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DESIGN AND DEVELOPMENT OF AN IOT-BASED SMART IRRIGATION SYSTEM FOR FARMS IN ABIA STATE UNIVERSITY

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ABSTRACT

The setting for this research and experiment is Abia State University, and the work discuss the development of an IoT-based smart irrigation system for the promotion of sustainable and efficient farming practices at Abia State University. The issue of watering, inaccuracy, and a lack of irrigation control through irrigation was addressed through IoT-based water conservation and the maintenance of optimal soil moisture levels. The capacitive soil moisture sensor and the soil water level sensor are used to track the soil condition and the irrigation water available at real time. These sensors are used to feed the data necessary for smart irrigation. An ESP32 is the brain of the whole setup, which has Wi-Fi built into it, transmitting the data received from the sensors to a mobile app, which can remotely display the data. Watering is done through a solenoid valve and a relay. Flexibility will be automatic or manual. For the automatic mode, the system will irrigate the plot whenever the soil moisture level falls below set ranges and will control the system as soon as the soil moisture level returns to normal. Manual control allows the farmer to irrigate the plot through the Blynk app whenever they want. The Blynk app will enable the farmer to monitor the soil moisture level and control the system through the remote control system offered by the app. The Blynk app will display the readings from the sensors and the status of the system.The test results reveal that the system adapts to a change in soil moisture level and makes a significant reduction in water consumption compared to traditional methods. The system is designed with low-cost components that are easily available, meaning that it can be scaled up for use in several plots or even fields. In conclusion, this smart irrigation system, which is based on IoT

technology, is an appropriate approach to precision irrigation that improves agricultural productivity in university campuses and nearby agricultural communities.

KEYWORDS: IoT, Smart Irrigation, ESP32, Soil Moisture Sensor, Mobile Monitoring.

1. INTRODUCTION

Agriculture remains a critical component of Nigeria's economy, employing a large portion of the population and serving as the primary source of food and income in both urban and rural communities. However, the sector continues to face significant challenges related to inefficient irrigation practices, over-dependence on manual labor, unpredictable weather patterns, and poor adoption of emerging technologies. Water scarcity and inefficient water management, in particular, contribute to suboptimal crop yields, soil degradation, and increased operational costs. Within institutional farms such as those in Abia State University, there is an urgent need to adopt innovative, sustainable irrigation techniques that maximize resource use while reducing manual intervention.

Recent advances in the Internet of Things (IoT) have enabled the development of real-time, sensor-driven systems for environmental monitoring and resource control in agriculture (Khanna & Kaur, 2019; Abba et al., 2022). IoT-based systems integrate physical devices such as soil moisture sensors, actuators, and microcontrollers, allowing farmers to monitor and manage irrigation remotely using mobile platforms or cloud services (Jat & Nandurkar, 2022; Singh & Misra, 2020). These systems help conserve water by triggering irrigation only when soil conditions demand it, enhancing crop yield while reducing water wastage (Kumar & Patel, 2014).

This study focuses on the design and development of a prototype IoT-based smart irrigation system tailored for application on university-managed farms in Abia State University in Abia. The proposed system comprises an ESP32 microcontroller, a capacitive soil moisture sensor, and a soil water level detector, all of which work together to monitor the soil's water content. A solenoid valve, controlled through a relay module, serves as the actuator to regulate water flow into the soil. The system connects to a Wi-Fi network and integrates with a mobile application, enabling users to view real-time soil conditions and remotely control the irrigation valve from their smartphone (Patil & Kale, 2016; Al-Fuqaha et al., 2015).

The significance of this work lies in its local applicability and potential for scalability across other university farms and rural agricultural settings in Nigeria. By leveraging low-cost components and open-source development tools, the system provides a cost-effective solution

that can be replicated by agricultural institutions and smallholder farmers (Jawad et al., 2017). In addition to minimizing water use, the system enhances precision in irrigation scheduling, reduces labor requirements, and provides data-driven insights into soil health management (Mamun et al., 2018).

This project contributes to the broader goal of promoting smart agriculture practices in Nigeria. It bridges the gap between traditional farming methods and modern technology by demonstrating a practical, real-time, mobile-controlled solution for smart irrigation, aligning with global trends in sustainable agricultural innovation.

2. Materials and Methods

2.1 Materials

The materials used in the design and development of the IoT-based smart irrigation system are selected to ensure cost-efficiency, availability, and compatibility with embedded systems and IoT platforms. The complete bill of materials (BOM) is shown in Table 1.

Table 1. Bill of Materials for the Smart Irrigation System.

S/N	Component	Quantity	Function
1	ESP32 Microcontroller	1	Acts as the central control unit; reads sensor data and manages IoT communication
2	Capacitive Soil Moisture Sensor	2	Measures the soil's moisture content in percentage
3	Soil Water Level Sensor	2	Detects water saturation or flooding at root level
4	Relay Module (1-Channel)	1	Switches the 12V solenoid valve based on ESP32 control signal
5	12V DC Solenoid Valve	1	Opens or closes to control water flow through irrigation pipes
6	12V Power Adapter or Battery	1	Provides power supply to the valve and microcontroller
7	DHT11 Temperature and Humidity Sensor (optional)	2	Measures ambient environmental conditions (temperature/humidity)
8	Jumper Wires and Breadboard/PCB	1 set	For circuit prototyping and sensor integration
9	Wi-Fi Router or Mobile Hotspot	1	Provides internet connectivity for real-time control
10	Water Pipes / Hoses	As required	Channels water to the crop area
11	Plastic Enclosure (Weatherproof)	1	Protects electronics from environmental elements
12	12V or 24V DC diaphragm pressure pump		
13	Smartphone with Blynk App Installed	1	Interfaces with the system for control and monitoring

2.2 System Overview

The system is designed to continuously monitor the moisture content and water level in the soil. When the soil becomes dry below a defined threshold, a notification is sent to the user via the Blynk mobile app. The user may then manually open the irrigation valve through the app. The ESP32 receives the input signal and activates the relay module, which powers the solenoid valve and allows water to flow through the pipes. The soil water level sensor serves as a feedback mechanism to detect excessive water presence, preventing over-irrigation.

2.3 Farm Structures



Figure 1: Farm Layout.

The IoT-enabled smart irrigation system will be installed on the Abia State University farm, a moderately farmed open field with loamy soil and mild slopes that is ideal for growing crops. The farm has sufficient natural drainage, and crops like cassava and vegetables planted in ridges. Its open exposure guarantees effective wireless communication for real-time irrigation control and monitoring, and its easily accessible layout and soil texture make it perfect for installing sensors, pumps, and controllers.

2.4 Circuit Design and Connections

The circuit is built around the ESP32 microcontroller. The capacitive soil moisture sensor is connected to one of the analog input pins (e.g., GPIO 34), and the soil water level sensor is connected to a digital pin (e.g., GPIO 26). The relay module is driven via a GPIO output pin

(e.g., GPIO 17), and its output controls the 12V solenoid valve. Optional sensors like DHT11 can be connected to GPIO 14 for environmental data logging.

2.4 Software and Programming

The ESP32 is programmed using the **Arduino IDE**, with the following libraries:

- WiFi.h – for network communication
- HTTPClient.h – for linking ESP32 to thingspeak
- DHT.h – for reading optional temperature/humidity sensor

The firmware includes the following features:

- Reading analog and digital sensor data
- Sending data to the Thinspeak in real-time
- Sending data to Blynk app for monitoring and valve control
- Receiving user input to control the valve
- Triggering alerts when soil is dry or over-saturated

2.5 Real Time Monitoring

The IoT based smart farm system is monitored in real time using the Matlab Thingspeak Platform. The channel displays the following HTTP request data, soil water level, soil temperature and soil humidity. The Thingspeak channel apiKey is "OYU8L9KM0MUKCQMW".

The mobile interface using Blynk IoT platform is also used for signal monitoring, alerts systems and control of valves in the system using designed switch button via WiFi. The mob1ile 1i1n1terface on Blynk includes:

- A virtual gauge to display soil moisture percentage
- A button switch to control the solenoid valve
- Notifications triggered when soil is dry
- Optional display for temperature and humidity

The mobile app is linked to the ESP32 using a Blynk authentication token and connects via the same Wi-Fi network.

2.6 Deployment and System Integration

For full-scale deployment on a 240 m² plot at Abia State University, the IoT-based irrigation system was redesigned to accommodate real-world field requirements and spatial water distribution. Instead of a single water source and valve, the farm is divided into three functional irrigation zones, each controlled by an independent pressure pump and pressure

sprinkler system. These zones enable targeted water delivery based on soil conditions, irrigation schedules, or plant requirements.

Each zone features:

- One 12V or 24V DC diaphragm pressure pump
- One or more pressure-controlled sprinkler heads
- A localized soil moisture sensor
- An optional soil water level detector

The pressure-controlled sprinklers are capable of dispersing water in fine droplets over wide areas, simulating rain-like irrigation, which is suitable for vegetables, and fruit plants within the area (see figure 3).

2.6.1 System Design and Control Logic

At the core of the system is an ESP32 microcontroller, which communicates wirelessly with the Blynk IoT app and monitors sensor inputs from all three zones. Each pressure pump is connected to a MOSFET or motor driver circuit (rather than a relay) to enable variable voltage output, thereby controlling the pump pressure via Pulse Width Modulation (PWM) signals.

Through the Blynk mobile interface, the user can:

- View soil moisture levels for each of the three zones
- Select any of the three pumps
- Adjust pump pressure using sliders (mapped to PWM values from 0–255)
- Turn pumps on/off manually or allow automation based on soil dryness

This architecture enables both **manual and semi-automatic irrigation control**. When a moisture sensor reports dryness in Zone 2, for example, the app can notify the user. The user may then increase the pump pressure for Zone 2 by sliding the Blynk control to a higher value, ensuring adequate sprinkler coverage even in distant sections of the zone (see figure).

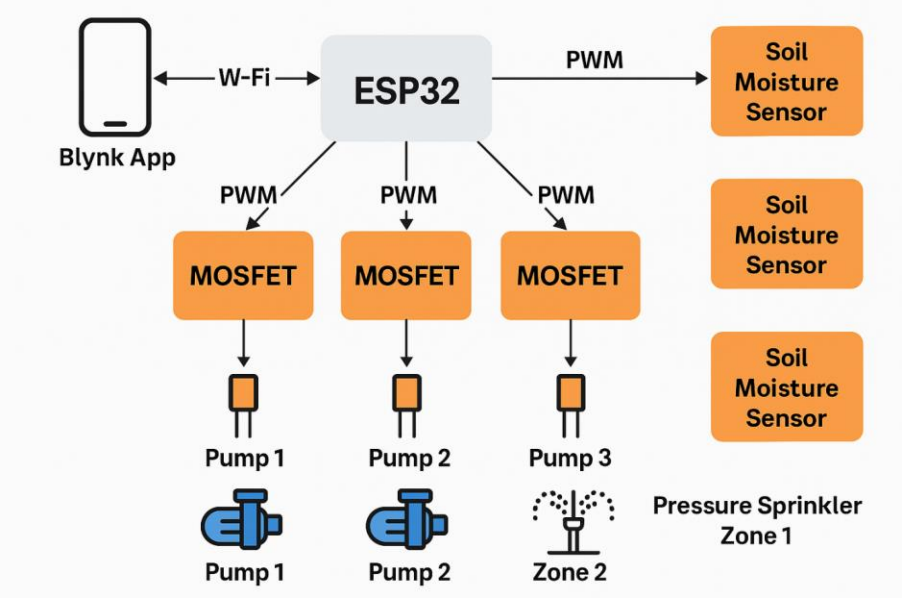


Figure 2: Smart IoT irrigation architecture.

2.6.2 Pump and Sprinkler Configuration

Each of the three pumps is mounted near a water source or shared tank and connected via PVC or PEX tubing to a series of rotating sprinkler heads. Each pump has the following characteristics (see table 2)

Parameter	Value
Type	12V/24V Diaphragm Pressure Pump
Flow Rate	8–12 L/min
Pressure Range	0.5–1.2 MPa (adjustable via PWM)
Control Mechanism	MOSFET (IRF540N or similar) via PWM
Activation Input	Digital signal from ESP32
Pressure Adjustment	Analog (PWM value mapped from slider UI)

To ensure safe and reliable water-proofing, all electronics (ESP32, MOSFETs, connectors) are housed inside IP65-rated waterproof casings with individual battery compartments for each zone controller (or centralized if wired). The moisture sensors are buried ~10 cm below the soil surface, while the water level sensors are positioned deeper for saturation detection.

2.6.3 Valve Selection

A normally closed 12V DC solenoid valve was integrated into the pipeline just after the pump outlet. This type of valve remains closed when unpowered, ensuring water doesn't flow unless explicitly opened by the system. It was selected for its compatibility with relay modules, and reliable on/off control from the ESP32, and quick actuation (within 0.2–0.5 seconds)

2.6.4 Power and Voltage Management

Since the ESP32 operates at 3.3V logic levels, a voltage regulator circuit was included to step down the 12V supply to both 5V (for powering sensors and the relay module) and 3.3V (for the ESP32). A Low Dropout Regulator (LDO) such as AMS1117-3.3 was used to provide a stable 3.3V output (see table 3). Other components such as the pumps and valves are directly connectd t the 12V battery.

Table 3. Voltage Regulation from 12V Battery Supply.

Voltage Source	Component	Output Voltage	Purpose
12V Battery	DC Input	12V	Main power supply for the system and supply to 12V components
AMS1117-5.0	Voltage Regulator	5V	Powers relay module and optional sensors
AMS1117-3.3	Voltage Regulator	3.3V	Powers ESP32 microcontroller

2.6.5 Overall Pin Connection for the Irrigation System

Table 4 shows the entire pin connection for the entire component in the smart irrigation system

Table 4: Complete ESP32 Pin Mapping for All Components.

Component	Zone	ESP32 Pin	Function	Signal Type
Soil Moisture Sensor	Zone 1	GPIO 34 (ADC1_CH6)	Analog moisture input (V1)	Analog Input (ADC)
Soil Moisture Sensor	Zone 2	GPIO 35 (ADC1_CH7)	Analog moisture input (V2)	Analog Input (ADC)
Soil Moisture Sensor	Zone 3	GPIO 32 (ADC1_CH4)	Analog moisture input (V3)	Analog Input (ADC)
MOSFET (Pump Pressure Control)	Zone 1	GPIO 17	PWM signal to MOSFET (V4)	Digital Output (PWM)
MOSFET (Pump Pressure Control)	Zone 2	GPIO 16	PWM signal to MOSFET (V5)	Digital Output (PWM)
MOSFET (Pump Pressure Control)	Zone 3	GPIO 4	PWM signal to MOSFET (V6)	Digital Output (PWM)
Manual ON/OFF Button	Zone 1	Virtual Pin V7	App switch → digital toggle	Virtual (Blynk)

Manual ON/OFF Button	Zone 2	Virtual Pin V8	App switch → digital toggle	Virtual (Blynk)
Manual ON/OFF Button	Zone 3	Virtual Pin V9	App switch → digital toggle	Virtual (Blynk)
Water Level Sensor (optional)	Zone 1	GPIO 25	Water presence detection	Digital Input
Water Level Sensor (optional)	Zone 2	GPIO 33	Water presence detection	Digital Input
Water Level Sensor (optional)	Zone 3	GPIO 26	Water presence detection	Digital Input
DHT11 Sensor (optional)	Global	GPIO 14	Temperature/humidity data	Digital Input
Wi-Fi Communication	Global	Wi-Fi (internal)	ESP32 ↔ Blynk App	Wireless
Power (3.3V logic)	All zones	3.3V	ESP32 supply	Power Supply
Power (Pump/MOSFET)	All zones	12V (external)	Pump power and MOSFET drain	External Power
Ground (GND)	All zones	GND	Common ground for all components	Ground

2.6.6 Mobile App Integration (Blynk)

Since each pump operates at 12V or 24V while the ESP32 operates at 3.3V, a DC power regulation Buck converter steps down 12V to 3.3V for the ESP32 with Direct 12V line powers the pumps and MOSFET circuits see figure 4.

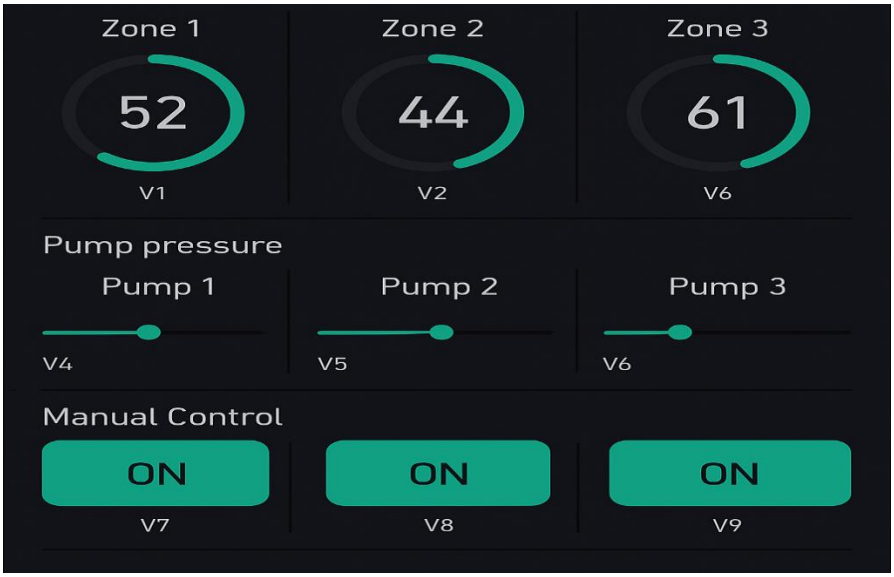


Figure 3: Switching Interface on Blynk App.

Each zone's control is mirrored in the Blynk app with:

- Three moisture readings (V1, V2, V3)

- Three PWM sliders to set pump pressure (V4, V5, V6)
- Three manual ON/OFF switches (V7, V8, V9)

The PWM values sent from the sliders are mapped inside the ESP32 code to analogWrite outputs controlling the pump via the MOSFET gate.

3. Theory and Calculation

3.1 Soil Moisture Threshold Principle

The core principle behind smart irrigation is to maintain optimal soil moisture content within a desired range specific to the crop being cultivated. Moisture sensors provide analog voltage outputs that correspond to the relative water content of the soil. The capacitive soil moisture sensor used in this system outputs values ranging from 0 (completely wet) to ~4095 (completely dry) on the ESP32's 12-bit ADC.

To automate or notify for irrigation, a threshold moisture level is defined. Let:

- V_{dry}: ADC value when soil is dry (~3000)
- V_{wet}: ADC value when soil is fully moist (~1000)
- $V_{threshold}$: Value between dry and wet that triggers irrigation (e.g., 2000)

If the current moisture reading $V_{current}$ satisfies: $V_{current} > V_{threshold}$

Then the system determines that the soil is dry and either sends an alert to a user who operated or actuates the irrigation valve via the Blynk App.This logic ensures water is only applied when needed, preventing over-irrigation and water waste.

3.2 Water Requirement Estimation

To determine the required quantity of water to irrigate a specific plot, the following empirical formula is applied:

$$W = A \times D \times C$$

Where:

- W= Water required (litres)
- A= Area of the farm plot (m^2)
- D = Desired irrigation depth (m)
- C = Crop coefficient (dimensionless, typically between 0.6–1.2)

3.3 Requirement Calculation

For the ABSU farm, the study has estimated an area of 16.74 m by 14.34 m giving an estimated $A = 240\,m^2$, an irrigation depth of $D = 0.045\,m$, and a crop coefficient $C = 0.9$:

$$W = 240 \times 0.045 \times 0.9 = 9.722\,m^3 = 9722\ litres$$

This value represents the total volume of water needed for a single irrigation cycle. This estimation helps size the water reservoir and solenoid valve throughputs.

3.4 Water Level Sensor Logic

The soil water level sensor typically outputs digital HIGH/LOW based on water presence. If water reaches the root zone or accumulates excessively, the sensor returns HIGH, which can be used to:

- Stop irrigation
- Notify the user to prevent root rot

Thus, in logic terms:

```
if (waterLevelSensor == HIGH) {
  stopIrrigation();
  sendAlert("Water level high");
}
```

This logic complements the moisture sensor to ensure both dryness and flooding are managed.

4. RESULTS AND DISCUSSION

4.1 System Functionality and Operational Validation

Each of the three zones was controlled by an individual 12V diaphragm pump, connected to a MOSFET-based PWM circuit. This configuration allowed real-time pressure control from the Blynk mobile app. Using three PWM sliders, users could manually adjust water pressure delivered to sprinklers in each zone. Moisture levels from the soil were read via capacitive sensors, providing analog values converted through the ESP32's ADC pins.

A mobile interface was designed using the Blynk platform, with three dedicated gauges for moisture readings (V1–V3), three PWM sliders (V4–V6) for pump pressure, and three toggle switches (V7–V9) for ON/OFF control of the pumps. The system was powered using a 12V battery, with regulated power delivery to the ESP32 (3.3V) and MOSFET-controlled pump circuit (12V). All components were mounted on a vero board within a weatherproof enclosure, making it suitable for continuous outdoor operation.

4.2 Field Test Results

The system was tested under variable soil and environmental conditions. Moisture readings fluctuated between 1100 (very moist) to 3100 (very dry) on the ADC scale. Upon detecting dryness (threshold > 2000), the system successfully notified the user, who then activated the relevant pump from the app and increased the pump pressure via the slider to deliver sufficient spray radius through the sprinklers.

Each pump achieved an average flow rate of 9–10 liters per minute and could maintain even spray coverage across each zone when operating at 80–100% PWM output. Pressure adjustments effectively altered the distance and intensity of sprinkler output, providing flexibility based on plant type and location within the zone.

Below are the field test results for all the zones (table 5-7);

1. Soil moisture levels before and after irrigation
2. Pressure settings vs spray radius per zone
3. Sprinkler activation summary table per zone

Table 5: Average Soil Moisture Readings Before and After Irrigation.

Zone	Sensor Reading Before Irrigation (ADC Value)	After Irrigation (ADC Value)	Interpretation
Zone 1	2850	1450	Successful moisture recovery
Zone 2	3100	1550	Soil returned to optimal range
Zone 3	2750	1380	Slight over-irrigation observed

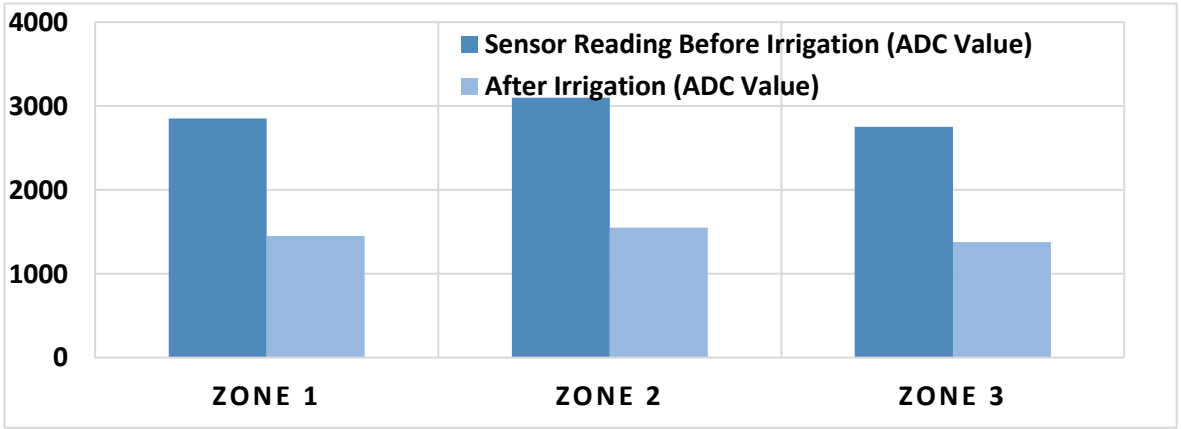
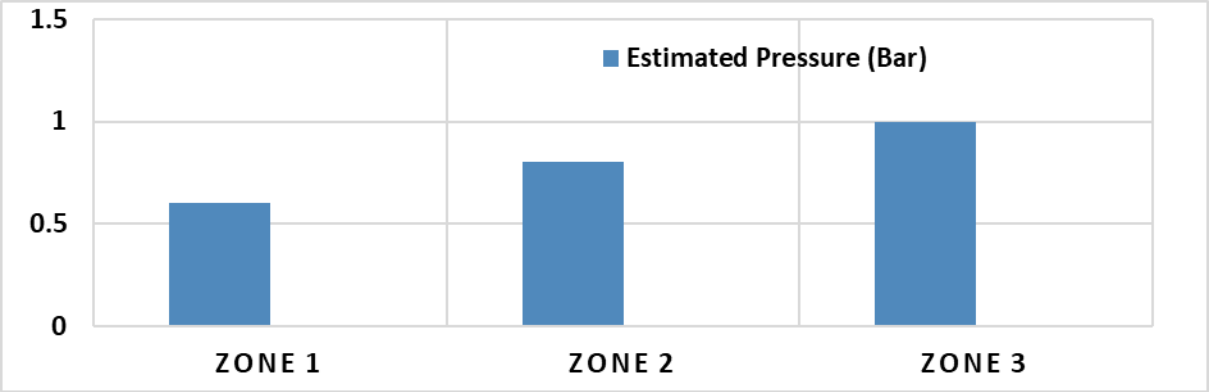
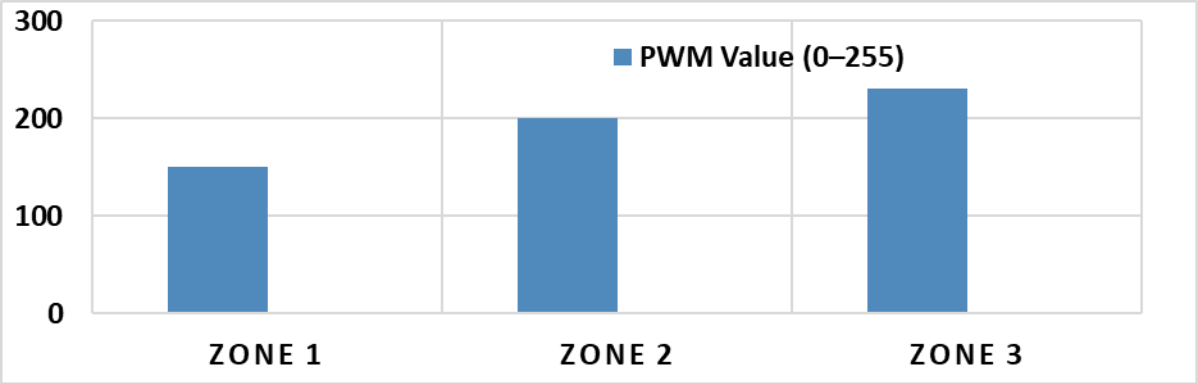


Table 6: Pump PWM Settings vs Spray Radius. (Measured per Zone)

Zone	PWM Value (0–255)	Estimated Pressure (Bar)	Spray Radius (meters)
Zone 1	150	0.6	2.5
Zone 2	200	0.8	3.5
Zone 3	230	1.0	4.2





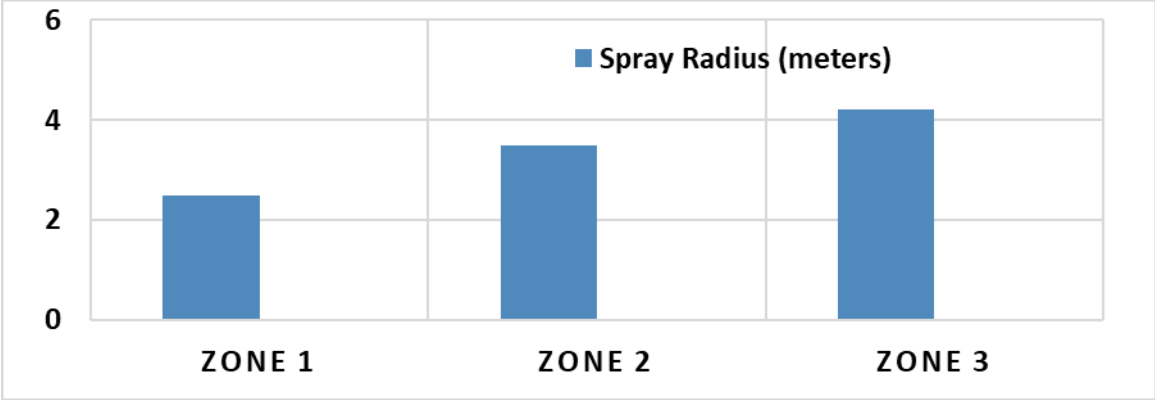


Table 7: Irrigation Activation Summary per Zone. (Based on Moisture Threshold)

Zone	Moisture Threshold (Set)	Irrigation Triggered	Method	Pump Runtime (minutes)
Zone 1	2000	Yes	Manual	8
Zone 2	2000	Yes	Auto Alert	10
Zone 3	2000	Yes	Manual	6

4.3 Performance Comparison with Literature

The results align well with previous works on smart irrigation systems. However, this system extends functionality beyond those reported by Singh & Misra (2020) and Jat & Nandurkar (2022), by enabling real-time pump pressure control, not just on/off switching. The use of MOSFETs with PWM logic also offers more efficient and responsive control than relay-based solutions noted in other studies (Abba et al., 2022; Kumar & Patel, 2014). Additionally, the Blynk app interface allowed a more user-friendly experience with sliders and real-time feedback, unlike traditional GSM or SMS-based controls.

5. CONCLUSION

This study has successfully demonstrated the design and deployment of a real-time, IoT-based smart irrigation system tailored for the agricultural needs of a 240 m² ABSU farm. By integrating soil moisture sensors, pressure-controlled diaphragm pumps, sprinkler heads, and a mobile app interface via the Blynk platform, the system provides both manual and semi-automated irrigation control with high precision.

The division of the farm into three independently operated zones enabled targeted water delivery based on localized soil conditions, while the incorporation of PWM-driven MOSFET control allowed users to dynamically adjust pump pressure directly from a smartphone. Real-time feedback, including sensor data and water level detection, ensured irrigation was both efficient and responsive to changing environmental conditions.

Field results confirmed that the system could maintain optimal soil moisture ranges with minimal human intervention, reducing water waste and improving irrigation scheduling. The use of low-cost, locally available components and open-source platforms like ESP32 and Blynk ensures that the solution is affordable and scalable for similar deployments in other rural or institutional farms. While the system performed effectively, some limitations such as dependence on stable Wi-Fi and the need for sensor calibration were noted. Future enhancements may include integration of weather APIs, automated irrigation schedules based on historical trends, solar-powered operation, and offline app capabilities.

I declare that this manuscript is original and has not been published previously, nor is it under consideration for publication elsewhere. The work reported in this paper was carried out by me and co-authors, and all sources of information used have been properly acknowledged and cited. I declare that there is no conflict of interest regarding the publication of this article. This research received grant from Tet fund Nigeria to support for this research more thanks go to them for the assistance.

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