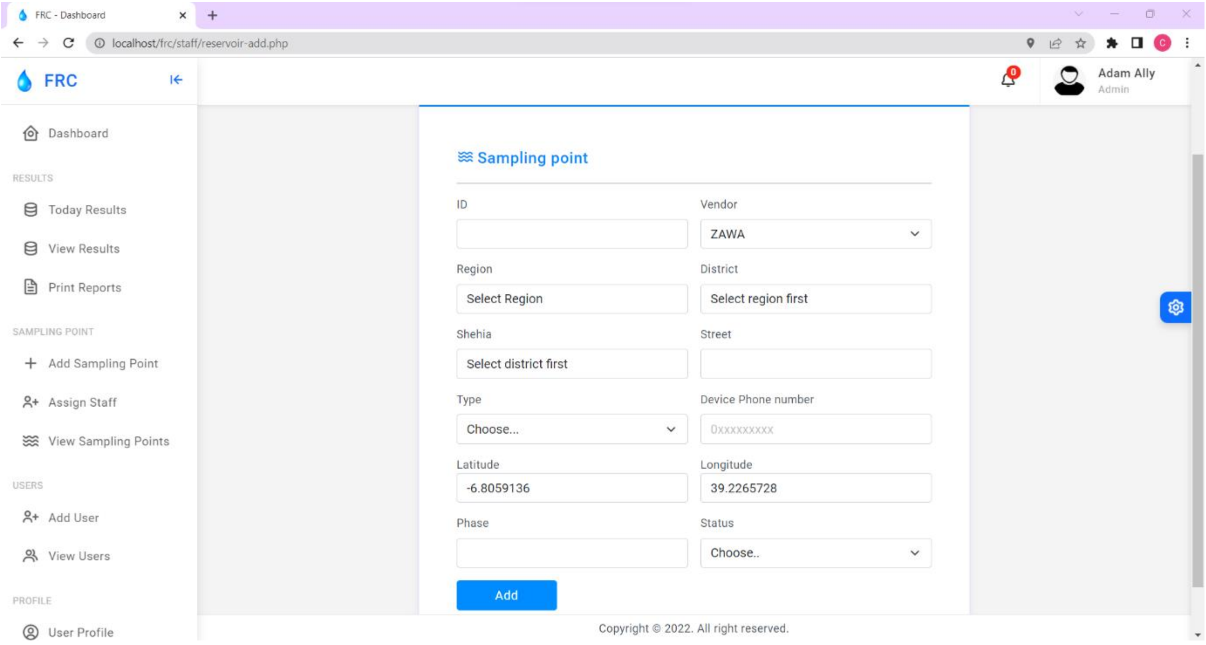


Figure 58: A page for mapping sampling points

(vii) Assignment of sampling point to a staff

Sampling points are assigned to a specific staff for a close monitoring and controlling chlorination. Assignment of the sampling point is done by either WASH specialist or vendor admin only. This process is done by selecting sampling point ID and the corresponding name of the staff. Staff can only monitor free chlorine and pH of the assigned water reservoirs. One sampling point cannot be assigned to a more than one staff, however staff can be assigned to more than one sampling point. A page for assigning sampling point a staff is shown in Fig. 59.

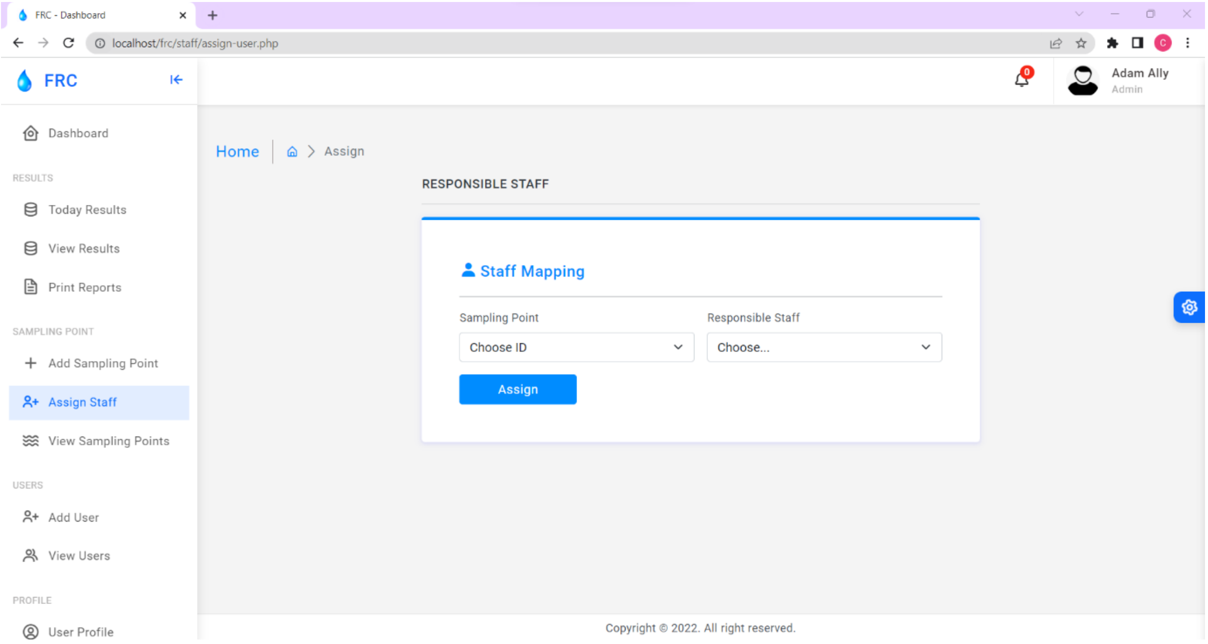


Figure 59: A page for assigning staff to water reservoir

(viii) View Sampling Points

A page for viewing all mapped sampling points in the system was developed. This page shows several details of the sampling point including ID, address, type and other details. User can either delete or edit sampling point's details in this page. A page for viewing all mapped sampling points is shown in Fig. 60.

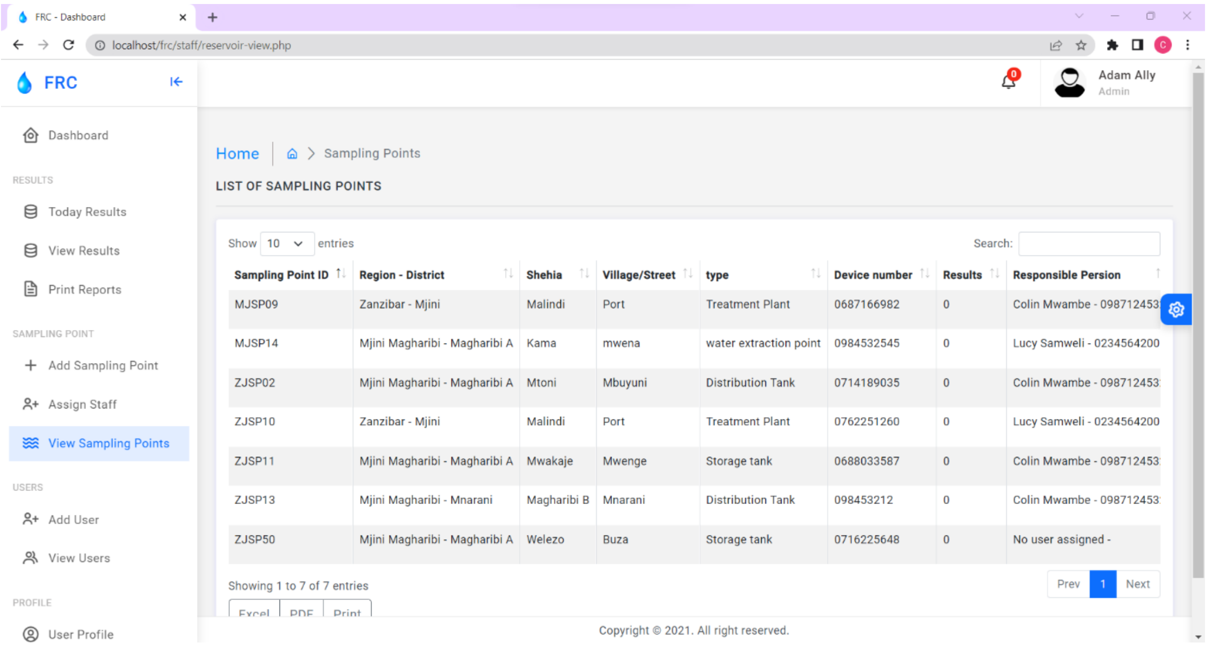


Figure 60: A page for viewing mapped sampling points

A page for editing sampling point's details is shown in Fig. 61. A page for editing sampling point's details pops up when user clicks edit icon in the column of action. Any field of the sampling point is editable.

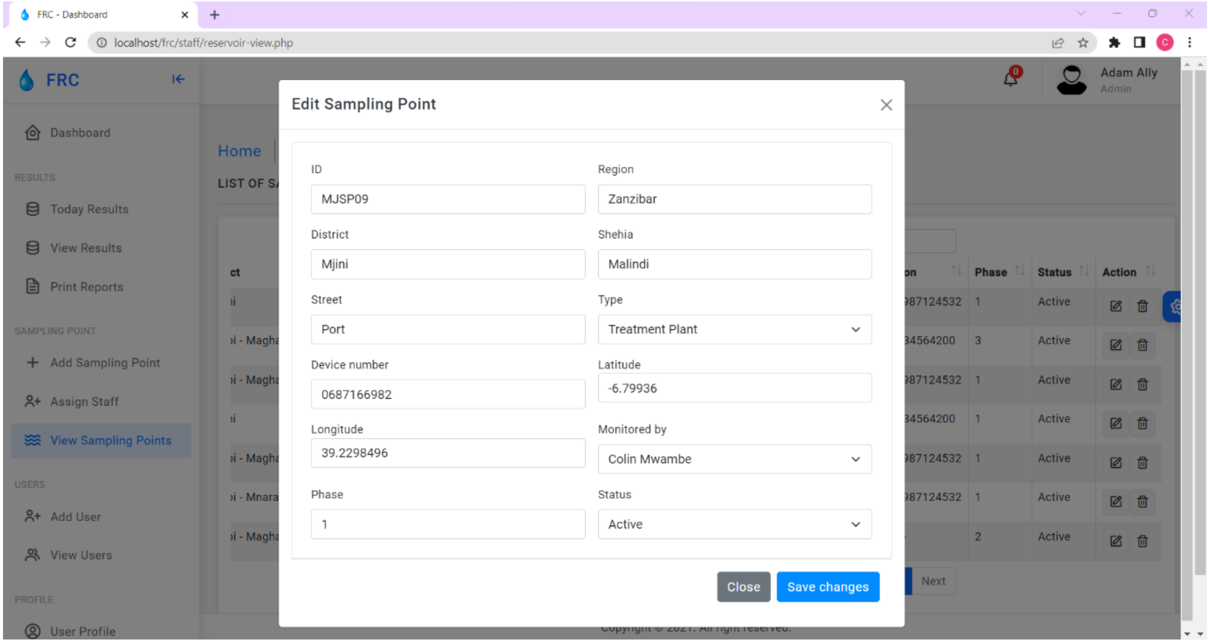


Figure 61: A page for editing sampling point's fields

A delete sampling point alert pop-up page shows up when a delete icon of a specific sampling point is clicked. A sampling point will be permanently deleted from the database after confirming the sampling point to be deleted and click the delete button on the delete pop-up page. A pop-up alert for deleting a sampling point is shown in Fig. 62.

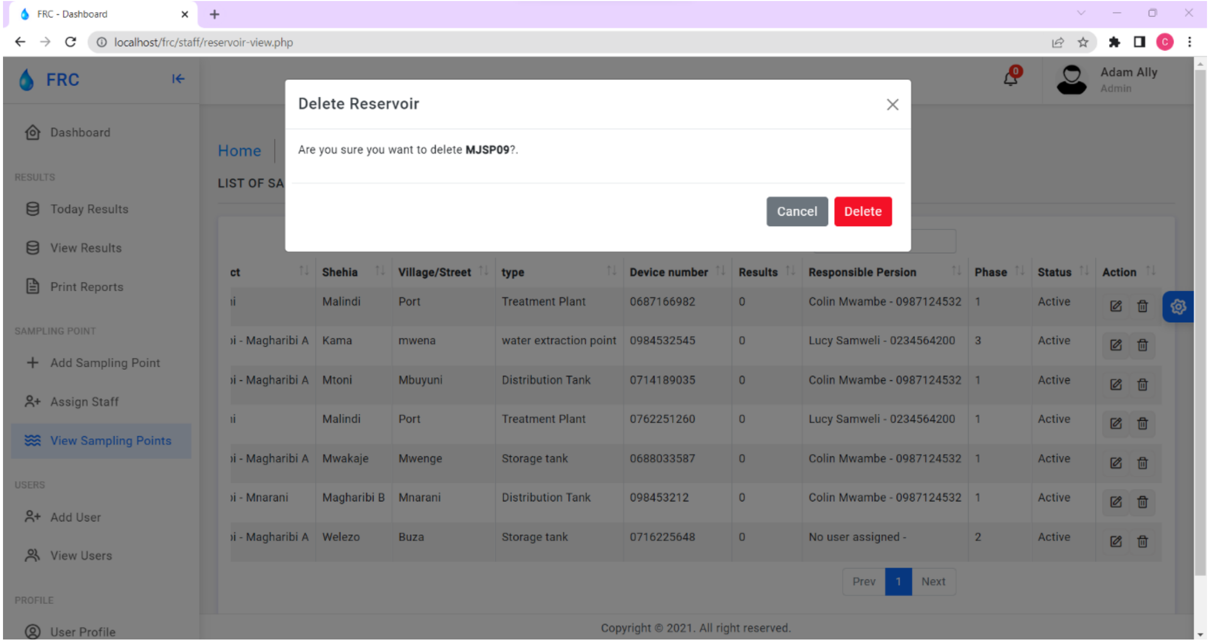


Figure 62: A pop up alert page for deleting a sampling point

(ix) View Free Chlorine and pH Results

The page for viewing free chlorine and pH levels of the water reservoirs sent by the hardware device is shown in Fig. 63. There are two separate pages for showing the sensor data results of the water reservoirs; one page shows today's results only and the other page shows all results in the system.

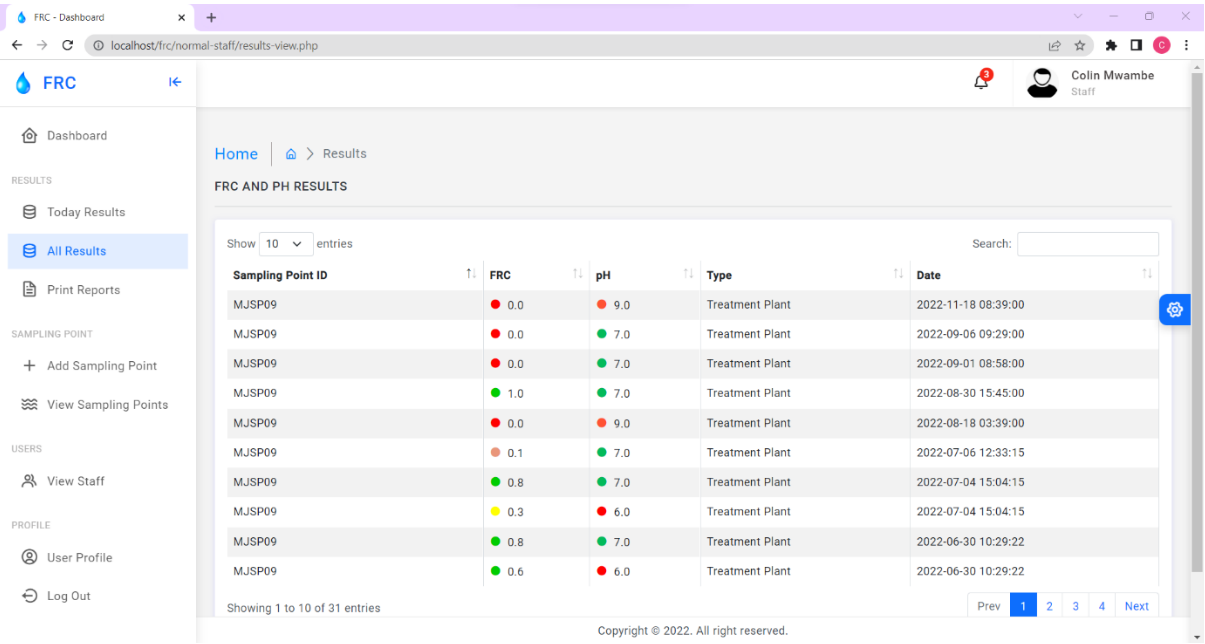


Figure 63: A page for viewing the sensor data results of the water reservoirs

(x) Print Reports

This is the page section for printing reports for several data including vendors, users, water reservoirs, FRC and pH sensor data. There is a drop down for selecting report type to be printed and report's data can be filtered accordingly. The reports are printed in PDF format. A page for printing vendors, users, reservoirs and sensor data reports is shown in Fig. 64.

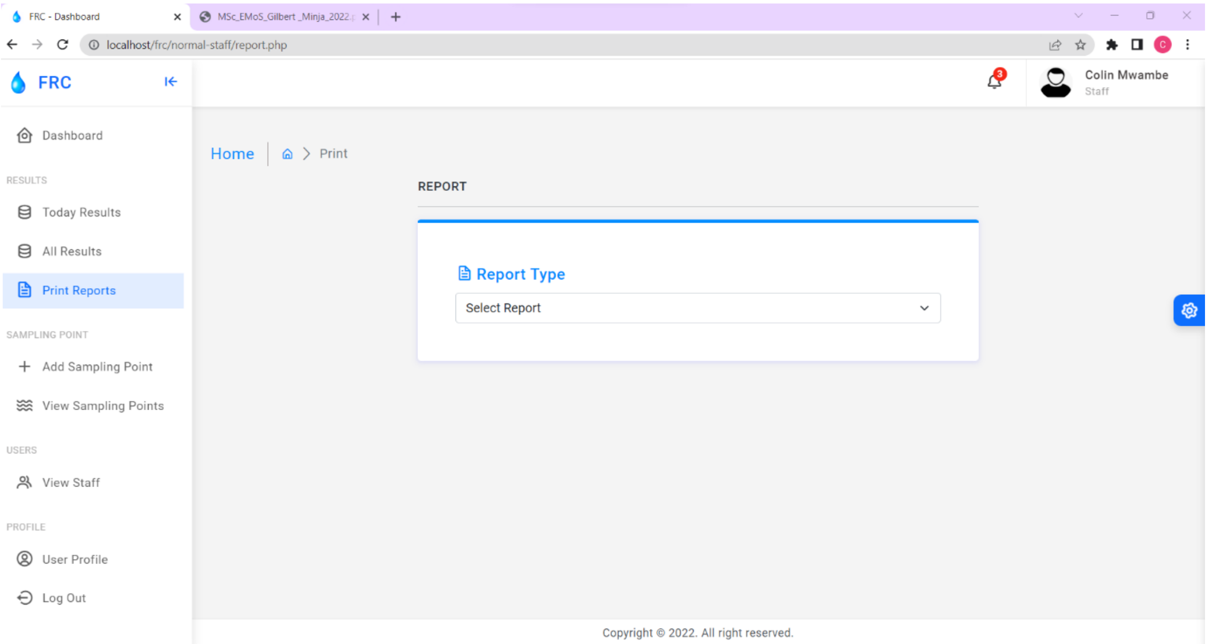


Figure 64: A page for printing vendors, users, reservoirs and sensor data reports

A printed report for the list of sampling points added into the system is shown in Fig. 65.

List of Reservoirs

S/N	ID	Vendor	Type	Region-District	Shehia-Street	Device Number	Staff	Status
1	ZJSP50	ZAWA	Storage tank	Mjini Magharibi - Magharibi A	Welezo - Buza	0716225648	Not assigned	Active
2	ZJSP11	ZAWA	Storage tank	Mjini Magharibi - Magharibi A	Mwakaje - Mwenge	0688033587	Colin Mwambe	Active
3	ZJSP02	ZAWA	Distribution Tank	Mjini Magharibi - Magharibi A	Mtoni - Mbuyuni	0714189035	Colin Mwambe	Active

Figure 65: Report for the list of sampling points

(xi) User Profile

The page for viewing user profile is shown in Fig. 66. The left section on this page displays user's details including full name, role, vendor, email and phone number. The right upper section, user can edit their details including name and phone. On the right bottom section, user can change their password by filling current password, new password and confirm new password.

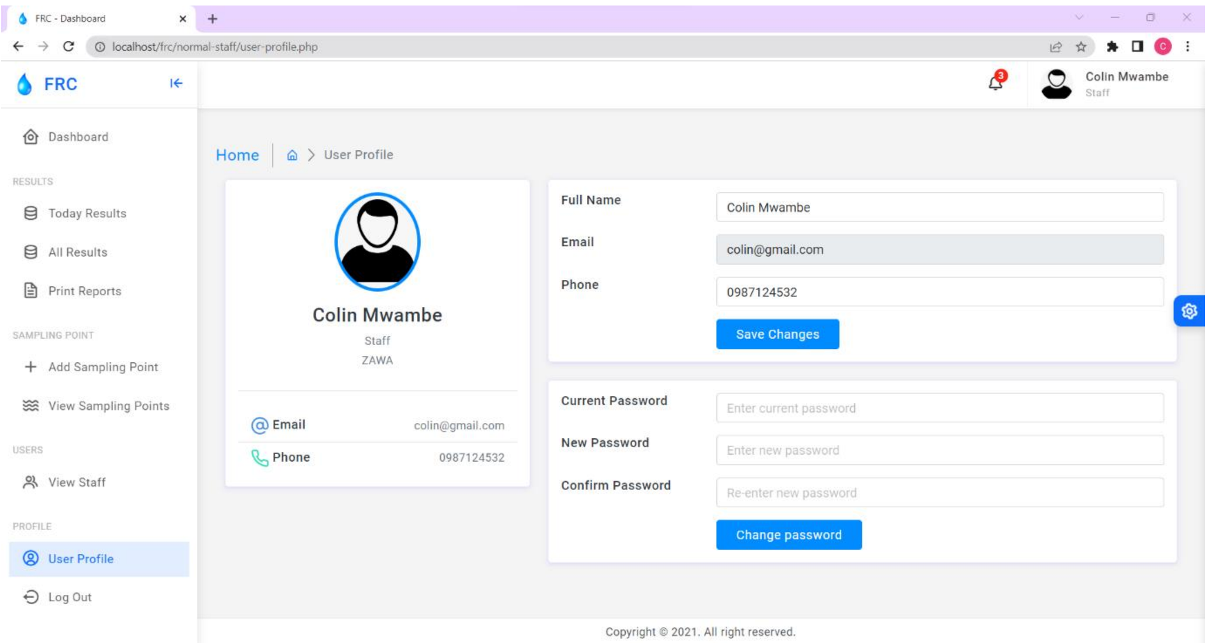


Figure 66: User profile page

(xii) Dashboard

Dashboard shows the data summary of the entire system as illustrated in Fig. 67. The top tabs on the dashboard show number of staff, sampling points, weekly results and today's results. The reservoir locations section shows the map with icons on the location of the water reservoirs. Big icon's color indicates the range of the free chlorine and the smaller one indicates the range of the pH value. Reservoir ID, free chlorine concentration, pH level and the date will pop up once the icon is clicked. In addition, daily visualization of the water reservoirs free chlorine and pH is displayed in the doughnut chart.

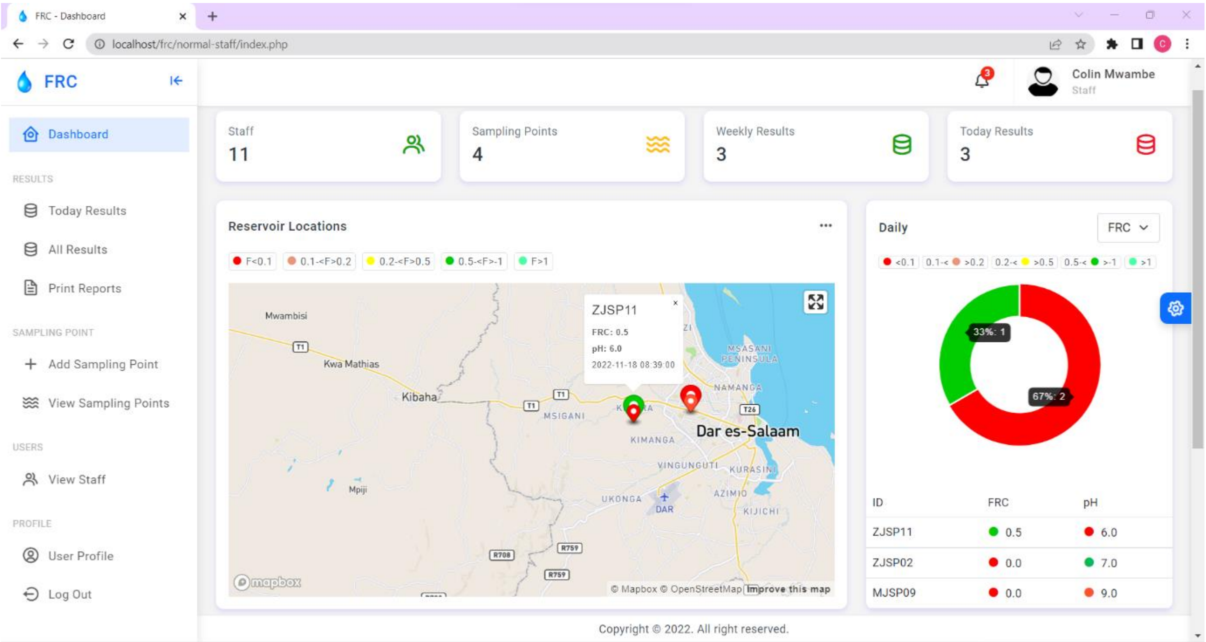


Figure 67: Dashboard of the system

The bottom section of the dashboard is illustrated in Fig. 68. The trends of the free chlorine concentration and pH for a specific water reservoir is shown in this section. Also, weekly visualization of the free chlorine and pH is shown in the pie chart.

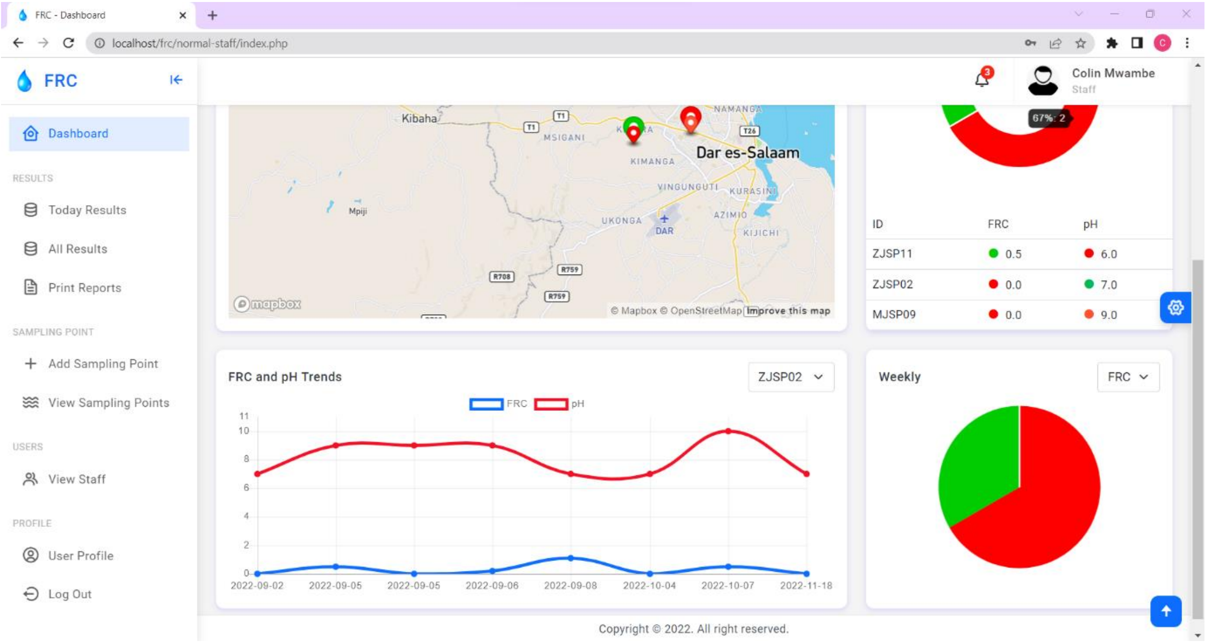


Figure 68: Bottom section of the dashboard

The colors for free choline concentration and pH ranges are shown in Table 6 and Table 7, respectively.

Table 6: Colors for free chlorine concentration ranges

Color	Free chlorine (frc) range (mg/L)	Description
	frc < 0.1	Frc is below 0.1 mg/L
	0.1 ≤ frc > 0.2	Frc is between 0.1 mg/L to 0.2 mg/L
	0.2 ≤ frc >0.5	Frc is between 0.2 mg/L to 0.5 mg/L
	0.5≤ frc ≥ 1	Frc is between 0.5 mg/L to 1 mg/L – Recommended range
	frc > 1	Frc is above 1 mg/L

Table 7: Colors for pH ranges

Color	pH range (mg/L)	Description
	pH < 6.5	pH is less than 6.5
	6.5≤ pH ≥ 8.5	pH is between 6.5 and 8.5 inclusive
	pH > 8.5	pH is above 8.5

4.4.3 RapidPro Results

RapidPro is the SMS gateway which collects sensor data as SMS from the hardware device. The hardware device sends WASH_FRC frc+pH as SMS to trigger rapidPro flow. The FRC and pH are the values of free chlorine concentration and pH respectively. The rapidPro extracts free chlorine and pH values from the key word WASH_FRC frc+ pH and saves them. The free chlorine and pH values are fetched from rapidPro to intermediate database by the API. The rapidPro flow is shown in Fig. 69.

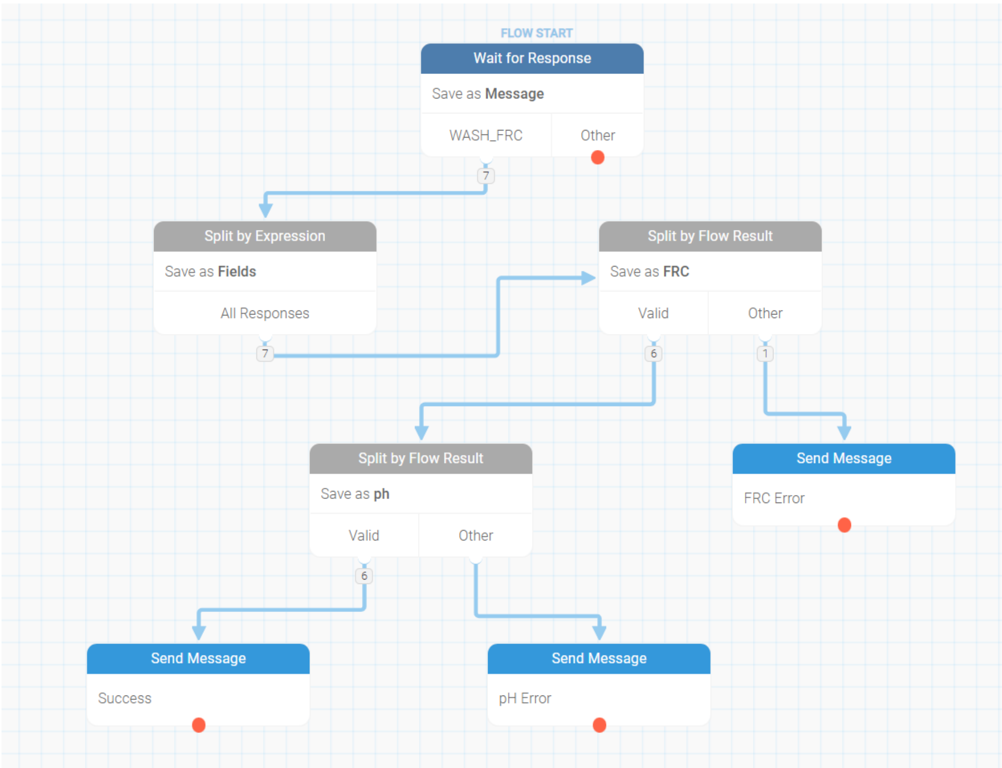


Figure 69: RapidPro flow

4.5 System Testing Results

The system was tested using V-Model testing methods such as unit testing, integration testing and system testing were employed in this current project. The results of the testing are presented in this section.

4.5.1 Unit Testing

Each module of the system was tested separately to ensure they perform as expected. Unit testing was conducted in several modules of the system including user module. The unit testing for the user module is shown in Table 8.

Table 8: Unit testing for user module

Modules	Outcome	Test results
User registration	Registered user's details including full name, email, phone number, vendor, role and password.	PASS
User login	Login with user's credentials including email and password	PASS
View user	View user's details including full name, email, phone number, vendor, role, number of sampling points assigned and status	PASS
Update user's details	An admin can update user's information including name, email, phone number, vendor, role and status.	PASS
Delete user	Admin can delete user permanently from the system	PASS

4.5.2 Integration Testing

Several hardware and software components were integrated and tested to ensure they can work together effectively as desired without errors. Hardware components tested were pH sensor, XY-K485 free chlorine sensor, LCD display, GSM and ESP32 microcontroller. The results for the integration testing for the hardware components are illustrated in Table 9.

Table 9: Integration testing for the hardware components

Case ID	Test Case	Output	Results
1.	Check the communication between ESP32 and pH sensor.	ESP32 was able to read data from the pH sensor.	PASS
2.	Check the communication between ESP32 and GSM.	ESP32 was able to command GSM to send and receive SMS by using AT commands.	PASS
3.	Check the communication between ESP32 and XY-K485 module.	ESP32 was able to communicate with XY-K485 by using UART protocol.	PASS
4.	Check the communication between free chlorine sensor and XY-K485 module.	free chlorine sensor was able to communicate with XY-K485 by using RS485 protocol.	PASS
5.	Check the communication between ESP32 and LCD display.	ESP32 was able to write data to LCD display.	PASS

The results of the integration testing for the software modules are illustrated in Table 10.

Table 10: Integration testing for the software modules

Case ID	Test Case	Description	Output	Results
1.	Check the interface link between the login and dashboard home module.	click sign in button after entering valid email and password.	Directed to the dashboard home module.	PASS
2.	Check the interface link between the home module and add vendor module.	Click add vendor link on the sidebar	Directed to the add vendor module	PASS
3.	Check the interface link between the add vendor module and view vendors module.	Click register after filling out the vendor’s details	Directed to the view vendors module and new vendor is displayed	PASS
4.	Check the interface link between the view vendors module and delete vendor alert pop up module.	From the view vendors select the vendor and click a delete icon.	Delete vendor alert pops up.	PASS
5.	Check the interface link between the delete vendor pop up and delete vendor module.	From the pop-up click delete button	A vendor will be deleted from the database.	PASS
6.	Check the interface link between the view vendors module and edit vendor module.	From the view vendors select the vendor and click an edit icon.	Directed to the edit vendor module.	PASS
7.	Check the interface link between the edit vendor module and view vendors module.	Click save-changes button after editing the vendor’s details	Directed to the view vendors module with edited vendor displayed	PASS

4.5.3 System Testing

All components of the system were integrated together and tested as a whole system to ensure the system works effectively as expected. The results of the system testing for the functional requirements are illustrated in Table 11.

Table 11: System testing results for the functional requirements

S/N	Functional requirement	Description	Result
1.	Detect free chlorine and pH in the water.	The system automatically captures free chlorine concentration and pH in the water.	PASS
2.	Display free chlorine concentration and pH on the LCD.	The LCD continuously displays free chlorine concentration and pH values.	PASS
3.	Send free chlorine concentration and pH values as SMS.	The system sends the values of free chlorine concentration and pH as SMS twice a day to the SMS gateway.	PASS
4.	Send SMS notification alert.	The system sends SMS notification alert to human operator when free chlorine concentration and pH values exceeds the threshold value.	PASS
6.	Visualize free chlorine and pH of the water reservoirs.	Visualize the free chlorine and pH of the water reservoirs on the dashboard.	PASS
7.	Manage users, sampling points and sensor data.	A system manages users, sampling points and sensor data.	PASS
8.	Generate reports.	A system generates users, reservoirs and sensor data reports.	PASS

The results for the system testing for the non-functional requirements are illustrated in Table 12.

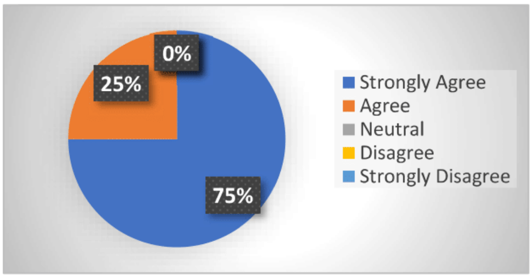
Table 12: System testing results for the non-functional requirements

S/N	Non-Functional Requirement	Description	Results
1.	Security	Authentication of the users before they access the system.	PASS
2.	Accessibility and availability	The system is accessible and available at any time whenever needed.	PASS
3.	Usability	The system is user friendly.	PASS
4.	Reliability	The system is reliable without facing major issues during the operation.	PASS
5.	Portability and Maintainability	The system is portable and easily maintained.	PASS
6.	Scalability	The system is easily scalable.	PASS

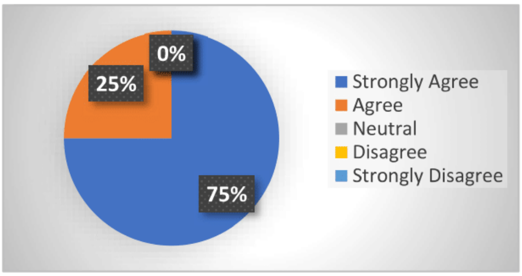
4.6 System Validation Results

The system was tested by end users including ZAWA staff and WASH specialist to ensure the system is easy to use and useful to them. The end users were issued questionnaire to validate the developed system based on their experience of using the system. The system was validated using the questionnaire shown in Appendix 4. The questionnaire was developed based on five points Likert scale; Strongly Disagree (1), Disagree (2), Neural (3), Agree (4), and Strongly Agree (5). The system validation involved 8 end users; 5 WASH specialists and 3 ZAWA staff. The results of the system validation are shown in Fig. 70.

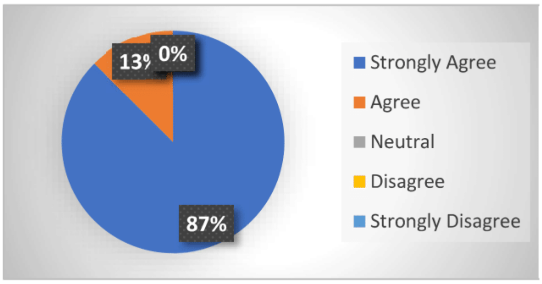
The system is easy to use.



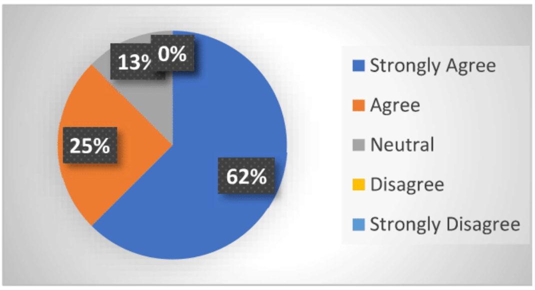
The system is easy to learn how to use.



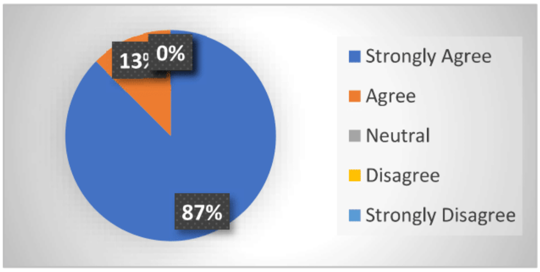
The system will require to perform less training to the users.



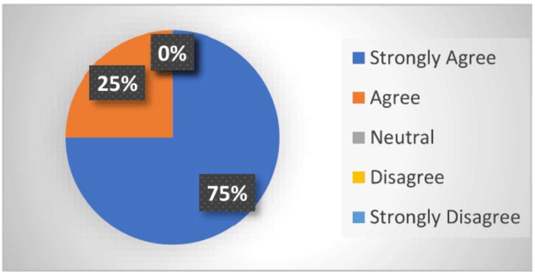
The dashboard is interactive and easy to navigate.



The system will enable effectively monitoring of water reservoirs.



The system will make it easier to manage water reservoirs.



The system is useful.

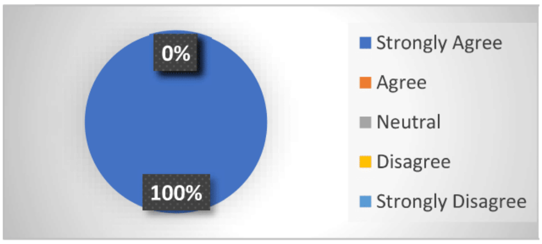


Figure 70: System validation results

4.7 Discussion

The developed system consists of a hardware device and dashboard for remote monitoring. The hardware device sends the free chlorine concentration and pH to the dashboard as SMS for remote monitoring. Also, the device sends notification alerts as SMS to responsible vendor staff. The device can be deployed in an environment with limited resources where the internet might not be available since it does not require internet to send data as it uses SMS. The device is energy efficient since it uses SMS to send sensor data instead of internet. The free chlorine sensor employed in this current project can be used in a noisy environment since it employs RS485 communication protocol to transfer data (Shanghai BOQU Instrument Co., 2019).

The current project provided an opportunity for validation of effectiveness and feasibility of using SMS technology for water quality monitoring. It displayed the practicality of utilizing SMS for environmental monitoring purposes. Furthermore, it facilitates the collection of data in a more accessible and convenient manner. This contributes to knowledge by expanding the availability of water quality data, enabling researchers, policy makers and other stakeholders to access information easily.

The developed dashboard is used for remote monitoring of free chlorine and pH in the water reservoirs. The dashboard is user friendly and useful since it was designed with the end users including ZAWA staff and WASH specialists. The system was tested and validated by the end users to ensure all requirements were included in the developed system. The system was successfully developed and met all functional and non-functional requirements.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study presents the development and implementation of energy efficient, and SMS based system for monitoring water quality parameters particularly free chlorine concentration and pH level in the water reservoirs. All the project objectives were successful achieved in this current project. Requirements were gathered for development of the system through interviews and observations. The system was developed and validated by users, demonstrating its ability to accurate and transmit data via SMS. The system employed GSM for sending sensor data since it is energy efficient, and it may be deployed in environment with limited resources where internet access may not be available. The system testing and validation results has shown that the system can detect free chlorine and pH continuously and send the sensor data as SMS to the dashboard for visualization. Two water quality parameters namely, free chlorine and pH, can be visualized on the dashboard, a web-based application. This dashboard can be accessed by authorized users from anywhere at any time. The dashboard is easy to use and understand since the sensor data are represented in a graphical and tabular format. The system has the potential capability to improve management of water reservoirs by enhancing transparency, cooperation, and accountability among stakeholders.

5.2 Recommendations

5.2.1 Implication to the Policy Makers

The proposed system is practical, and it can be deployed in water reservoirs for monitoring free chlorine concentration and pH level. The proposed solution can potentially be used by Zanzibar Authorities to institute a policy for ensuring all waters sources are thoroughly chlorinated.

5.2.2 Implication to the Practitioners

Currently, ZAWA staff are regularly visiting water reservoirs to manually measure free chlorine in the water reservoirs. The proposed system should be installed in the water reservoirs for effectively monitoring of water quality parameters including free chlorine and pH. This system will benefit practitioners such as ZAWA staff to remotely manage and monitor water reservoirs. The proposed system will save resources such as time and people since ZAWA has limited number of staff and the water reservoirs are scattered throughout Zanzibar.

As a future work, the system will be upgraded to monitor other water quality parameters including turbidity, Oxidation-Reduction Potential (ORP), Escherichia coli and conductivity. The device will be enabled to send real time data to the dashboard for visualization. Also, controlling module for the chlorination plant will be added to the system for regulating the amount of chlorine to be added into the water.

REFERENCES

Alam, A. U., Clyne, D., & Deen, M. J. (2021). A low-cost multi-parameter water quality monitoring system. *Sensors*, *21*(11), 3775.

Babiuch, M., Foltýnek, P., & Smutný, P. (2019). Using the ESP32 microcontroller for data processing. *2019 20^th International Carpathian Control Conference*, 1-6.

Bi, Q., Abdalla, F., Masauni, S., Reyburn, R., Msambazi, M., Deglise, C., Seidlein, L., Deen, J., Jiddawi, M., Olson, D., Nemes, I., Taib, J., Lessler, J., Andemichael, G., & Azman, A. (2018). The Epidemiology of Cholera in Zanzibar: Implications for the Zanzibar Comprehensive Cholera Elimination Plan. *The Journal of Infectious Diseases, 218* (supp_3), S173-S180.

Carlsson, K., Moberg, L., & Karlberg, B. (1999). The miniaturization of the standard method based on the N,N′-diethyl-p-phenylenediamine (DPD) reagent for the determination of free or combined chlorine. *Water Research, 33*(2), 375-380.

Dmitrienko, S. G., Sviridova, O. A., Pyatkova, L. N., Zhukova, V. A., & Zolotov, Y. A. (2000). Rapid determination of free active chlorine in water by diffuse reflectance spectroscopy after reaction with polyurethane foams. *Analytica Chimica Acta*, *405*(1-2), 231-237.

Dou, J., Shang, J., Kang, Q., & Shen, D. (2019). Field analysis free chlorine in water samples by a smartphone-based colorimetric device with improved sensitivity and accuracy. *Microchemical Journal, 150*, 104200.

ElKamchouchi, H., & ElShafee, A. (2012). Design and prototype implementation of SMS based home automation system. *2012 IEEE International Conference on Electronics Design, Systems and Applications*, 162-167.

Faustine, A., Mvuma, A. N., Mongi, H. J., Gabriel, M. C., Tenge, A. J., & Kucel, S. B. (2014). Wireless sensor networks for water quality monitoring and control within lake victoria basin: Prototype development. *Wireless Sensor Network*, *6*(12), 281-290.

Geetha, S., & Gouthami, S. J. S. W. (2016). Internet of things enabled real time water quality monitoring system. *Smart Water*, *2*(1), 1-19.

Hsu, L. H., Hoque, E., Kruse, P., & Selvaganapathy, P. R. (2015). A carbon nanotube based resettable sensor for measuring free chlorine in drinking water. *Applied Physics Letters, 106*(6).

Kanani, P., & Padole, M. (2020). Real-time location tracker for critical health patient using Arduino, GPS Neo6m and GSM Sim800L in health care. *2020 4th International Conference on Intelligent Computing and Control Systems*, 242-249.

Knott, E., Rao, A. H., Summers, K., & Teeger, C. (2022). Interviews in the social sciences. *Nature Reviews Methods Primers*, *2*(1), 73.

Łangowski, R., & Brdys, M. A. (2018). An optimized placement of the hard quality sensors for a robust monitoring of the chlorine concentration in drinking water distribution systems. *Journal of Process Control*, *68,* 52-63.

McFadden, M., Loconsole, J., Schockling, A. J., Nerenberg, R., & Pavissich, J. P. (2017). Comparing peracetic acid and hypochlorite for disinfection of combined sewer overflows: Effects of suspended-solids and pH. *Science of the Total Environment*, *599,* 533-539.

Momin, S. A., & Narayanaswamy, R. (1991). Chlorine sensing by optical techniques. *Chemical and Medical Sensors, 1510,* 180-186.

Olushola, T., & Abiola, J. O. (2017). The efficacy of technology acceptance model: A review of applicable theoretical models in information technology researches. *Journal of Research in Business and Management*, *4*(11), 70-83.

Qin, Y., Alam, A. U., Pan, S., Howlader, M. M., Ghosh, R., Hu, N. X., Dong, S., Chen, C., & Deen, M. J. (2018). Integrated water quality monitoring system with pH, free chlorine, and temperature sensors. *Sensors and Actuators B: Chemical*, *255*, 781-790.

Qin, Y., Kwon, H. J., Howlader, M. M., & Deen, M. J. (2015). Microfabricated electrochemical pH and free chlorine sensors for water quality monitoring: Recent advances and research challenges. *RSC Advances, 5*(85), 69086-69109.

Ralfs, M., & Heinze, J. (1997). Disposable optochemical sensor for the determination of chlorine concentrations in the ppb-range. *Sensors and Actuators B: Chemical*, *44*(1-3), 257-261.

Sumriddetchkajorn, S., Chaitavon, K., & Intaravanne, Y. (2013). Mobile device-based self-referencing colorimeter for monitoring chlorine concentration in water. *Sensors and Actuators B: Chemical*, *182*, 592-597.

Tabassum, A., Bhatti, S., & Asghar, A. (2017). Optimized Quality Model for Agile Development: Extreme Programming (XP) as a Case Scenario. *International Journal of Advanced Computer Science and Applications*, *8*(4), 392-400.

Taherdoost, H. (2016). Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research. *International Journal of Academic Research in Management*, *5*(2), 18-27.

Waters, B., & Hung, Y. (2013). Evaluation of different methods for determination of properties of chlorine-based sanitizers. *Food Control*, *30*(1), 41-47.

WHO. (2017). *Guidelines for drinking-water quality: fourth edition incorporating the first addendum.* Geneva.

Yen, Y. K., Lee, K. Y., Lin, C. Y., Zhang, S. T., Wang, C. W., & Liu, T. Y. (2020). Portable nanohybrid paper-based chemiresistive sensor for free chlorine detection. *ACS Omega*, *5*(39), 25209-25215.

Zidan, N., Maree, M., & Samhan, S. (2018). An IoT based monitoring and controlling system for water chlorination treatment. *Proceedings of the 2nd International Conference on Future Networks and Distributed Systems*, 1-6.

APPENDICES

Appendix 1: Interview Guide to UNICEF Staff to Identify Challenges on WASH, Education, Health and Nutrition

Interview Guide

Area 1: UNICEF Section information

1. What are your tasks as a section? (Explain the tasks in detail)
    a. Key or flagship activities
    b. Expected results of the activity (what is the purpose of the activity)
2. Priority setting:
    a. From the activities which ones are:
        i. Constrained
        ii. More important / Priority ranked

Area 2: Focus on the program

3. What is the activity in detail?
4. Who implements the activity
5. Who are your target beneficiaries?
6. Where do the beneficiaries receive the activity
7. When / how often they receive the activity
8. Stakeholders mapping, are there other stakeholders of relevance?

Constraint	**Desire**
9. What are the challenges beneficiaries face?	How do you think it would be the ideal beneficiary experience?
10. What are the Challenges other stakeholders face?	How do you think it would be the ideal stakeholder experience?
11. What are the potential challenges are Implementing partners are facing in implementing these activities?	How do you think it would be an ideal to improve the performance of implementing partners?

12. What do you think can be done to address the issue? / If there was a device, a robot, or a magic box in that location, what would it do?

Appendix 2: Interview Guide for UNICEF - WASH Specialists

Interview Guide

(WASH Specialist for Zanzibar Water Authority (ZAWA) and Community bulk)

"Research Title: Short Message Service-Based System for Monitoring Free Chlorine Concentration and Ph in the Water Reservoirs"

Section A: Opening Question

1. Could you briefly tell us, why do you have to monitor the water quality?

Section B: Introductory Questions

2. What challenges do you face in monitoring the water quality?
3. What are your views on how the challenges should be addressed?

Section B: Key Questions

4. Which water quality parameter is being monitored, and why?
5. What is your role as a supervisor of the water quality monitoring program?
6. How many people are involved in the water quality monitoring for ZAWA and community bulk?
7. What are the procedures for data collection and analysis?
8. Who is responsible for data analysis and data collection?
9. What are the challenges in the data collection and analysis?

Section C: Concluding Questions

10. Could you tell us based on your opinions, how could the system be improved to be more effective?

Thank you very much for your valuable time and participation!

Appendix 3: Interview Guide to ZAWA Staff and Environmental Officer

Interview Guide

(ZAWA staff and environmental officer)

"Research Title: Short Message Service-Based System for Monitoring Free Chlorine Concentration and Ph in the Water reservoirs"

Section A: Opening Question

1. Could you please tell us about the FRC monitoring program for ZAWA and community bulk?

Section B: Introductory Questions

2. What are the challenges in monitoring the water quality?
3. Could you please explain how you do the water chlorination and what the challenges?

Section B: Key Questions

4. What is your role in the water quality monitoring program?
5. How many people are involved in the monitoring with how many sampling points?
6. Which water quality parameters are being monitored, and why?
7. How do you monitor water quality (tools and frequency)?
8. What are the procedures for submitting the results of the water quality, and how long does it take?
9. What are the procedures and parameters for mapping a location to be monitored?

Section C: Concluding Questions

10. Could you tell us based on your opinions, how could the system be improved to be more effective?

Thank you very much for your valuable time and participation!

Appendix 4: Questionnaire for System Validation

Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The system is easy to use.					
The system will require to perform less training to the users.					
The dashboard is interactive and easy to navigate.					
The system is useful.					
The system will enable effectively monitoring of water reservoirs.					
The system makes it easier to manage water reservoirs.					

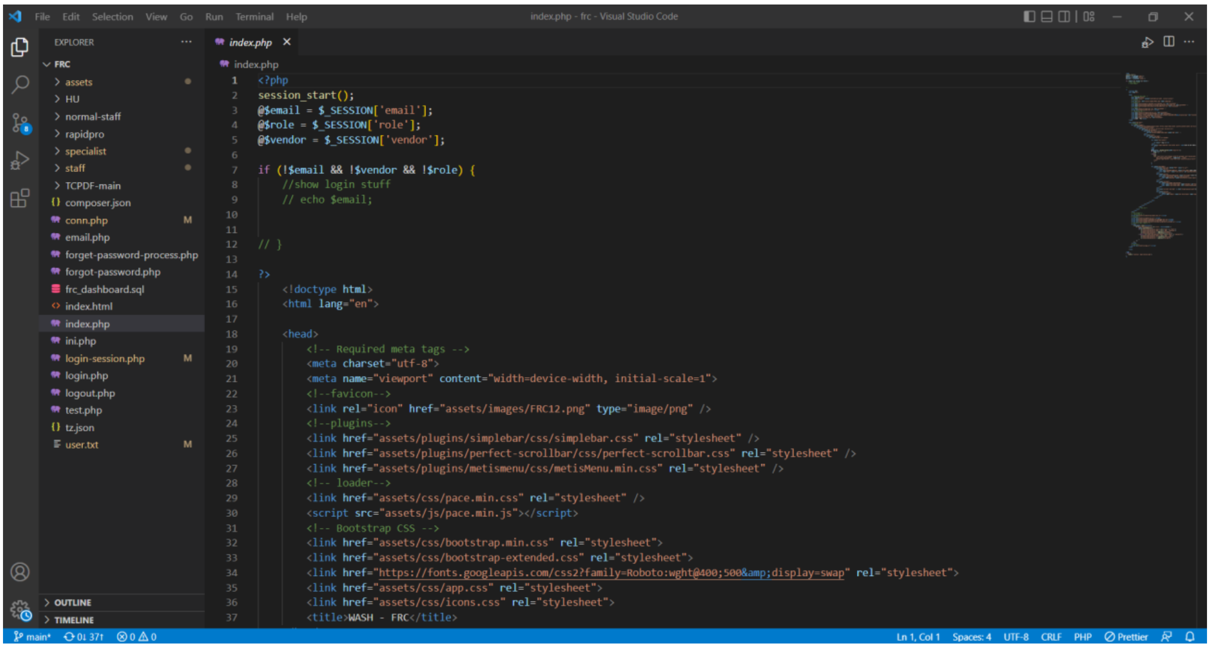
Appendix 5: Sample Codes for the Hardware Device

```
#include <SoftwareSerial.h>
#include <LiquidCrystal_I2C.h>

#include <Wire.h>
LiquidCrystal_I2C lcd(0x27, 16, 2);

#define ph_pin 13 //This is the pin number connected to Po
// serial for xy485
#define RXD2 16
#define TXD2 17
#define GSM_TX 12
#define GSM_RX 14

SoftwareSerial mySerial(GSM_TX, GSM_RX);

byte ByteArray[250];
int ByteData[20];
String s,s1,phone,admin="+255656288050";
float Po,fr;
int i=0,j=0;
unsigned long previousMillis = 0, previousMillis2 = 0;
const long interval = 1800000, interval2=2000;

void setup() {
  Serial2.begin(9600, SERIAL_8N1, RXD2, TXD2);
  mySerial.begin(9600);
  Serial.begin(9600);
  Serial.println("Initializing...");

  lcd.init();
  lcd.clear();
  lcd.backlight();      // Make sure backlight is on
  delay(1000);

  frc();
  pH();

  delay(14000);
  mySerial.println("AT"); //Once the handshake test is successful, it will
back to OK
  updateSerial();
  mySerial.println("AT+CSQ"); //Signal quality test, value range is 0-31 , 31
is the best
  updateSerial();
  mySerial.println("AT+CCID"); //Read SIM information to confirm whether the
SIM is plugged
```

```
  updateSerial();
  mySerial.println("AT+CREG?"); //Check whether it has registered in the
network
  updateSerial();
  mySerial.println("AT+CREG?"); //Check whether it has registered in the
network
  updateSerial();
  mySerial.println("AT+CMGF=1");
  updateSerial();
  mySerial.println("AT+CNMI=1,2,0,0,0"); // Decides how newly arrived SMS
messages should be handled
  updateSerial();
  mySerial.flush();
}

void loop() {
  unsigned long currentMillis = millis();
  if(currentMillis - previousMillis >=  interval || j==0){
    previousMillis = currentMillis;
    monitor();
  }

  if(currentMillis - previousMillis2 >=  interval2){
    previousMillis2 = currentMillis;
    pH();
    frc();
  }
  //receive sms
  while(mySerial.available() >0){

    s = mySerial.readString();
    Serial.println("Number: "+s);
    phone = s.substring(9,22);
    phone.trim();
    Serial.println("Number: "+phone);
    s1 = s.substring(49);
    Serial.println("Message body: "+s1);
    if(s1.indexOf("ripoti")>0 || s1.indexOf("Ripoti")>0 ||
s1.indexOf("RIPOTI")>0){
      //call a function to send data
      i=1;
      SendMessage();

    }
    if(s1.indexOf("nambie")>0 || s1.indexOf("Nambie")>0 ||
s1.indexOf("NAMBIE")>0){
      //call a function to send data
      i=2;
```

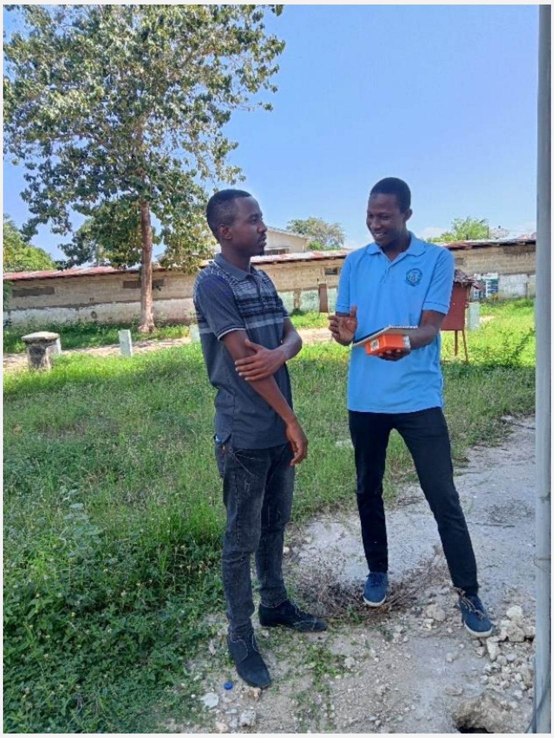
```
      SendMessage();

    }
    mySerial.readString() = "\0";

    // Serial.write(Serial2.read());

  }
  delay(500);
}
```

Appendix 6: Hypertext Preprocessor (PHP) Sample Codes for the Dashboard



Appendix 7: Images During UNICEF TCO Field Visit

Appendix 8: Images of the Field Visit During Data Collection in Zanzibar



Appendix 9: Poster Presentation

SHORT MESSAGE SERVICE (SMS) BASED SYSTEM FOR MONITORING FREE CHLORINE CONCENTRATION AND PH IN THE WATER RESERVOIRS

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Abstract

Chlorine is the most common chemical reagent used for killing harmful microorganisms in the water to eliminate the spread of waterborne diseases such as cholera and diarrhoea. According to World Health Organization, a free chlorine level within 0.5~1 mg/l and a pH level within 6.5~8.5 is recommended for human consumption. It is essential to monitor free chlorine and pH in the water since extreme values may affect the community's health. Zanzibar Water Authority (ZAWA) employs calorimetric approach to manually measure free chlorine in the water reservoirs and submit the results into the kobocollect mobile application. However, this approach is prone to human errors, ineffective and time consuming. The objective of this current project was to develop a SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs.

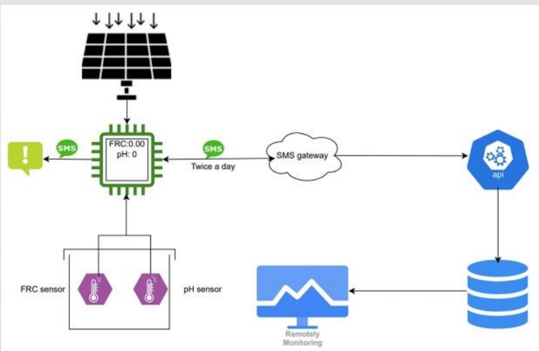
Problem statement

ZAWA staff currently performs manual measurements of the free chlorine concentrations of the water reservoir by utilizing pooltester or HACH instruments atleat once a week. This approach is prone to human errors, ineffective and time consuming for ZAWA staff. It is exceedingly difficult for ZAWA staff (about 4) to constantly examine the pH and free chlorine of the water reservoirs (about 45). Therefore, this current project intends to develop a digital system for simplifying the process of monitoring free chlorine and pH in the water reservoirs to match the limited resources of ZAWA.

Main Objective

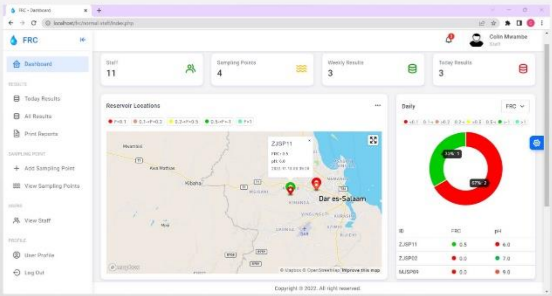
The main objective of the project was to develop a SMS-based system for monitoring free chlorine concentration and pH in the water reservoirs.

System Architecture



Hardware device

Dashboard



Conclusion

- This study presents the development of energy efficient system for monitoring free chlorine concentration and pH level in the water reservoirs.
- The system has the potential capability to improve the management of water reservoirs by enhancing transparency, cooperation and accountability among stakeholders.