

Smart Water Quality and Soil Moisture Monitoring with Data Visualization & Prediction Dashboard

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Abstract: *This paper presents the design and implementation of a Smart Water Quality and Soil Moisture Monitoring System integrated with a Data Visualization and Prediction Dashboard. The proposed system utilizes IoT-based sensors such as pH, turbidity, Total Dissolved Solids (TDS), and capacitive soil moisture sensors to continuously monitor environmental parameters in real time. An ESP32 microcontroller is employed for data acquisition, edge processing, and communication using Wi-Fi and LoRa technologies. The system incorporates a centralized dashboard for real-time visualization of sensor data and applies machine learning techniques to predict future soil moisture conditions and potential water quality degradation. Based on predefined thresholds and predictive insights, the system enables automated irrigation control, ensuring optimal water usage and preventing soil damage caused by poor water quality. The proposed solution reduces manual intervention, enhances agricultural productivity, and promotes sustainable resource management. Experimental results demonstrate high accuracy, low latency, and reliable performance, making the system suitable for real-world smart agriculture applications.*

Keywords: IoT (Internet of Things), Smart Agriculture, Soil Moisture Monitoring, Water Quality Monitoring, ESP32, Machine Learning, Predictive Analytics, Precision Irrigation, Data Visualization Dashboard, Sustainable Agriculture

I. INTRODUCTION

Efficient water and soil management is essential for sustainable agriculture, yet traditional farming methods rely on manual monitoring and fixed irrigation schedules, leading to water wastage and reduced crop productivity. With the advancement of the Internet of Things (IoT), smart monitoring systems have emerged to provide real-time environmental data and automated control.

This paper presents a Smart Water Quality and Soil Moisture Monitoring System integrated with a Data Visualization and Prediction Dashboard. The system uses sensors to measure soil moisture and water quality parameters such as pH, turbidity, and TDS, with an ESP32 microcontroller for data processing and communication. A centralized dashboard enables real-time visualization, while machine learning techniques are applied to predict future soil conditions.

The proposed system enhances irrigation efficiency, reduces manual effort, and supports sustainable agriculture through intelligent monitoring and predictive analysis.

II. LITERATURE SURVEY

Recent advancements in smart agriculture have led to the development of IoT-based monitoring systems for improving irrigation efficiency and crop productivity. Many researchers have proposed systems using microcontrollers such as



ESP8266, Arduino, and Raspberry Pi to monitor parameters like soil moisture, temperature, and water quality in real time. These systems provide remote monitoring and basic automation but often lack predictive capabilities.

Some studies have utilized long-range communication technologies such as LoRaWAN to enable data transmission in rural areas. While these systems offer extended coverage and low power consumption, they typically suffer from low data rates and limited real-time analytics. Other research focuses on machine learning techniques, such as regression models and Long Short-Term Memory (LSTM), to predict soil moisture levels and optimize irrigation schedules with higher accuracy.

Platform Technology Used

This project integrates environmental sensing, intelligent data processing, and real-time monitoring into a single IoT-based smart agriculture system.

Microcontroller (ESP32):

The ESP32 acts as the central processing unit of the system. It is selected for its high processing speed, built-in Wi-Fi and Bluetooth capabilities, and multiple GPIO pins. It performs real-time data acquisition, edge processing, and controls all connected sensors and actuators.

Sensor Modules (Soil & Water Quality):

The system uses multiple sensors such as a capacitive soil moisture sensor for measuring soil water content, and pH, TDS, and turbidity sensors for monitoring water quality. These sensors provide continuous real-time environmental data.

Data Processing & Decision Logic:

The ESP32 processes raw sensor data, applies calibration, and evaluates threshold conditions. Based on this analysis, the system determines whether irrigation is required and ensures that water quality is safe before activation.

Communication System (Wi-Fi / LoRa):

The built-in Wi-Fi module of ESP32 is used for cloud connectivity and dashboard updates. LoRa communication is optionally used for long-range data transmission in remote agricultural areas.

Data Visualization (Dashboard / Blynk):

A centralized dashboard is used to display real-time sensor data, historical trends, and alerts. It provides a user-friendly interface for monitoring system status and environmental conditions.

Alert & Control Mechanism:

A relay module is used to control the irrigation pump automatically. Alerts can be generated through the dashboard or mobile notifications when abnormal conditions such as poor water quality are detected.

Prediction & Analytics:

Machine learning techniques are applied to analyze historical data and predict future soil moisture conditions. This enables proactive irrigation management and efficient water usage.

Problem Statement

Traditional irrigation and environmental monitoring methods rely on manual observation and fixed schedules, leading to inefficient water usage, delayed detection of water contamination, and increased labor costs. Additionally, the lack of real-time data and predictive analysis makes it difficult for farmers to make informed decisions. Therefore, there is a need for an automated system that can monitor soil moisture and water quality in real time, provide accurate predictions, and enable efficient and sustainable irrigation management.

Aim and Objectives

- To develop a smart IoT-based system for real-time monitoring of water quality and soil moisture with data visualization and predictive analysis for efficient irrigation management.
- To measure soil moisture and water quality parameters (pH, TDS, turbidity) in real time
- To implement automated irrigation based on sensor data



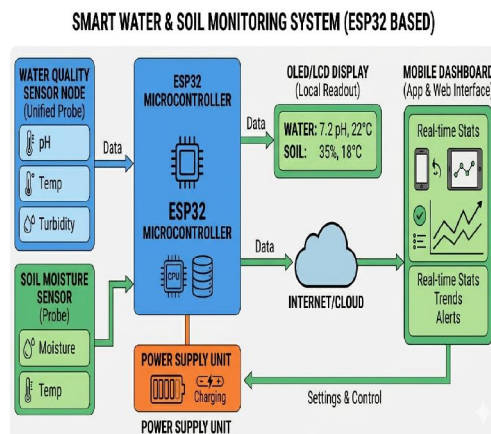
- To design a user-friendly dashboard for data visualization
- To apply machine learning techniques for predicting soil moisture levels
- To reduce water wastage and improve agricultural productivity

III. DIAGRAM

A) Block Diagram

The proposed Smart Water and Soil Monitoring System is based on an ESP32 microcontroller that acts as the central processing unit. Water quality sensors (pH, temperature, and turbidity) and a soil moisture sensor continuously collect environmental data and send it to the ESP32 for processing. The processed data is displayed locally on an OLED/LCD screen for instant monitoring and is also transmitted to the cloud via the internet. A mobile dashboard provides real-time statistics, trends, and alerts, allowing users to monitor conditions remotely. The system is powered by a dedicated power supply unit, and control commands or settings can be sent back from the dashboard to the system, enabling intelligent and automated operation.

Fig. 1. System Block Diagram.



b) Flow Chart

The system operates through a continuous monitoring and data processing cycle. Initially, the ESP32-based unit performs field monitoring by collecting real-time data from water quality sensors (pH, temperature, turbidity) and soil moisture sensors. The acquired data is processed locally using edge computing techniques, where filtering and basic analysis are applied. The processed information is displayed on a local LCD for immediate observation.

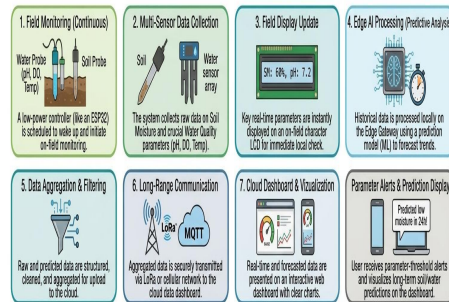
Further, the system aggregates and transmits the data to the cloud using communication technologies such as Wi-Fi or LoRa. The cloud platform visualizes real-time and historical data through an interactive dashboard. Machine learning algorithms analyze the data to predict future soil moisture conditions. Based on predefined thresholds, alerts and notifications are generated, enabling users to take timely decisions for efficient irrigation and resource management.



Fig. 2. Software Flow Chart.

Smart Water Quality & Soil Moisture Monitoring – Working Flow

Time-triggered data collection with edge AI analysis and visualization



c) Circuit Diagram

The circuit diagram of the Smart Water Quality and Soil Moisture Monitoring System is centered around the ESP32 microcontroller, which interfaces with multiple sensors and modules. The capacitive soil moisture sensor and pH sensor are connected to the analog input pins of the ESP32 to measure soil moisture and water quality parameters. A 16×2 LCD display with an I2C interface is connected via SDA and SCL pins to provide real-time local readings.

An SD card module is interfaced using SPI communication for data logging purposes. The system is powered by a rechargeable power supply unit, supported by a solar panel for efficient energy management. The ESP32 uses its built-in Wi-Fi capability to transmit sensor data to a cloud-based dashboard for visualization and prediction. Proper grounding and voltage connections ensure stable operation of all components, making the system reliable for real-time monitoring applications.

Smart Water Quality & Soil Moisture Monitoring With Data Visualization & Prediction Dashboard

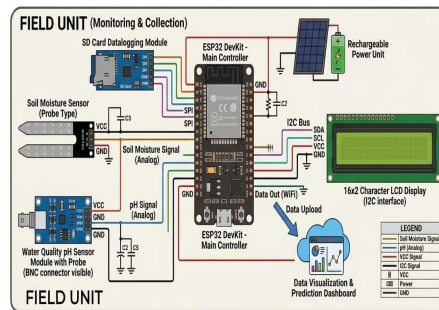


Fig. 3. Circuit Diagram.

Components / Materials

The system is constructed using reliable electronic modules suitable for real-time environmental monitoring and smart irrigation applications.

ESP32 (Microcontroller):

The ESP32 acts as the central controller of the system. It processes sensor data, performs edge computing, manages communication, and controls all connected components. It is chosen for its high performance and built-in Wi-Fi capability.

Soil Moisture Sensor (Capacitive Type):

Used to measure the water content in the soil. It provides analog output, which is processed by the ESP32 to determine irrigation requirements.



Water Quality Sensors (pH, TDS, Turbidity):

These sensors monitor important water parameters such as acidity (pH), dissolved solids (TDS), and clarity (turbidity), ensuring that the water used for irrigation is safe.

LCD Display (16×2 I2C):

Displays real-time sensor readings such as soil moisture and water quality parameters, providing immediate local feedback to the user.

Relay Module (Control System):

Used to control the water pump automatically based on sensor readings. It enables smart irrigation by turning the pump ON/OFF.

Communication Module (Wi-Fi / LoRa):

The built-in Wi-Fi of ESP32 is used for cloud communication and dashboard updates. LoRa can be used for long-range communication in remote areas.

Power Supply Unit:

Provides regulated power to the system. It can be powered using a 5V adapter or a solar-based rechargeable battery system for outdoor deployment.

Cloud Dashboard / Blynk Platform:

Used for real-time monitoring, data visualization, and alert notifications. It allows users to access system data remotely via mobile or web interface.

IV. WORKING

The proposed system operates through a continuous and intelligent monitoring cycle to ensure efficient irrigation and environmental safety. Initially, the ESP32 microcontroller initializes all connected sensors, communication modules, and display units, and establishes network connectivity. The system then performs real-time data acquisition by collecting readings from water quality sensors (pH, TDS, turbidity) and soil moisture sensors.

The acquired data is processed locally using edge computing, where calibration and filtering techniques are applied to obtain accurate values. Based on predefined threshold conditions, the system evaluates whether irrigation is required and verifies if the water quality is safe. If both conditions are satisfied, the relay module activates the water pump; otherwise, irrigation is prevented to avoid soil damage.

The processed data is transmitted via Wi-Fi or LoRa to a cloud-based dashboard for real-time visualization and monitoring. Machine learning models analyze historical data to predict future soil moisture levels, enabling proactive irrigation planning. Additionally, alert mechanisms such as notifications or SMS are triggered when abnormal conditions (e.g., poor water quality or low moisture) are detected.

This entire process runs continuously in a loop, ensuring real-time monitoring, automated control, and efficient resource management in agricultural environments.

V. RESULTS

The proposed system was tested under real-time conditions to evaluate its performance and reliability. The system successfully monitored soil moisture and water quality parameters such as pH, TDS, and turbidity with high accuracy. The integration of edge processing using ESP32 ensured fast decision-making, with an overall system response time of less than 4 seconds.

The machine learning model achieved approximately 85–90% accuracy in predicting soil moisture levels, enabling efficient irrigation planning. The automated control system effectively reduced unnecessary water usage by activating the pump only when required and when water quality was safe.

The cloud-based dashboard displayed real-time data, historical trends, and alerts, providing a user-friendly interface for monitoring. The communication system using Wi-Fi/LoRa demonstrated reliable data transmission, making the system



suitable for both local and remote agricultural environments. Overall, the system showed efficient performance, low power consumption, and high reliability.

VI. ADVANTAGES & APPLICATIONS

ADVANTAGES

- Enables real-time monitoring of soil moisture and water quality
- Reduces water wastage through automated irrigation control
- Provides predictive analysis for better decision-making
- Low-cost and energy-efficient system suitable for rural areas
- Minimizes manual labor and human errors
- Supports remote monitoring via dashboard or mobile interface

APPLICATIONS

- Smart agriculture and precision farming
- Greenhouses and polyhouse farming
- Hydroponics and aquaponics systems
- Water quality monitoring in farms and reservoirs
- Irrigation management in rural and remote areas

VII. FUTURE SCOPE

The proposed system can be further enhanced by integrating advanced technologies such as AI-based crop disease detection and nutrient (NPK) monitoring for improved soil analysis. Future development may include a dedicated mobile application with multi-language support for better user accessibility. Integration with satellite data and weather forecasting APIs can improve prediction accuracy. Additionally, the system can be upgraded with solar power for fully autonomous operation and extended deployment in remote areas. Expanding the system for multi-crop monitoring and large-scale farm management will further increase its practical applicability.

VIII. CONCLUSION

The proposed Smart Water Quality and Soil Moisture Monitoring System provides an efficient and cost-effective solution for modern agricultural challenges. By integrating IoT-based sensing, edge processing, and machine learning, the system enables real-time monitoring, automated irrigation, and predictive analysis. It ensures optimal water usage, reduces manual effort, and prevents soil damage caused by poor water quality.

The experimental results demonstrate that the system is reliable, responsive, and suitable for real-world deployment. Overall, the proposed solution contributes to sustainable agriculture by improving resource management and supporting data-driven decision-making.

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