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Development of IoT-Based Smart Irrigation System for Farmland Preparation: A Case Study

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ABSTRACT: Agriculture accounts for approximately 24.23% of total GDP and 22% of total exports in Nigeria. It is the most important occupation, providing a source of income for the majority of rural dwellers in Nigeria. Water is the most important resource for agriculture, and irrigation is still one of the most basic water-acquisition processes. Previously, irrigation procedures were carried out manually, resulting in a significant waste of time and an inaccurate volume of water deployed at any given time. In recent times, an artificial intelligence (AI)-based irrigation management method using Internet of Things (IoT) has gained prominence. The irrigation industry has taken advantage of this new technology called Internet of Things to improves irrigation management and drastically reduces operating expenses related to infrastructure maintenance. One of the most serious issues confronting smart irrigation systems is stakeholders' inability to convert available data into detailed and accurate information that can be used in decision making, particularly when it comes to water waste due to improper timing and the proportion.With water scarcity and inefficient traditional irrigation methods posing significant challenges to agricultural productivity,IoT-based technology offers a sustainable solution to manually operated irrigation systems. IoT-based smart irrigation system is an efficient farmland preparationtool and to managing scarce resources such as water and time.Based on the Internet of Things technology, the study analysed key parameterssuch as soil moisture, temperature, and water management using IoT-based technique that work with various sensors. The temperature, humidity, plant and soil moisture sensors are used in the design to detect different soil conditions and automatically irrigate the farmland based on the soil moisture contentand the plant requirements. The results demonstrated the effectiveness of the IoT-based smart irrigation system in optimizing water use in scarcity and enhancing crop yields.

Keywords: Internet of things (IoT), microcontroller, smart irrigation system, soil moisture,sensors, water scarcity

I. INTRODUCTION

Agriculture is a crucial sector contributing significantly to global food security and economic development. The current economic situation in Nigeria today, sustainable agriculture with crop productivity is key to ameliorate food shortage currently. With the astronomical increase in price of food commodities, increase in agricultural productivity will improve food security and reduce the high cost of food currently.

Nigeria is Africa's most populous country. Agriculture is Nigeria's main source of income for maintaining a healthy economy. Agriculture employs nearly 35% of the share of the total employment in Nigeria and accounts for almost 25% of the country's GDP. The government is providing farmers with a variety of online resources and service providers in an effort to maintain healthy agricultural profitability as the country's agricultural sector expands. The majority of farmers are currently facing a serious water shortage. According to a UN report, water demand has more than doubled the rate of population growth over the last century. As a result of

population growth, water use, and climate change, approximately 1.8 billion people, or two-thirds of the world's population, will live in areas with insufficient water by 2025 (Raju and Manasi, 2017).Climate change and its consequences are frequently discussed in academic publications on water resources and agriculture. There are various factors that affect agricultural productivity such as climate change and its impacts are topics that are frequently discussed in various researches on water resources and agriculture (Badrun and Manaf, 2021). People are thinking about developing water adaptation strategies to ensure water supply for agricultural production, human consumption, and ecosystem support because of the potential effects of global warming (Iglesias et al., 2018). Climate change poses potential threats to water scarcity, water quality, soil salinity, biodiversity loss, increased irrigation needs, and the cost of emergency and corrective action.

Due to the fact that many nations today face several challenges in water usage, the irrigation industry must adopt new creative technology to help it improve, manage, and distribute water more effectively (Aspen-Nicholas, 2015). If we want to end the nation's water shortage, we must conserve as much water as possible. Agriculture is heavily reliant on irrigation. Excessive irrigation, on the other hand, should be avoided. Farmers have always controlled irrigation manually. They water the land at specific times of the year.These factors have prompted an increase in studies focusing on developing novel irrigation water usage. Some of these studies recommend using technological advancements, social, economic, and climate change policies, or a combination of the two, to improve irrigation management. The vast majority of irrigation is transitioning from traditional irrigation systems to modern irrigation systems, or from traditional operations to the new digital revolution of smart water management systems that use IoT-based technology.So, water management may be regarded as a critical concept in irrigation. Lack of access to clean water has become a global concern on a global scale, and as a result, the agriculture sector and other industries must pay attention to and focus on the issue.Furthermore, because food and water are two of the world's most important commodities, agriculture is important to humanity because it uses water to produce food. Agriculture is under severe strain as a result of climate change and rapid population growth, which has an impact on water supply, which is critical for sustainable development (Micheal and Alabi, 2019).Irrigation addresses several SDGs (Sustainable Development Goals) related to poverty reduction and food security. Smart irrigation, on the other hand, points to a broader set of SDGs for industry innovation and promoting more responsible consumption and production in the interest of food security. It has a direct impact on how the SDGs are currently progressing. The country's water resources rely on irrigation expansion to increase food grain production (Raju and Manasi, 2017).The Internet of Things' applications have recently shifted toward intelligent systems networks that must handle interactions between autonomous systems and humans. The Internet of Things enables irrigation users to manage water infrastructure and supply effectively through the use of smart devices.Smart irrigation has been shown to significantly increase crop production, reduce water use, and increase agricultural profitability. This strategy promotes the development of the SDGs while addressing the sector's need for more effective, equitable, and long-term irrigation management. However, there are numerous factors working against the adoption of smart technology. Smart irrigation is hampered by the device's high-power consumption, exposure to harsh climatic conditions, weakened communication signals, and farmers' lack of knowledge (Iglesias et al., 2018).The integration of the Internet of Things (IoT) in agriculture has revolutionized traditional farming practices, offering solutions to critical challenges such as water management, labour efficiency, and resource optimization.However, traditional irrigation systems often lead to inefficient water usage, increased costs, and lower crop yields. IoT-based smart irrigation systems have emerged as a promising solution to address these challenges by integrating real-time monitoring and automation. This paper examines the development of IoT-based smart irrigation systems for farmland preparation: acase study.

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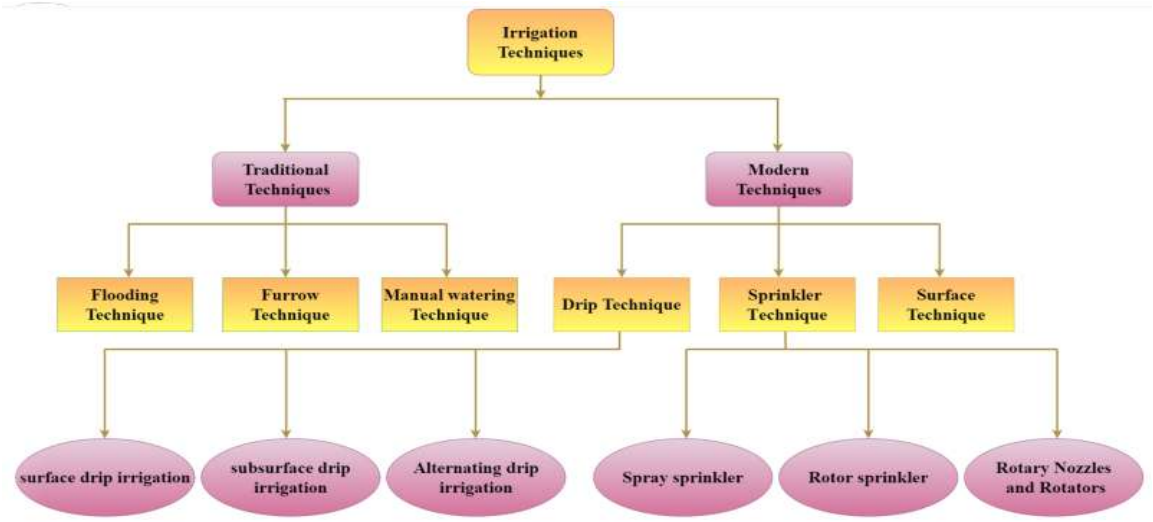

Figure 1: Block Diagram of various Irrigation Techniques

The block diagram shows various techniques adopted in irrigation system to keep the soil moisturized. These techniques are divided into traditional and modern techniques.

II. LITERATURE REVIEW

The Internet of Things (IoT) is rapidly growing and expanding exponentially. IoT is known as a technology that assists businesses in a variety of fields in coming up with novel ideas and solutions. IoT is being applied to irrigation management systems and their distribution to reduce costs and increase efficiency of water management systems, along with IoT optimization and predictive analytics approaches. Water distribution and transportation networks can detect water breaches more quickly; thanks to pipeline water pressure readings enabled by the Internet of Things. Sensors and actuators can now be used in water management systems and operations thanks to the Internet of Things (AIOTI, 2018; Gutiérrez et al., 2014). This technology provides new perspectives on operational effectiveness, water quality, and management (Liner and Kenel. 2016). Irrigation management is critical for people, plants, animals, and a country's economy.Reviewing of multiple research papers was conducted in this workto examine various IoT-based irrigation systems and their impact on the subject matter.

Verma (2015), Joseph (2018), Shahanas and Sivakumar(2016), Bayoumi and McCaslin(2017) evaluated IoT devices with centralized management that enable network scalability across all linked devices. Engineers and staff can centrally monitor the irrigation management network at the same time.

Bajare et al. (2018) and Civerchia et al. (2017) proposed the use of IoT for reducing unplanned downtime and preventing unexpected repairs. The irrigation industry may use IoT technology in conjunction with other technologies and tools, such as computer vision, machine learning, big data, and analytics, to monitor other infrastructure and identify when scheduled repairs are required.

Shevale, (2018), Kusuma and Anil (2018), Punpale and Borole (2018)monitored real-time water control in irrigation systems. The work done by the researchers based on the Internet of Things (IoT), field engineers and technicians can now remotely monitor and configure many aspects of irrigation management operations and it provides real-time access and control to the field engineers and technicians which can save money and time by working remotely.

Radhakrishnan and Wu (2018) detected water leaks using the internet of things. IoT technology makes it easier to pinpoint leakages and increase leakage detection rates. It also provides an intelligent method of operating irrigation system facilities and operations. Today's IoT uses the generated data to gain a better understanding of how to improve irrigation operations and services by lowering losses and increasing efficiency. The Internet of Things encourages more efficient water usage and loss rates.

Kamaludin and Ismail (2017), Spandana and Rao (2018), and Pappu et al. (2017) employed IoT to monitor water quality. Smart irrigation system monitoring equipment can be used to collect and monitor pH, turbidity, pressure, flow rate, and temperature data using IoT devices and

communicate it to the mobile network, allowing irrigation user utilities to observe and assess water quality in real-time.

Ravi Kumar et al. (2018) developed an automated irrigation system that monitors soil moisture and other environmental parameters to optimize water usage for improved crop growth. The system integrates soil moisture sensors, temperature monitoring, and GSM modules, with data processed via a PC-based LabVIEW system and NI myRIO. The setup tests of various soil types and climatic conditions for different cropswas done and the system effectively maintains soil moisture at optimal levels, automates irrigation based on real-time data, and provides a database backup for weather forecasting. This leads to enhanced crop yield and reduced water wastage but the reliance on PC-based control (LabVIEW/NI myRIO) can limit scalability and cost-effectiveness for small-scale farmers, and further work is needed to simplify the system for broader adoption.

Badrun and Manaf (2021) integrated IoT, cloud computing, and Big Data techniques to modernize irrigation management by enabling remote monitoring, leak detection, and optimized water distribution. A proposed system architecture where IoT sensors collect data (e.g., soil moisture, temperature), which was then transmitted to cloud platforms for storage and analysis was done using Big Data analytics. Then, enhanced monitoring capabilities and a reduction in operational costs were demonstrated, with the system providing real-time irrigation management and improved decision-making but a critical challenge identified was converting raw sensor data into actionable insights, particularly for stakeholders with limited technical expertise. Therefore, more work is needed to develop user-friendly data interpretation tools.

Dhanaraju et al. (2022) explored how IoT technologies can promote sustainable agriculture by monitoring critical parameters such as soil moisture and crop health. The study reviews and analyzes IoT-based applications in agriculture, focusing on the integration of wireless sensors, cloud analytics, and real-time data monitoring. The results show that IoT systems enhance crop management and resource conservation by enabling precise irrigation and reducing water waste. These systems also support timely interventions that improve crop productivity.Despite promising results, challenges remain in ensuring reliable sensor connectivity and integration in remote agricultural areas, as well as the need for cost-effective solutions.

Ananthan (2022)automated the irrigation process using an IoT framework that minimizes manual intervention while optimizing water usage.The work implemented a system based on the ESP8266 microcontroller, paired with soil moisture (FC-28) and temperature (DHT-11) sensors. Data is transmitted via Wi-Fi or LoRaWAN to a cloud platform and visualized through an HMI.The system demonstrated a reduction in water and energy consumption, improved irrigation scheduling, and enhanced crop productivity but while it is effective in controlled conditions, the scalability and robustness of the system in diverse and harsh environmental conditions require further testing.

Kaur, Bhatt and Raja (2024) designed a hybrid irrigation system that leverages IoT sensors and machine learning algorithms for precise irrigation scheduling and resource optimization.The approach combines environmental sensors (for soil moisture, temperature, etc.) with various machine learning models (e.g., KNN, Naïve Bayes, Random Forest, Logistic Regression, SVM) to predict irrigation requirements based on real-time data. The result showed that the integrated system achieved high prediction accuracies (ranging from approximately 98.8% to 99.5%) in determining optimal irrigation timing, leading to efficient water management.Despite the high accuracy of ML predictions, further research is needed to ensure robust performance in heterogeneous field conditions and to simplify the integration process for end users.

Sreelatha Reddy, Harivardhagini and Sreelakshmi (2024) developed a sustainable and remotely accessible smart irrigation system that utilizes IoT and cloud computing to manage water resources in real time.The system employed the NodeMCU as the central controller, with various sensors (soil moisture, weather data) feeding information to cloud servers. The system then dynamically adjusts irrigation schedules based on environmental inputs. The results show significant water savings and improved crop yields were observed, with the system enabling remote monitoring and control via web/mobile interfaces but the key challenges were ensuring system scalability, managing power consumption, and maintaining reliable connectivity in areas with limited infrastructure.

Gamal et al. (2016) it provided an extensive overview of smart irrigation systems, outlining the evolution, current state, and future directions of these technologies.The study reviews a broad spectrum of literatures on smart irrigation,

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comparing traditional and modern techniques, and analyzing key components such as sensor networks, wireless communication, and energy harvesting.The review highlights the significant improvements brought by IoT integration in irrigation management, including real-time monitoring, enhanced water use efficiency, and the potential for remote control and automation but the emphasiswas on the need for standardization of sensor technologies and call for more comprehensive field studies to validate long-term performance and reliability.

III. MATERIALS AND METHODS

The system is a software/hardware design that allows a farmer to monitor and control simple and/or complex farming processes such as plant watering. It works with a Wi-Fi connection (local area network only, not the internet), where a farmer can connect to the irrigation from a remote location to water its crop without having to be in the physical location.

3.1 Materials

The materials used are: NodeMCU (ESP8266), Soil Moisture Sensor (FC-28), DHT11 Temperature/Humidity Sensor, Relay Module, Water Pump, etc. These components were connected and mounted on the soil to test itssuitability.

3.2 Methods

A smart irrigation system makes use of the Internet of Things (IoT) technology which comprises of hardware components that is combined to gather data, analyze the data, and then regulate the irrigation process in real time using the information deducted from the data analysis. The system employed a GSM-based communication, a network of IoT sensors (for soil moisture, temperature, and humidity), and automated motor control to regulate water supply in response to sensor data. The block diagram of the system is shown in Figure 2.

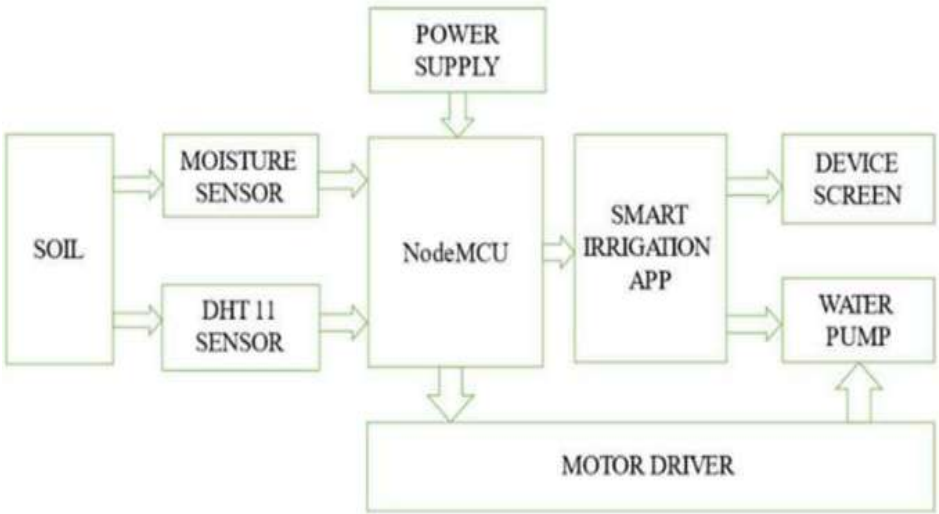

Figure 2: Block Diagram of IoT Smart Irrigation System

3.2.1 Brief Description of the Functions of the System Components

The sensors are used to gather information in the field. Temperature and humidity sensors, as well as soil moisture sensors, might fall within this category. Real-time data on soil and weather conditions is provided, allowing for more precise irrigation scheduling. The Internet of Things gateway connects the sensors in the field to the cloud or command hub. It takes readings from the sensors and sends them over to a remote server or control hub for examination, while the centralized control system or cloud, receives data from the IoT gateway and processes it, analyzes it, and makes decisions based on that data. The data collected may be stored and processed using cloud-based platforms or dedicated servers (Zhang et al., 2022). The cloud or control system must use smart algorithms to fine-tune watering times and distribution rates, and the communication network allows information to flow from the sensors to the IoT gateway to the cloud or control system. The Wi-Fi, cellular networks, and other wireless communication protocols are only some of the technologies it may use to guarantee a constant connection and the smart irrigation system's user interface that allows human interaction with the system. A dashboard, smartphone app or online

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interface all be used to manage and monitor an irrigation system in real-time. Users may see sensor data, set up watering schedules, and make fine-tuned modifications. Also, the actuators (motor drivers), which is in charge of operating the irrigation machinery in response to commands from the cloud or control system (Chouhan et al., 2022). Based on the results of the data analysis, it may trigger valves, pumps, sprinklers, or drip irrigation systems to water the plants as necessary. Then, the power supply unit in the system is key. Without,the sensors, IoT gateway, communication devices, and actuators in the smart irrigation system can't function. This can be achieved through a combination of mains, batteries, solar panels or other renewable energy sources to guarantee stable electricity supply to the system.

IV. DEVELOPMENT OF IOT-BASED SMART IRRIGATION SYSTEM

The NodeMCU (ESP8266) acts as the central controller. Then, the analog input (A0) receives analog signal from the soil moisture sensor (FC-28) and the digital input (D2) receives data from the DHT11 temperature and humidity sensor. Digital output (D1) sends a control signal to the relay module to switch the water pump on or off. Optionally, the NodeMCU can interface with a GSM module via TX/RX pins for remote communication and soil moisture sensor (FC-28) Powered by the NodeMCU's 3.3V (or regulated 5V) supply. The sensor's analog output is connected to the NodeMCU's A0 pin to measure soil moisture. DHT11 Temperature/Humidity Sensor is connected to a digital pin (D2) on the NodeMCU to measure environmental conditions that can affect irrigation scheduling. Relay Module receives the control signal from NodeMCU (D1) to activate/deactivate and the relay's Normally Open (NO) contact is used to control the water pump powered by the NodeMCU's 5V supply (if needed) and interfaces with the external mains. The water pump is connected to the relay module's output (NO contact) powered by an external main (commonly 12 Vdc) due to its higher power requirements.The relay acts as a switch, allowing the NodeMCU to control when the pump operates.External Mains to supplies the necessary voltage (e.g., $12V_{dc}$) to the water pump and common ground is shared with the NodeMCU and sensors to ensure proper operation. These form an overall system that functions smartly to produce the desired results. Therefore, a smart irrigation system is a system that reduces the intercession of farmers in the field by automatically irrigating the field when needed. In this way, it makes it easy for the farmers to get healthy growth of the crops and check the status of the field anywhere anytime through a platform. This system avoids water wastage and provides stable and healthy growth of the crop.

4.0 Workings of IoT-Based Smart Irrigation System

The soil moisture sensor continuously monitors the moisture level of the soil and sends an analog signal to the NodeMCU. Also, the DHT11 sensor measures ambient temperature and humidity, providing additional data for irrigation decisions and the NodeMCU processes these sensor inputs and, based on predefined thresholds or control logic (possibly enhanced with IoT/cloud analytics), determines whether irrigation is needed. When irrigation is required, the NodeMCU sends a digital signal through D1 to activate the relay module. The relay module closes its Normally Open contact, completing the circuit between the external power supply and the water pump, thereby starting the pump. Once the soil moisture reaches the desired level, the NodeMCU deactivates the relay, stopping the water pump. Figure 4 shows the monitoring techniques adopted in the work, while Figure 3gives a greenish-like space radar of the farm.Together with the Internet of Things and other pieces of hardware, the system allows for better water management, higher agricultural yields, and environmentally friendly farming.

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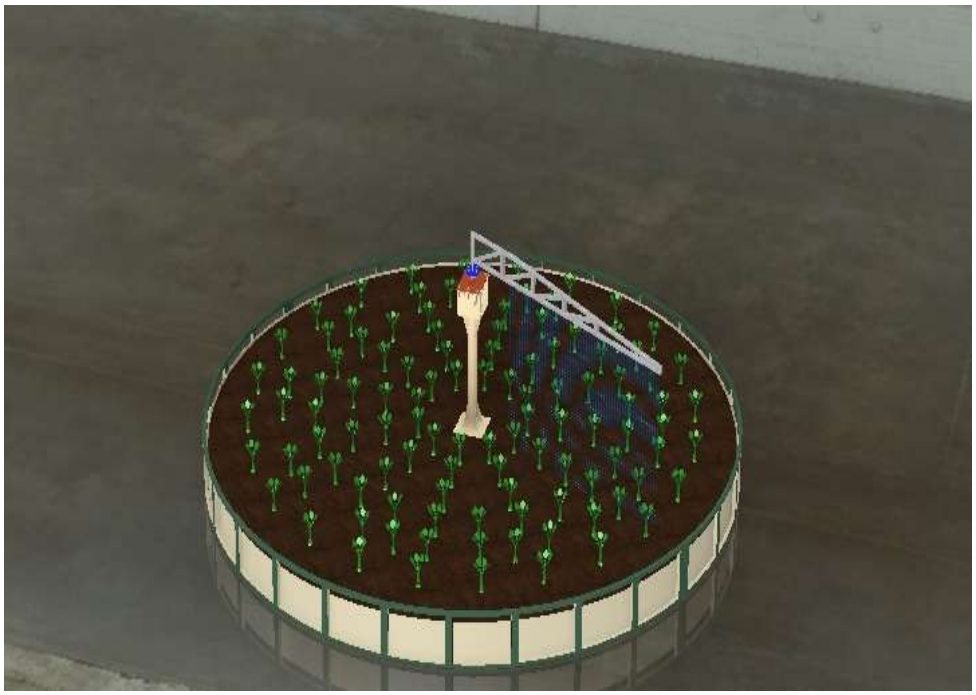

Figure 3:Platform for Farmland Space

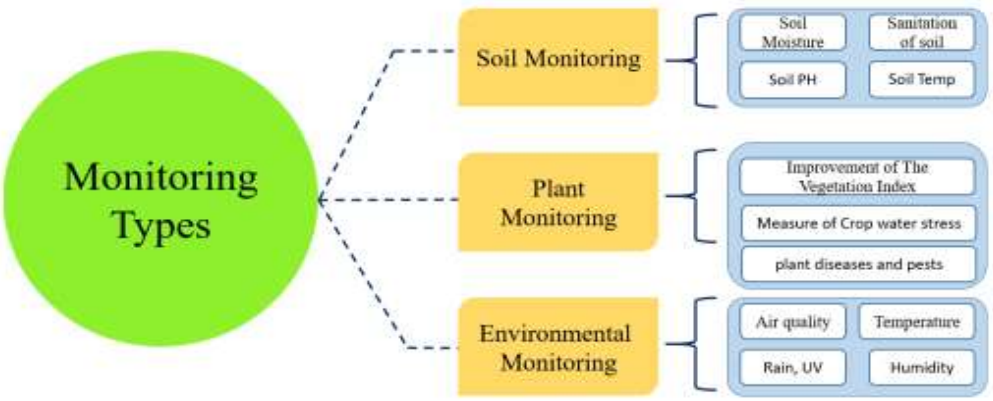

Figure 4: Monitoring Techniques in IoT-Based Smart Irrigation System.

V. RESULTS ANALYSIS

The development and mounting of the IoT-based smart irrigation system have revolutionized local and low-income farming patterns especially in Amedokhian community and its environs with several advantages and some of the advantages are highlighted in sub-headings as follows:

5.1 Water Management: the smart irrigation system optimizes water usage by delivering the right proportion of the amount of water required by the plant and soil when its necessary. This is achieved through proper soil moisture sensors that collect relevant data on the soil and plant. In this way, significant water conservation is achieved by avoiding overwatering and reducing water wastage in the process of irrigation. Therefore, scarce water resources are preserved and the environmental impact on excessive irrigation is reduced maximally. Figure 5 shows the relationship between the soil moisture and the water level which is crucial to water management during irrigation and farmland preparation.

5.2 Cost Saving: minimizing water consumption and removing manual irrigation processes, the developed smart irrigation system helps the users to save water bills and optimization of water usage which led to cost saving over time

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and making the system economically beneficial to small and low-income farmers in Amedokhian community and its environs.

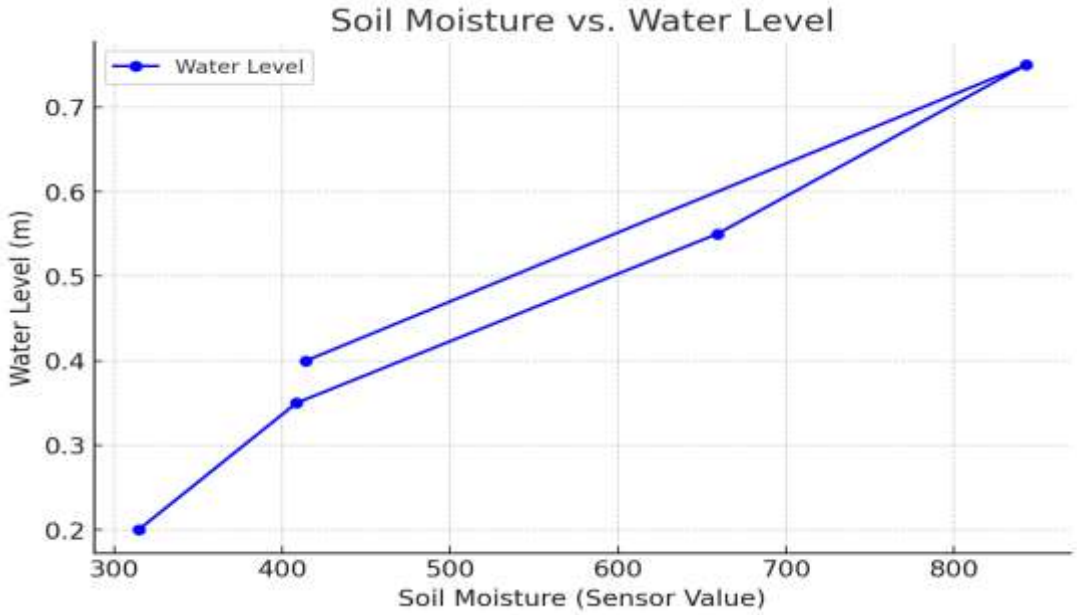

Figure 5: Showing Soil Moisturevs Water Level

5.3 Improved Plant Health and Productivity: smart irrigation system ensures plants receive the right proportion of water needed at the right time. This promoteshealthy growth of the plants and thereby improves the plants productivity. This is because the smart irrigation system prevents under and overwatering of the plants and soil. Also, the system monitors the soil moisture and collects the data to make informed decisions on the appropriate water level needed for the plant and soil. All these resulted in better plant health and an increase in productivity of the plant as well.

5.4 Time Efficiency: the automation of the smart irrigation system eliminates the high labour involved in manual operated irrigation system. The user of the IoT-based smart irrigation system can programme the watering routine based on plant needs and environmental factors, and the system will do that automatically by irrigating the farm accordingly. This saves time for the user and effort, thereby allowing the user to focus on other tasks at that time.

5.5 Data Analysis and Precision Farming: the smart irrigation system collects and analyzes data based on various environmental factors and enabling the users to gain valuable insight on the plant water requirements, soil conditions and weather conditions at time t. The information deduced from the data analyzed makes the user take precise and informed decision in relation to irrigation strategies needed, crop selection and resource management. These help to support precision agriculture practices leading to more efficient and productive agronomy.

The overall performance of the IoT-based smart irrigation system leads to appropriate water management, cost savings, improvement on plant health and productivity, time efficiency, friendly environment and good data analysis, and precision agronomy. The results demonstrated more efficient water usage, elimination of manual labour and improved irrigation precision, thereby enhancing overall farming productivity for small and low-income farmers in the Amedokhian community and its environs.

VI. CONCLUSION

The IoT-based smart irrigation system brings significant advantages to high levels of water management in agricultural, residential and commercial space. Leveraging on real-time data collections, automation and central remote-control capabilities, the smart irrigation system optimizes water usage, conserves scarce resources, and increases plant health and productivity. The integration of IoT sensors, soil sensors and weather data collection; the system enables precise

monitoring of soil moisture level, weather conditions and plant water requirements. This information deduced allows for the right proportion of water at the right time and avoiding under or overwatering, and also, preventing plants from stress or damages caused by under or overwatering. Additionally, the model developed to accommodate small and low-income farmers and its ease of usage. Therefore, the IoT-based smart irrigation system promotes good water management practice, guarantee environmentally friendly and enhance agricultural productivity. It is a promising solution to addressing the water scarcity and unpredictability of weather conditions challenges in the Amedokhian community and its environs, reduce water wastage during manual irrigation processes and give efficient use of scarce resources in all aspect of the system.

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