MAKERERE UNIVERSITY

SOFTWARE DESIGN DOCUMENT

for

Affordable Water Quality Monitoring System (AWQMS)

Version 1.0 approved

MAKERERE UNIVERSITY, DEPARTMENT OF NETWORKS
02 MARCH, 2024

Prepared by BSE 25-30

Name	Registration Number	Student Number
KISEJERE RASHID	21/U/11543/EVE	2100711543
SSEMAGANDA TREVOUR	21/U/18348/EVE	2100718348
SSENTEZA EMMANUEL	21/U/13955/PS	2100713955
GUM PRICILLA	21/U/17674/EVE	2100717674

Table of Contents

1. INTRODUCTION.....1

2. SYSTEM OVERVIEW.....3

3. SYSTEM ARCHITECTURE.....4

3.1 Architectural Design.....4

High-Level Architecture Overview.....4

Collaboration Between Subsystems.....6

3.2 Decomposition Description.....7

Object-Oriented Decomposition.....7

3.3 Design Rationale.....9

4. DATA DESIGN.....10

4.1 Data Entities.....10

4.2 Data Schema.....11

4.2.1 Database Schema Diagram Description.....11

5.0 COMPONENT DESIGN.....13

5.1.Data Acquisition Layer.....13

5.2. Data Processing Layer.....13

5.3. Analysis Layer.....14

5.4 Presentation and visualisation layer.....14

6. HUMAN INTERFACE DESIGN.....15

6.1 Overview of User Interface.....15

6.2 Screen Images.....16

6.3 Screen Objects and Actions.....19

7. REQUIREMENTS MATRIX.....21

Table of figures

Table 1 Anomaly table ,will store unusual or unexpected sensor readings detected based on predefined thresholds, statistical models, or machine learning techniques. 11
Table 2 Parameters table, will store metadata about the environmental sensors deployed in the field. 11
Table 3 Alerts table ,will store notifications generated when sensor readings exceed predefined thresholds. 12
Table 4 Locations table , will store information about the geographical locations where water quality monitoring sensors are deployed.. 12
Table 5 Requirements Matrix of the AWQMS 22

1. INTRODUCTION

1.1. Purpose

This Software Design Document (SDD) describes the architecture and system design of the **Affordable Water Quality Monitoring System**. Traditional water quality testing methods are often time-consuming, expensive and provide only sporadic snapshots of water quality. This system leverages Machine Learning (ML) and Embedded Systems to provide real-time monitoring and predictive analysis of water quality parameters such as pH, temperature, conductivity and turbidity. This document is intended for developers, project managers, testers and stakeholders to ensure clear understanding of the system's design, functionality and implementation.

1.2. Scope

The Affordable Water Quality Monitoring System is designed to address the challenges of water quality monitoring in resource-constrained regions like Uganda, where traditional laboratory-based methods are costly, time-consuming and inaccessible. The system aims to:

- Continuously monitor water quality using affordable biosensors.
- Transmit data in real-time using GSM modules to a cloud-based platform.
- Provide predictive insights using AI/ML models to forecast water quality trends and assess water potability.
- Offer user-friendly web interface for data visualization and reporting.

The goals of this project are to:

- Ensure access to clean and safe water by providing real-time monitoring and actionable insights.
- Reduce the cost and complexity of water quality monitoring through the use of affordable and scalable technologies.
- Empower local communities, policy makers and stakeholders with data-driven decision making tools.

The benefits of this system include:

- Improved public health by reducing exposure to contaminated water.
- Enhanced environmental sustainability through proactive water resource management.
- Cost-effective and scalable solutions for water quality monitoring in underserved regions.

1.3. Overview

This document is organized to provide a comprehensive description of the architecture, design and implementation details of the system. The document is structured as follows.

1. **Introduction**: Provides an overview of the document, including its purpose, scope and intended audience. It also includes reference materials and definitions of key terms and acronyms.
2. **System Overview**: Offers a high level description of the system's functionality, context and design, providing background information necessary to understand the system's objectives and benefits.
3. **System Architecture**: Describes the modular structure of the system, including the relationships between subsystems, their roles and how they collaborate to achieve the system's functionality. This section includes diagrams and design rationale.
4. **Data Design**: Explains how the system's information domain is transformed into data structures, including the storage, processing and organization of major data entities.
5. **Component Design**: Provides a detailed description of each component's functionality, including algorithms or pseudocode for key functions or methods.
6. **Human Interface Design**: Describes the system's user interface, including its functionality, screen images and the actions associated with screen objects.
7. **Requirements Matrix**: Maps system components and data structures to functional requirements outlined in the Software Requirements Specification (SRS).
8. **Appendices**: Includes supplementary information, such as additional diagrams, technical details or references, to support the understanding of the document.

This document serves as the primary reference for developers, testers and stakeholders, ensuring a clear understanding of the system's design and implementation. It also supports future scalability, maintenance and quality assurance efforts.

1.4. Reference Material

This section lists the documents and resources referenced during the creation of this Software Design Document:

1. **Software Requirements Specification (SRS):** The SRS document outlines the functional and non-functional requirements of the Affordable Water Quality Monitoring System.(bse25-30 - Google Drive)
2. **IEEE 1016-2009:** Standard for software design descriptions.

2. SYSTEM OVERVIEW

The Affordable Water Quality Monitoring System is an innovative solution designed to address the critical challenges of water quality monitoring in resource constrained regions, such as Uganda. The system leverages emerging technologies including biosensors, Embedded Systems and machine learning to provide real-time, affordable and user-friendly water quality assessments.

The system will consist of both hardware and software components, working together to collect, process and analyze water quality data. The hardware includes a suite of sensors (pH, temperature, conductivity and turbidity) connected to a micro controller and a GSM module for data transmission. This data is to be used for predictive analysis (forecasting and potability assessment). The software component encompasses a cloud-based platform for data storage, machine learning algorithms for predictive analysis and a user-friendly web interface for real-time data visualization and reporting.

The system is designed to meet the following key requirements:

- **Continuous Monitoring:** The system is to provide continuous, automated monitoring of the specified water quality parameters. Real-time data acquisition is crucial for detecting sudden changes and enabling timely interventions.
- **Affordability and Accessibility:** The system must be affordable to deploy and maintain in resource-constrained settings. This necessitates the use of low-cost sensors and readily available communication technologies such as GSM modules.
- **Data Transmission and Storage:** The system is to reliably transmit the collected sensor data to a central cloud-based platform for storage and analysis. GSM modules are used for data transmission due to their widespread availability and coverage.
- **Artificial Intelligence/Machine Learning- Driven Analysis**: The system must utilize machine learning algorithms to analyze the sensor data, identify patterns, detect anomalies and predict potential water quality issues(forecasting and potability).
- **User-Friendly Interface:** The system is to provide a user-friendly web interface, accessible via desktop and mobile devices, for data visualization, reporting and alert generation.

The system architecture comprises three main components:

- **Embedded Sensor Network:** This network consists of multiple low-power, microcontroller-based devices deployed in the water sources. Each device is equipped with a suite of sensors (pH, temperature, conductivity and turbidity) as specified in the SRS. These devices collect data at regular intervals.

- **Data Transmission (GSM):** The sensor data is transmitted wirelessly using GSM modules to a cloud-based platform. This choice is based on the availability and cost-effectiveness of GSM networks.
- **Cloud Platform and AI/ML Analysis:** The cloud platform stores the incoming sensor data. The trained machine learning (forecasting and potability), hosted on the cloud, analyzes this data.The results of this analysis, including real-time readings, anomaly detection, predictive forecasts and potability assessments, are made accessible through the web interface.

3. SYSTEM ARCHITECTURE

3.1 Architectural Design

The Affordable Water Quality Monitoring System (AWQMS) follows a layered microservices architecture pattern, divided into four main subsystems that work together to provide water quality monitoring and analysis capabilities.

High-Level Architecture Overview

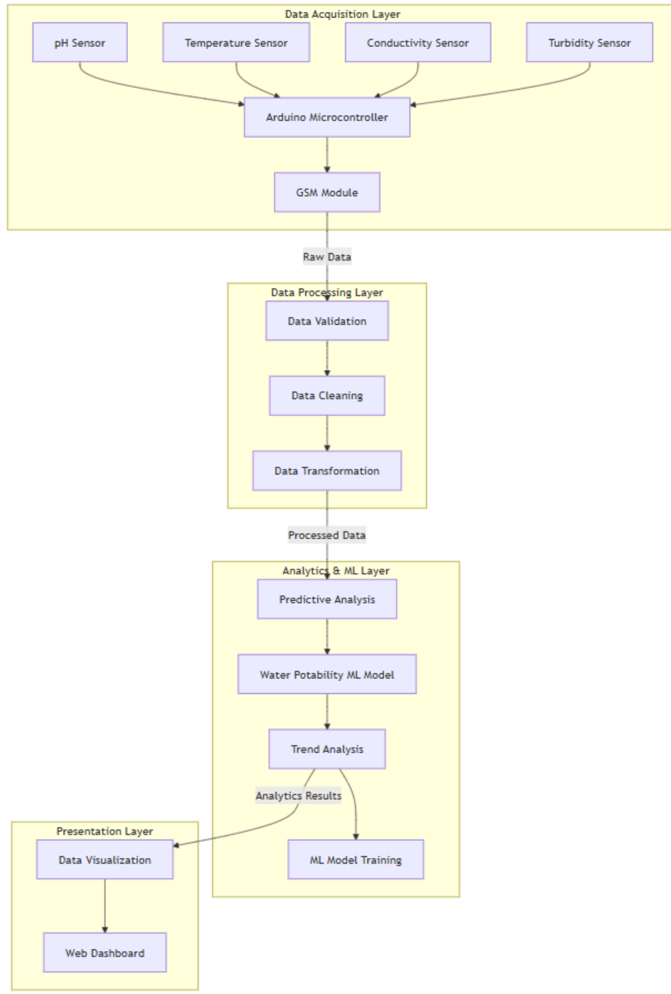


Figure 1 Illustration of the High Level System Architecture

The system is composed of the following major subsystems:

1. **Data Acquisition Layer**
   - Responsible for collecting raw data from various sensors (pH, temperature, conductivity, turbidity)
   - Handles sensor calibration and initial data validation
   - Manages communication with the GSM module for data transmission

2. **Data Processing & Storage Layer**

    - Processes incoming sensor data and performs necessary transformations
    - Implements data cleaning and validation algorithms
    - Manages the database for both real-time and historical data
    - Handles data backup and archival processes
3. **Analytics & ML Layer**
    - Executes predictive analysis algorithms for water quality forecasting
    - Implements anomaly detection using machine learning models
    - Performs trend analysis and generates insights
4. **Presentation Layer**
    - Provides the web-based dashboard interface
    - Handles user authentication and authorization
    - Manages real-time data visualization
    - Implements the alert and notification system

Collaboration Between Subsystems

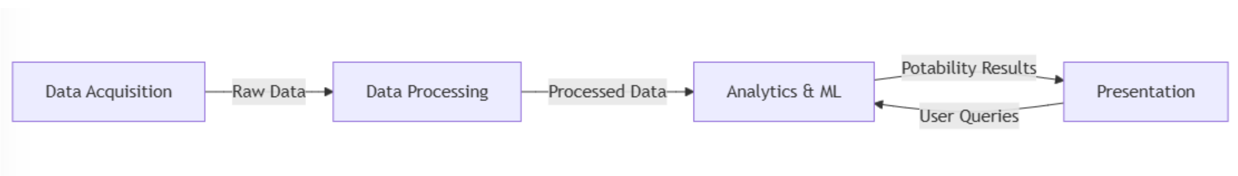


Figure 2 Illustrates the collaboration of the different subsystems and how data flows through each of the sub systems.

- The Data Acquisition Layer sends collected sensor data to the Data Processing Layer via the GSM module.
- The Data Processing Layer stores cleaned data and makes it available to the Analytics Layer.
- The Analytics Layer processes data and sends results to the Presentation Layer.
- The Presentation Layer retrieves data from both Processing and Analytics layers to display to users.

3.2 Decomposition Description

Object-Oriented Decomposition

Core Components

1. **Sensor Management Module**

The sensor management module includes the Data Acquisition Layer which includes all the sensors, SensorController which aggregates sensor readings, CalibrationManager which Applies temperature compensation and linearity adjustments to raw sensor data. As illustrated in the figure 2, GSMTransmitter handles packet serialization and transmissions.

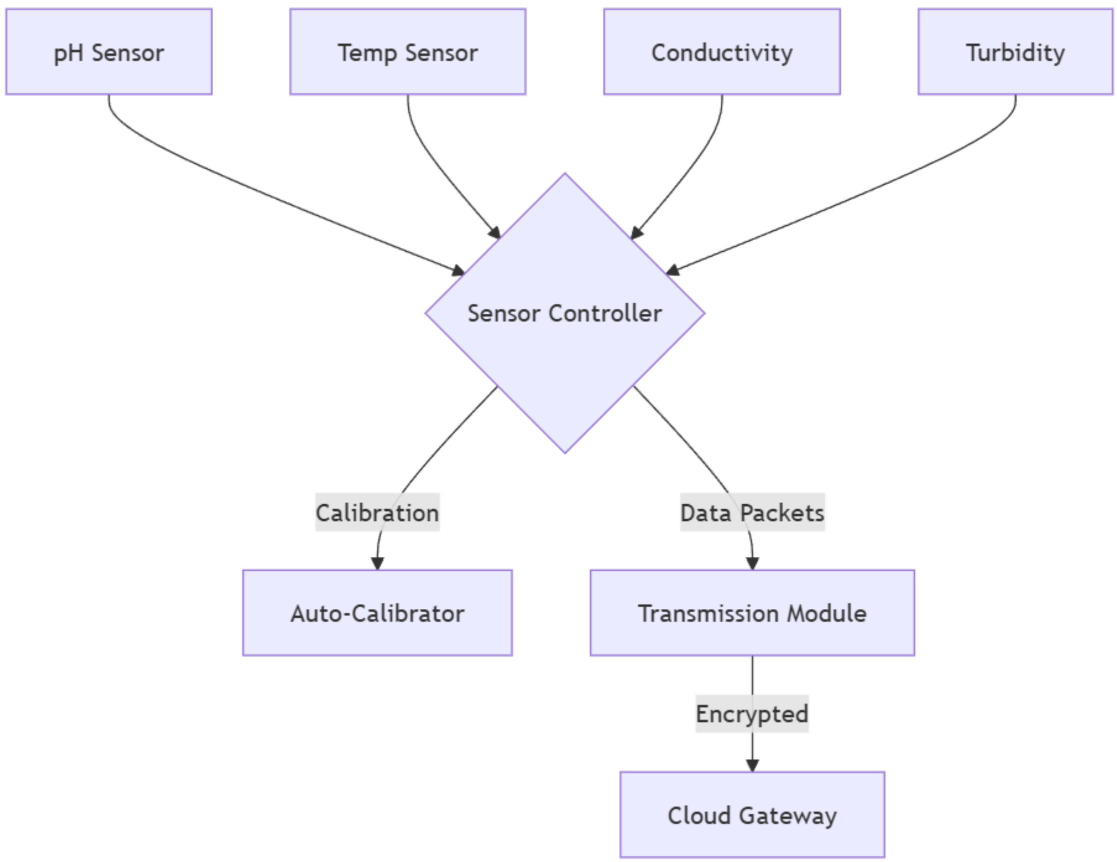


Figure 3 Coordinates four sensor inputs through a centralized controller, handling simultaneous data collection and transmission. Implements dynamic calibration routines for GSM transmission.

Data Processing & Storage Layer

- DataPipeline: Orchestrates the Extract, Transform, and Load process.

Analytics & ML Layer

- ModelExecutor: Hosts ML models and schedules batch predictions.
- ResultAggregator: Combines outputs from multiple models (e.g., anomaly scores).

Presentation Layer

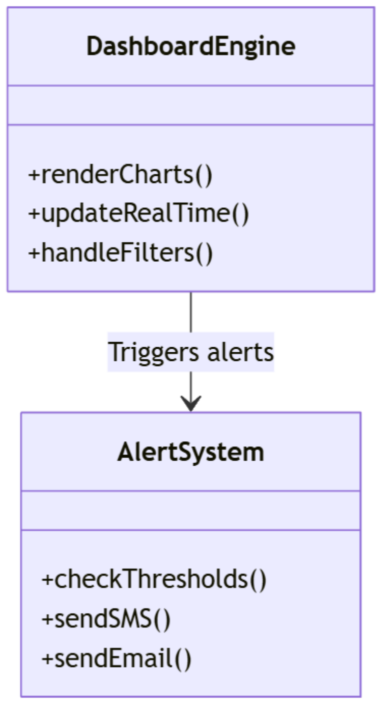


Figure 4 The class models of the presentation layer

- VisualizationBuilder: Dynamically generates charts using user-selected metrics.

Sequence Diagram

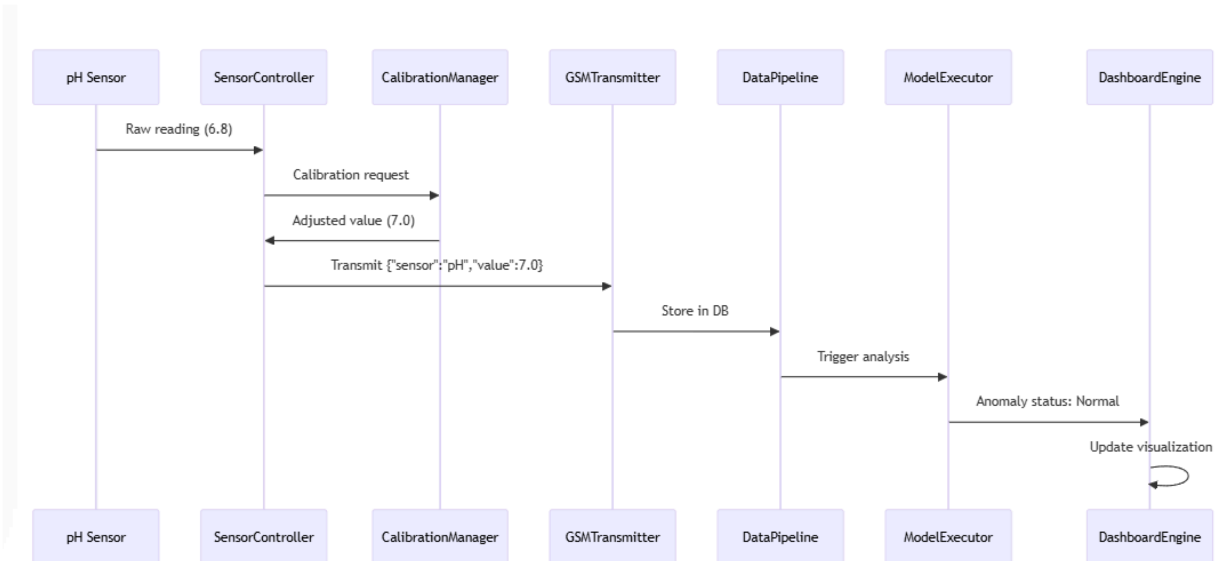


Figure 5 Data flow in the monitoring system. The sensor collects a raw pH value (6.8) and sends it to the SensorController for calibration (7.0). The CalibrationManager processes the data and transmits a JSON packet via the GSMTransmitter. The DataPipeline store

3.3 Design Rationale

Key Trade-offs

- Latency vs. Decoupling: Inter-layer network calls introduce minor delays but enable independent scaling.
- Resource Usage: Microservices increase memory footprint but allow selective deployment on edge devices.

Rejected Alternatives

- Serverless Architecture: Avoided due to unpredictable costs and cold-start latency issues.
- Hybrid Monolithic-Microservices: Complexity in managing mixed deployments outweighed potential benefits.

4. DATA DESIGN

4.1 Data Entities

The data entities and schema are customly designed to fit the system architecture ,therefore there are different streams instead of tables due to the real-time aspect of our project .

Table 1 Anomaly table ,will store unusual or unexpected sensor readings detected based on predefined thresholds, statistical models, or machine learning techniques.

Column	**Data type**
timestamp	TIMESTAMP
alert_type	VARCHAR
severity	VARCHAR
message	TEXT

Table 2 Parameters table, will store metadata about the environmental sensors deployed in the field.

Column	**Data type**
timestamp	TIMESTAMP
pH	FLOAT
temperature	FLOAT
conductivity	FLOAT
turbidity	FLOAT
status	VARCHAR

Table 3 Alerts table ,will store notifications generated when sensor readings exceed predefined thresholds.

Column	Data type
timestamp	TIMESTAMP

Table 4 Locations table , will store information about the geographical locations where water quality monitoring sensors are deployed..

Column	Data type
location_id	VARCHAR(50)(PK)
name	VARCHAR(100)
latitude	DECIMAL(10,6)
longitude	DECIMAL(10,6)
region	VARCHAR(100)

4.2 Data Schema

4.2.1 Database Schema Diagram Description

The database schema below describes how the different entities will be relating with each other to make a whole ,The sensors are the primary factor for this use case and they will determine everything else that happens,the locations in which the sensors are installed will also enable users to know where exactly the issue is ,the anomaly table will also work hand in hand with the alerts table to make known hazards that could cause dangerous after effects.

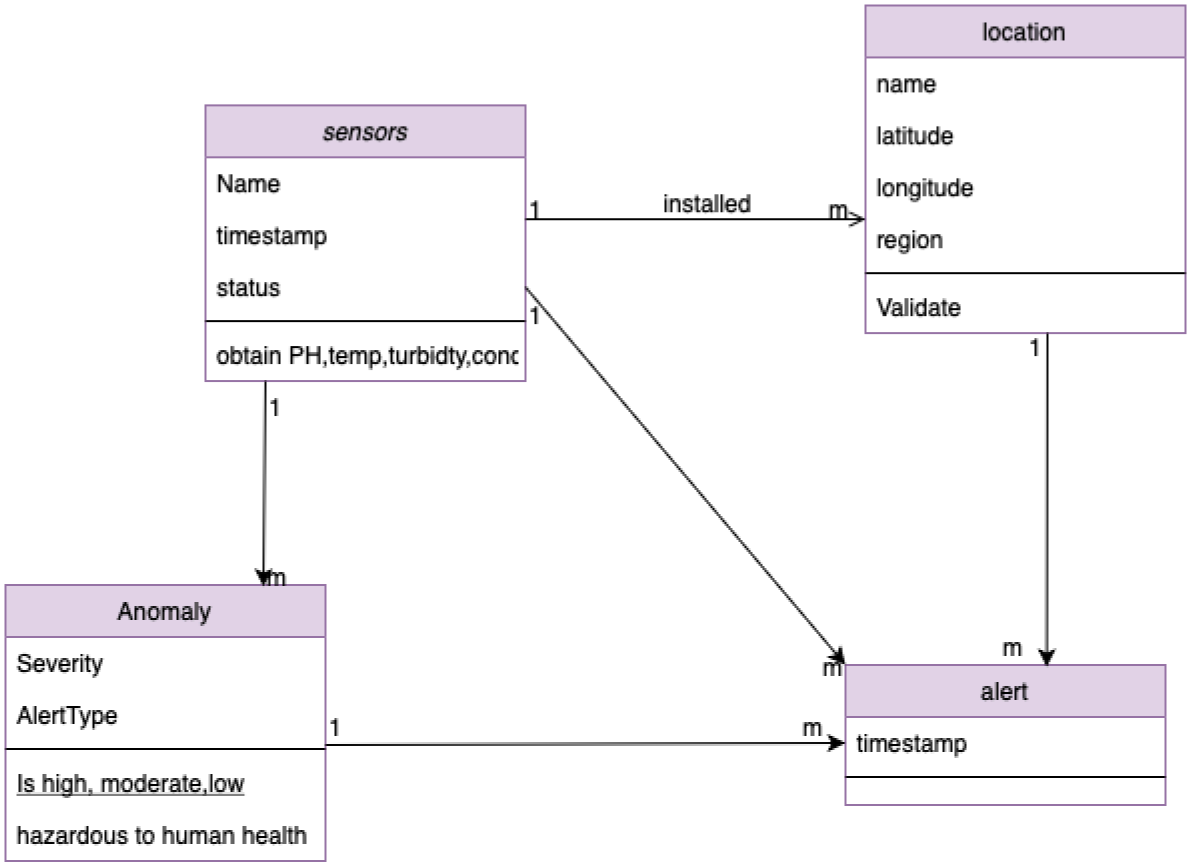


Figure 6 This ER diagram represents a sensor monitoring system where sensors at validated locations measure environmental factors, triggering alerts based on detected anomalies, which are classified by severity and potential health risks.

4.3 DATA HANDLING

Most of the sensors we have,such as pH, temperature, conductivity, and turbidity sensors, generate analog signals which are continuous voltage output.

Since computers and microcontrollers cannot process analog signals directly, an ADC (Analog-to-Digital Converter) shall be used which will convert the analog values to binary values that can be decoded by the microcontroller.

The analog readings obtained from the sensors shall then be converted to digital signal values for easy and simplified manipulation and interpretation.

The analog to digital conversion will take place in the microcontroller or the built in digital ADC since some of our sensors output digital data directly.

Once converted to digital, the data shall be transmitted to the processing unit (microprocessor).

After transmission, the data will be expected to reach the Processing Layer, where it is cleaned, analyzed, and stored temporarily for real-time monitoring.

On detection of values that are outliers from the threshold values i.e below or above the threshold values,users shall be notified through alerts .

5.0 COMPONENT DESIGN

The AWQMS follows a layered microservices architecture, which divides the system into four key components:

Each of these layers has well-defined components to ensure real-time water quality monitoring, anomaly detection, and alert generation.

5.1.Data Acquisition Layer

This layer shall be incharge of collecting raw data, converting it to digital signals and performing filtration to reduce noise that could affect the accuracy.

In this layer ,sensor values will be checked to ensure no missing values ,and then abnormal values shall be spotted out by the AI and Machine learning techniques being used .

Key components

- Sensors
- Analog to Digital Converter
- Microcontroller
- Anomaly detection

5.2. Data Processing Layer

Upon receiving data from the Acquisition layer, this layer shall be responsible for filtering, validating and processing incoming data from the sensors.

Additionally it shall distribute this processed data to the analytics layer for analysis and recommendations .

Key Components

- Data cleaner
- Websockets/APIS
- Dashboard

5.3. Analysis Layer

Based on the outcome of the previous layer , real-time predictive analysis is carried out to detect trends,negative or positive using a machine learning model .

Incase any anomalies are detected ,an alert is triggered to notify the user of the problem and potential dangers and outcomes

Key components

- Predictive Analysis module
- Threshold based alert system
- Event notification service

5.4 Presentation and visualisation layer

In this layer a dashboard that displays real-time data is available for purpose of monitoring sensor readings after which alerts and notifications are sent to users

Key components

- Dashboard
- Visualisation
- Push Notifications

6. HUMAN INTERFACE DESIGN

6.1 Overview of User Interface

The **Affordable Water Quality Monitoring System** provides a **web-based dashboard** that allows users to monitor water quality in real-time. The interface is designed to be **user-friendly** and **responsive**, ensuring accessibility on both **desktop** and **mobile devices**. The primary goal of the interface is to provide users with **real-time data visualization**, **predictive analysis**, and **alert notifications** to help them make informed decisions about water quality.
The key functionalities of the UI include:

Real-Time Data Visualization:

- Users can view live sensor data (e.g., pH, temperature, conductivity, turbidity) in graphical and tabular formats.
- The dashboard updates automatically every few seconds or minutes depending on the user's settings to reflect the latest sensor readings.

Historical Data Analysis:

- Users can access historical data and analyze trends over time using interactive graphs and charts.
- Data can be filtered by time range, or specific water quality parameters.

- Users can also choose the timeframe in which the data can be stored in the database.

Predictive Analysis:

- The system provides predictive insights into water quality trends and potability assessments using AI/ML models.
- Users can view forecasts for future water quality issues and receive recommendations.

Alert Notifications:

- The system generates real-time alerts when water quality parameters exceed predefined thresholds.
- Alerts are displayed on the dashboard and sent via SMS or email.

Sensor Locations:

- Users can view the geographical distribution of all sensors installed by the user in different locations.

The UI is designed to be **responsive**, ensuring a seamless experience across devices. It also supports **localized date/time formats** to cater to users in different regions.

User Interaction:

- Users must log in to the system and access the dashboard, where they can view real-time data, historical trends, and predictive analysis.
- The interface includes a **navigation bar** for easy access to different sections (e.g., Home, History, Settings, Analytics, Alerts).
- Users can configure alert thresholds, manage sensors, and adjust notification preferences in the **Settings** section.

Feedback Mechanism:

- The system provides **real-time feedback** through live data updates and alerts.
- Users receive **visual indicators** for example color-coded alerts like red for danger, orange for warning and blue/green for safe/normal for quick identification of issues.
- Error messages are displayed in **user-friendly language** to help users troubleshoot issues.

6.2 Screen Images

Below are the mockups of the key screens in the user interface:

1. **Dashboard Screen**:
    - The dashboard displays real-time sensor data (pH, temperature, conductivity, turbidity) in graphical and tabular formats. Users can hover over graphs to view detailed readings and filter data by location or time range.
    - Includes live graphs, key metrics, and a header with an alert button for active notifications.
    - The dashboard also includes real-time geographical distribution of the installed sensors

Mockup:

Figure 7 Illustrates the dashboard of the AWQMS

2. **Alert Screen**:
    - Shows a list of active alerts with details such as parameter, severity, and timestamp.
    - It also includes an alerts configuration menu where the user can configure the alerts based on their preferences such as setting up alert thresholds and the mode in which to receive the alerts i.e., by email Notifications or Push notifications.

Mockup:

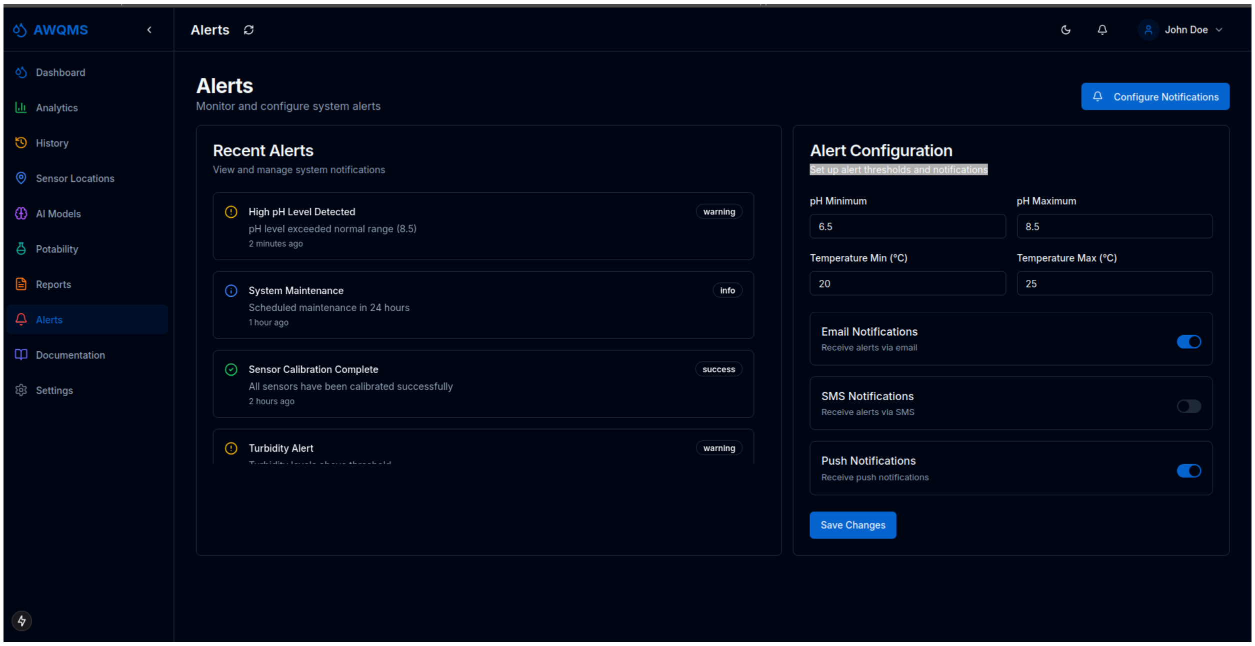


Figure 8 Illustrates the alert page of the AWQMS

3. **Historical Data Screen**:
    - Allows users to view historical data, period comparisons and trends over time.
    - Includes a date range selector and filter options for location and parameters.
    - Users can export data in CSV or PDF format for offline analysis.

Mockup:

4. **Settings Screen**: Includes;
    - **System Settings**: Allows users to configure system parameters for sensor readings, set custom thresholds and also set the time in which the system should take the sensor readings.
    - **Notifications Settings**: Lets users adjust notification preferences, such as enabling or disabling SMS or email alerts and also set the duration in which the user can receive alerts.
    - **Profile Settings**: Enables users to Update your personal information and preferences such as their name, bio, password and email.

Mockup:

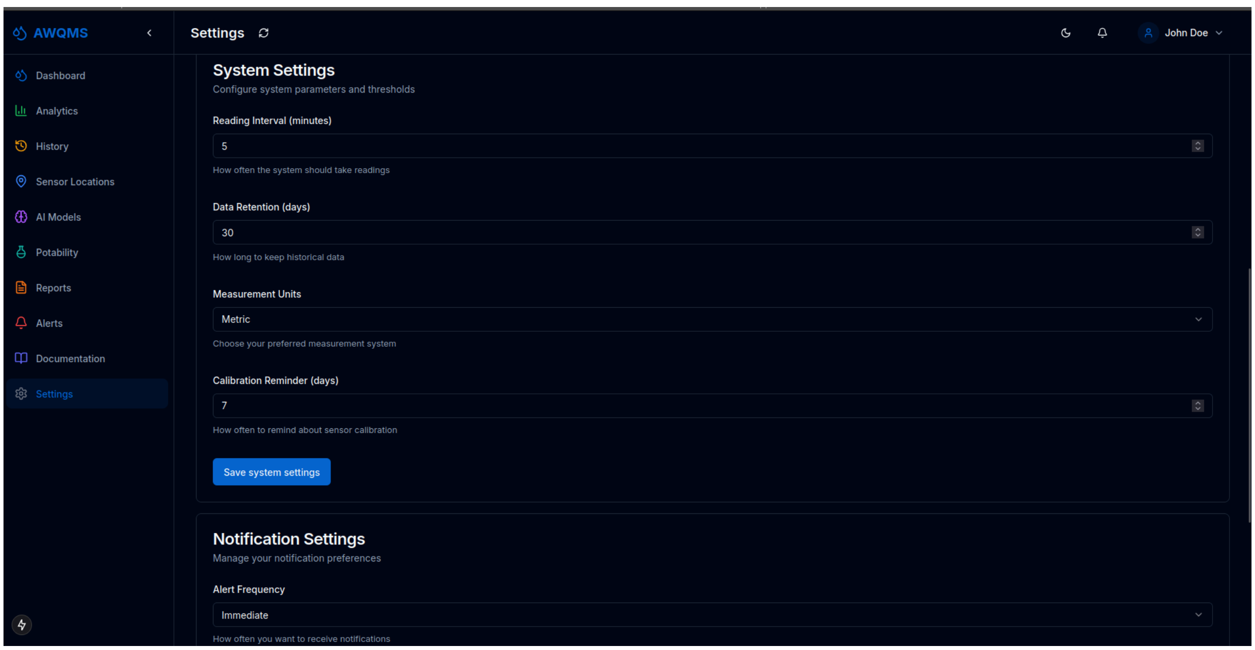
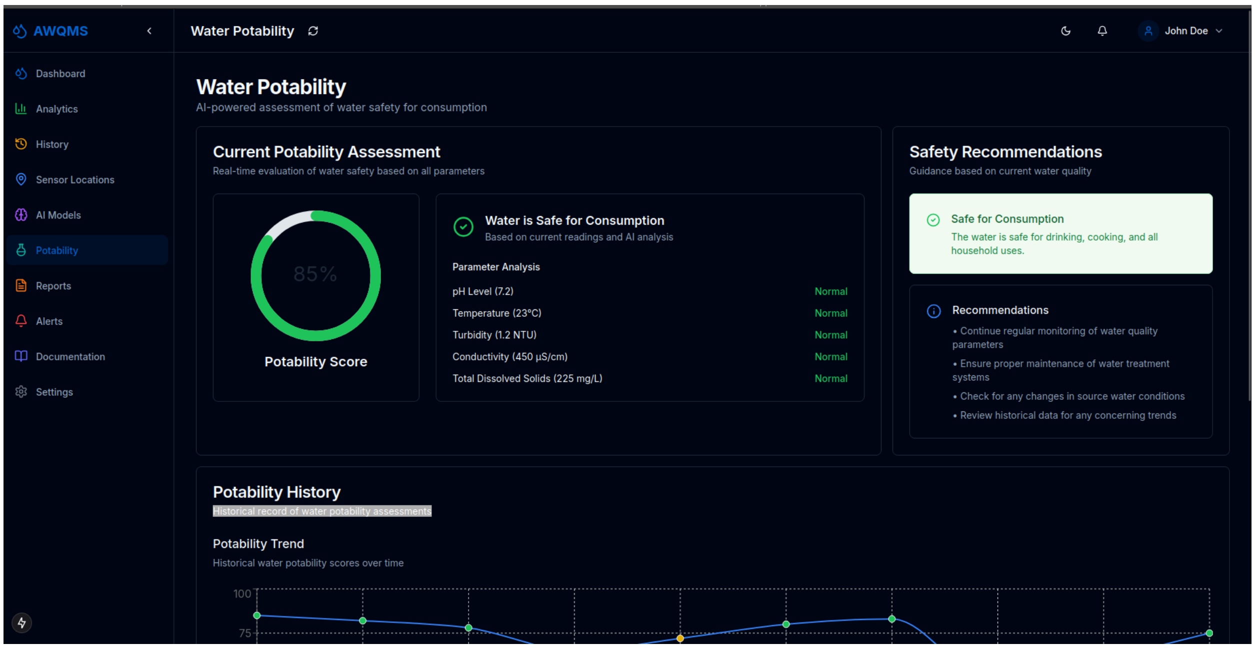


Figure 9 Illustrates the settings page of the AWQMS

5. **Water Potability Screen:**
    - This includes an AI-powered assessment of water safety for consumption showing the current potability assessment with real-time evaluation of water safety based on all sensor parameters (Ph, Turbidity, Conductivity and Temperature)

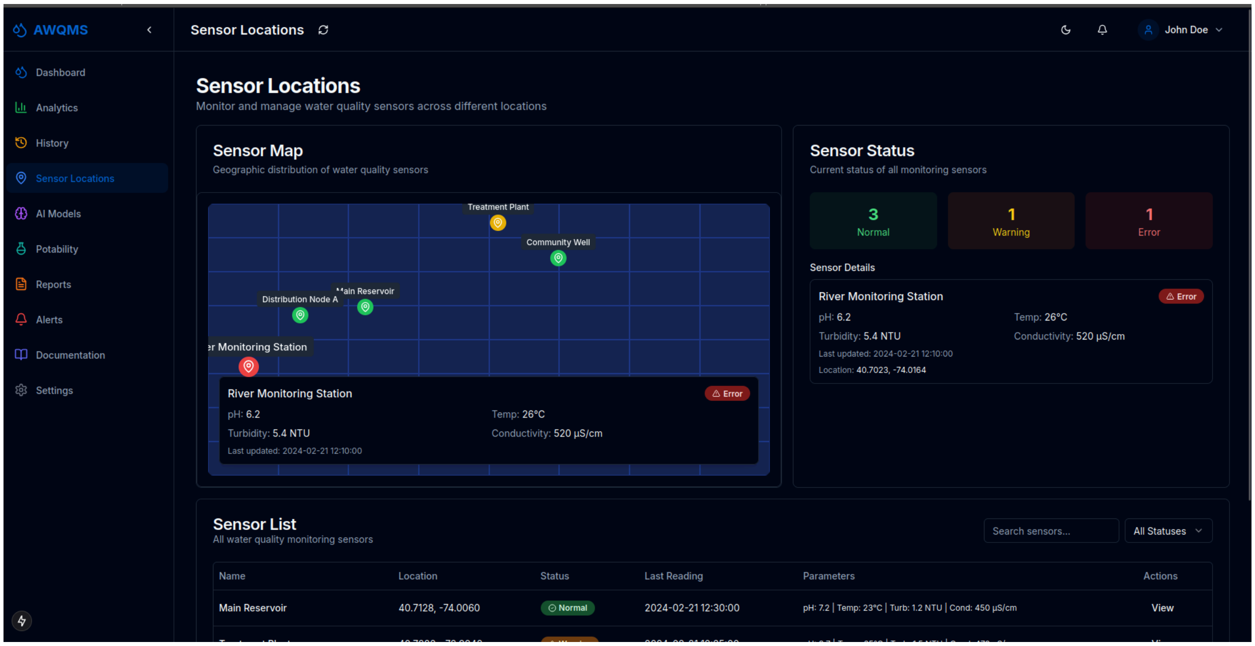
- It also includes a safety recommendations section based on the current water quality and a potability trend graph with historical record of water potability assessments.

Mockup:



6. **Sensor Locations Screen:**
    - This page displays the geographical distribution of all sensors installed by the user including a section for the current sensor calibration status identified by color codes where red stands for an error in the sensor calibration, orange for a warning and green for normal sensor calibration.

Mockup:

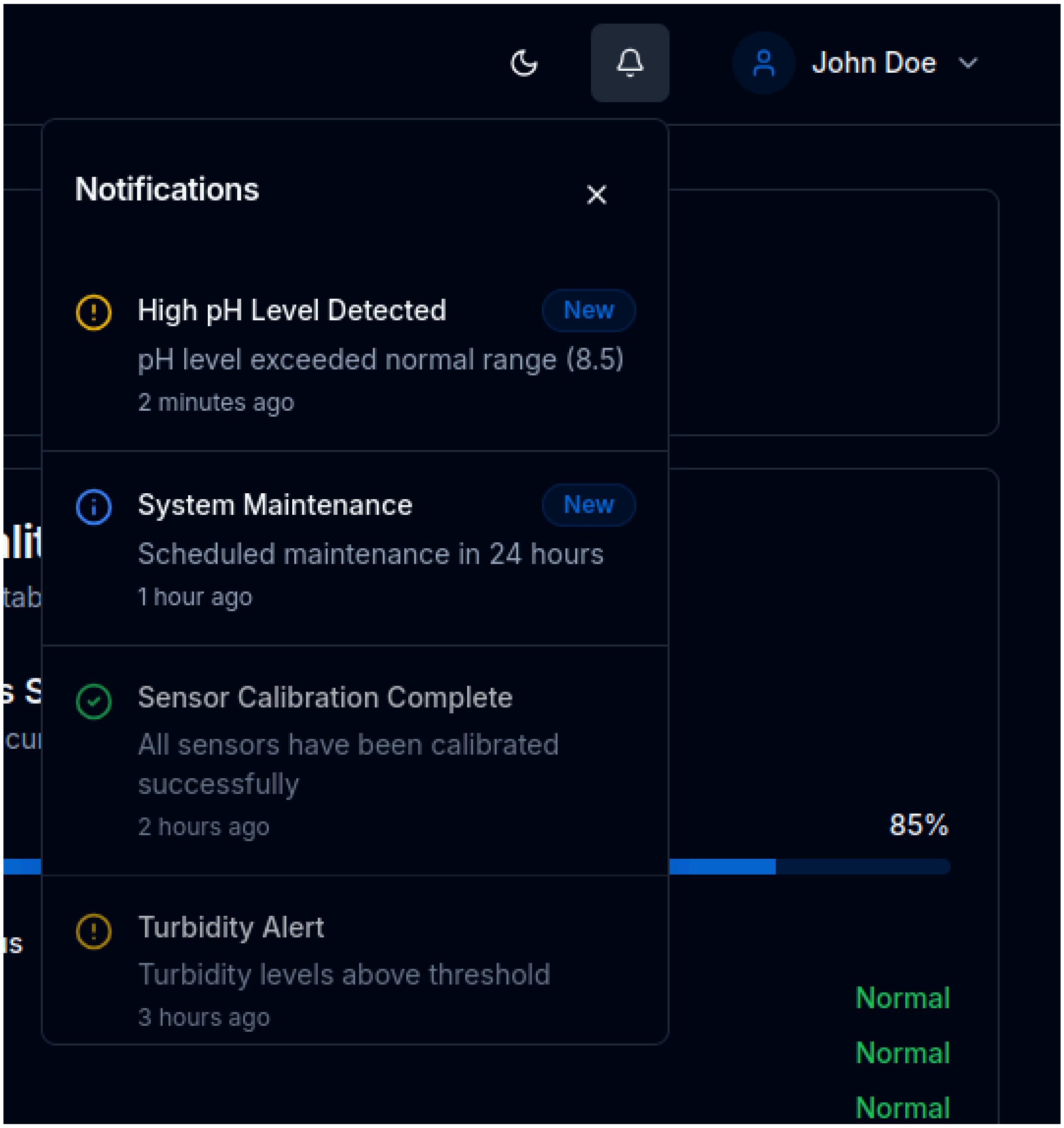


6.3 Screen Objects and Actions

The user interface includes several interactive objects that allow users to perform specific tasks. Below is a description of the key objects and their associated actions:

Dashboard Screen:

- **Graphs/Charts**: Display real-time and historical data for water quality parameters. Users can hover over the graphs to view detailed readings.
- **Refresh Button**: Allows users to manually refresh the data displayed on the dashboard.
- **Export Button**: Enables users to export the current data view in CSV or PDF format for offline analysis.
- **Alert Panel**: Displays active alerts with details such as parameter, severity, and timestamp. Users can click on an alert to view more details.



Alert Panel

Alert Screen:

- **Alert List**: Displays a list of active alerts. Each alert includes details such as the affected parameter, severity level, and timestamp.
- **Acknowledge Button**: Allows users to acknowledge and dismiss alerts. Once acknowledged, the alert is removed from the active list.

Settings Screen:

- **System Settings**: Allows users to set custom thresholds for alerts based on their specific requirements, set data retention period and also calibration reminders of how often a user will be reminded about calibration for sensors.
- **Profile Settings**: Enables users to update their user information like Name, email and their Bio.
- **Notification Settings**: Lets users adjust notification preferences, such as enabling or disabling SMS or email alerts and also set the alert frequency for receiving notifications.

7. REQUIREMENTS MATRIX

This section provides a cross-reference matrix that traces the system components and data structures described in this Software Design Document (SDD) to the functional requirements. This matrix demonstrates how the system design fulfills each functional requirement. Functional Requirements (FR) are derived from the Software Requirements Specification (SRS) as referenced in section 1.4 of this document.

Table 5 Requirements Matrix of the AWQMS

FR ID	Functional Requirement Description (from SRS)	System Components Satisfying Requirement	Data Structures Related to Requirement
FR1	Continuous Water Quality Monitoring: The system shall continuously monitor water quality parameters including pH, temperature, conductivity, and turbidity.	- Sensors (pH, Temperature, Conductivity, Turbidity	- Parameters Table (real-time data)
FR2	Affordable and Accessible Solution: The system shall be affordable to deploy and maintain in resource-constrained settings and utilize readily available communication technologies.	- Low-cost Sensors	-Design choice reflected in component selection rather than specific data structures

FR3	Data Transmission and Storage: The system shall reliably transmit collected sensor data to a cloud-based platform for storage and analysis using GSM modules.	- GSM Transmitter	- Parameters Table (historical and real-time data)
FR4	AI/ML-Driven Analysis: The system shall utilize machine learning algorithms to analyze sensor data, identify patterns, detect anomalies, and predict potential water quality issues (forecasting and potability assessment).	- Analytics & ML Layer	- Parameters Table (input data for analysis
FR5	User-Friendly Interface: The system shall provide a user-friendly web interface, accessible via desktop and mobile devices, for data visualization, reporting, and alert generation.	- Presentation Layer	- Alerts Table
FR6	Real-time Data Visualization: The user interface shall display real-time sensor data in graphical and tabular formats with automatic updates.	- Presentation Layer	- Parameters Table
FR7	Historical Data Analysis: Users shall be able to access and analyze historical data and trends over time through the user interface.	- Presentation Layer	- Parameters Table
FR8	Predictive Analysis Display: The user interface shall present predictive analysis results, including forecasts and potability assessments, to users.	- Presentation Layer	- Parameters Table (potability status as attribute)
FR9	Alert Notifications: The system shall generate and display real-time alerts on the user interface and via SMS or email when water quality parameters exceed	- Presentation Layer	- Alerts Table (alert information)

	predefined thresholds.		

Explanation of the Matrix:

- **FR ID:** A unique identifier for each Functional Requirement, numbered for easy reference.
- **Functional Requirement Description:** A concise description of the functional requirement as interpreted from the SRS (and elaborated in Section 2 of this SDD).
- **System Components Satisfying Requirement:** Lists the system components (from Section 3 & 5 of this SDD) that are designed to implement and fulfill the respective functional requirement. This column demonstrates the design choices made to address each requirement.
- **Data Structures Related to Requirement:** Lists the key data entities and tables (from Section 4 of this SDD) that are utilized or affected by the functional requirement. This highlights the data flow and management aspects of each requirement.

This Requirements Matrix provides a clear and concise way to verify that the system design adequately addresses all the defined functional requirements, ensuring traceability and completeness of the design documentation.