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Wireless sensor networks: A vital tool for improved agricultural practices in Nigeria

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Abstract
Agricultural practices in Nigeria are still mainly based on conventional methods of farming which usually result in wastage of resource wastage and low crop yield making it impossible to meet the country's food demand. Wireless sensor networks (WSNs) have emerged as a vital tool for enhancing agricultural productivity by enabling real-time monitoring and efficient resource management. This technology integrates various sensors to gather critical environmental data such as soil moisture, soil temperature, humidity and water levels, providing valuable insights for precision agriculture. By automating irrigation and improving crop monitoring, wireless sensor networks help optimize water usage, reduce resource wastage and increase crop yields. This paper explores the applications and benefits of wireless sensor networks in agriculture, demonstrating their potential to transform farming practices and contribute to sustainable agriculture in Nigeria particularly in terms of massive food production. It was observed that the sensor data fusion value of 55.48 integrates all sensor data over 31 days. This result represents a comprehensive, averaged value that can be used to make more reliable decisions about agricultural practices in Nigeria in order to improve its productivity.

Keywords: Wireless technology, Agricultural crops, Irrigation, Wireless sensor networks, Sensor data fusion

1. Introduction

In Nigeria, agriculture remains the bedrock of the economy as it gives a living to most of its general population. World Bank (World Bank, 2018) announced that the agricultural area alone records for 33% of the complete Gross domestic product of Nigeria and the area utilizes around 23% of the absolute financially dynamic populace (FAO, 2018). Farming used to be the Nigerian significant wellspring of unfamiliar trade from independence in 1960 up to the mid-1970s when Nigeria was the world's biggest maker of groundnuts, palm oil, and cocoa, and one of the significant makers of millet, maize, sweet potato, cassava, coconuts, citrus products of the soil stick (Ladan, 2014).
Present day farming requires mechanical apparatuses that can further develop creation effectiveness, meet the expanding request of food, and diminish their ecological effect, (Sadiku et al, 2019).

Agriculture is a high water-intensive sector but most times, water is not utilized effectively resulting to large amount of water being wasted. The wasted water will be worth a lot of money in the near future. Those who effectively manage this resource will save time and money (Rasyid et al., 2015). Thus, by monitoring water and overseeing plant formative circumstances simultaneously, a low degree of water utilization and an improved yield can be accomplished. The need to have sufficient water to help other biological capabilities is turning out to be better perceived. To practice smart farming, it is crucial to consolidate new advances like remote sensor networks with agriculture, (Nawandar and Satpute, 2019). Irrigation is an important factor in improving crop yield and ensuring all season's agricultural practice. Irrigation is the practice of applying additional water, beyond what is available from rainfall, to the soil to enable or enhance plant growth and yield, and, in some cases, the quantity of foliage or harvested plant parts. Currently techniques used for irrigation in Nigeria include manual irrigation such as furrow, basin, rooftop and watering can. These techniques remained ineffective with low performance because they are intended only to control the distribution of water at required locations without investigating and considering real time water requirements, (Odo and Abonyi, 2023). This causes a huge loss of water during every water system activity. Moreover, a few regions might be impacted by expanding or diminishing how much water utilized during water system, while under inundated districts are dependent upon unfortunate harvest yield and water pressure, over flooded locales are impacted by plant sicknesses and conceivable soil disintegration. Dry season (Mishra and Singh, 2010), contamination and water pollution, environmental change (Kalra et al., 2007; Haddeland et al., 2014), and the risks of salinity have led to a dangerous decline in water resources that is seriously affecting the agricultural sector, especially the efficiency of irrigation systems. Wireless sensor networks (WSNs) in some cases called wireless sensor and actuator network (WSAN), are organization of spatially disseminated independent sensors that screen physical or ecological circumstances, like temperature, soil moisture, humidity, and so on and cooperatively pass their data through the network to a central server, (Idris et al, 2021). The structure of wireless sensor network is shown in figure 1.

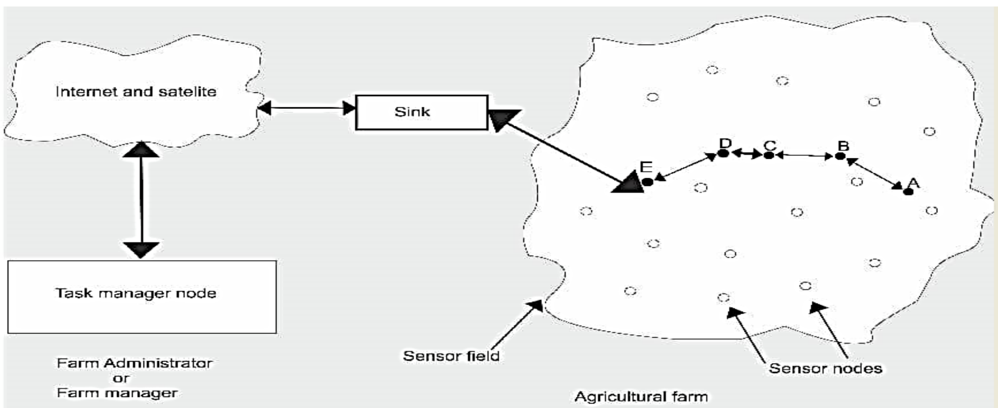

Figure 1: Structure of wireless sensor network

Wireless sensor network (WSN) is widely used in various applications including environmental monitoring, (Faseth et al, 2010), healthcare systems, (Hussain et al, 2013), industrial process monitoring, (Misra et al, 2015), smart agriculture, (Mohan et al, 2020), home automation, (Lee et al, 2010), traffic management, (Jain et al, 2011). Its application in irrigation systems in Nigeria has not been achieved.

1.1 Review of related works

Loubna and Bouchaib (2018) explored on towards a savvy water system framework in view of remote sensor organizations. The creators proposed another model of a total and shrewd water system framework in light of remote sensor organization. The framework controls and manages water system framework by checking a bunch of soil related boundaries, for example, temperature, moistness and wind speed. Regardless of the triumphs accomplished by these specialists, Zigbee innovation was utilized as a channel of correspondence. Syeda et al (2020) introduced the outline of horticulture checking by implies IoT based frameworks. They said that ranchers are confronting what is happening where the impacts of air conditions are extreme on the yield. Then again, the ill-advised arranging of the kind of harvest to be developed may prompt the low gets back from market. The savvy frameworks for checking the yield and soil assist the rancher with improving the development.

The IoT based framework can be carried out to screen the yield and soil to control the utilization of assets relying on the necessity. In any case, their exploration didn't carry out the utilization of IoT in observing the harvest for improved efficiency. In crafted by Rehman et al (2022) named a return to of Web of Things advances for checking and control methodologies in shrewd farming. The creators expressed that with the ascent of new advances, for example, the Web of Things, raising the efficiency of rural and cultivating exercises is basic to further developing yields and cost-viability. This brilliant horticultural framework expected to find existing methods that might be utilized to support crop yield and save time, like water, pesticides, water system, harvest, and compost the executives yet didn't carry out the utilization of IoT in checking the yield for improved efficiency. Ndunagu et al (2022) studied development of a wireless sensor network and Internet-of-Things (IoT) based smart irrigation system.

The review proposed a savvy water system framework utilizing dribble strategy, which was planned and executed utilizing remote sensor organizations and an open-source IoTs distributed computing stage for information assortment, putting away and information investigation. The authors used only two sensors (soil moisture and temperature) and recommended that more sensors should be incorporated for collection of data and the use of alternative power supply like solar power or backup batteries due to epileptic power supply in Nigeria. We have seen the limitations of various authors in the reviewed literature. Based on this, we have carried out research work on wireless sensor networks as s vital tool for the improvement of agricultural practices in Nigeria. These wireless sensor networks will help in transforming traditional farming to a more efficient method in that it can automatically monitor environmental parameters such as soil moisture, soil temperature, humidity by continuously collecting data from the farm and transmitting it wirelessly to the central server. It will also control water dispensing on the farm to improve crop yield and reduce water consumption in the farm without human efforts and labour.

2.0 Material and methods

The materials required for this research work include soil moisture sensors, soil temperature sensors, humidity sensor, ultrasonic sensor, solenoid valve, microcontroller, Wi-Fi module, solar panel, charge controller, 12V DC battery, DC bulk converter, Proteus software and Matlab computing software.

2.1 Method

2.1.1 Flowchart of the research work

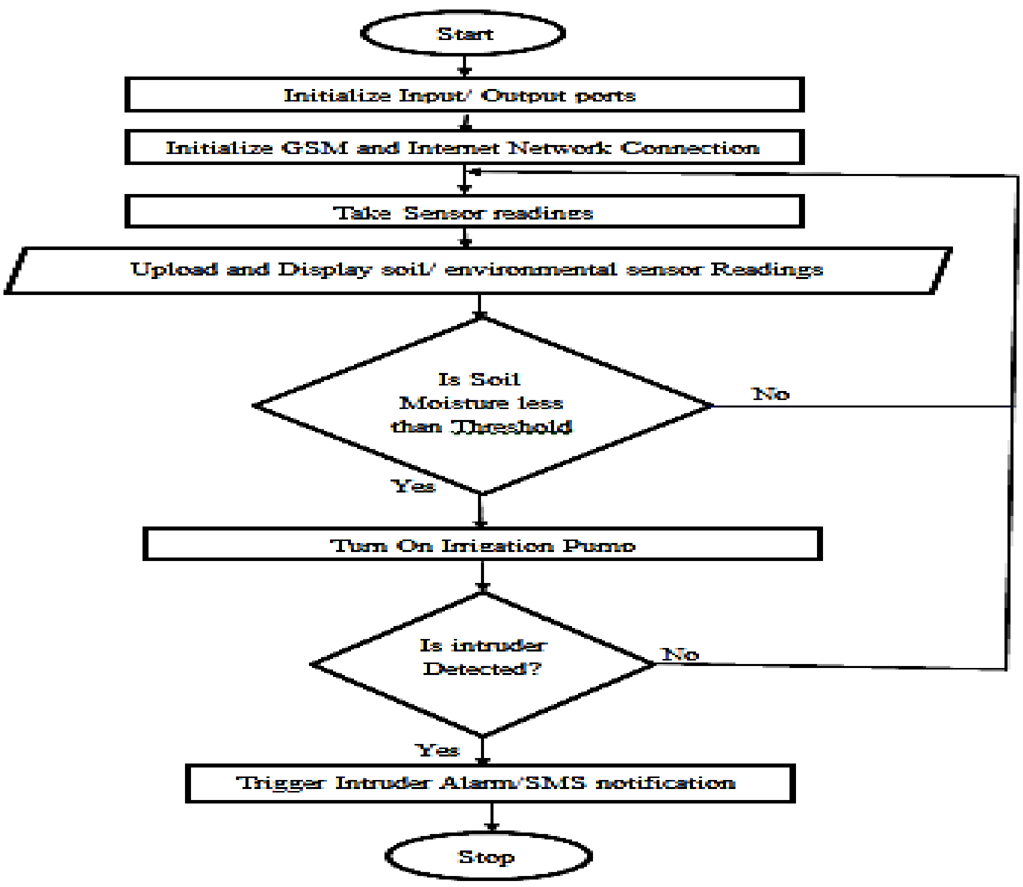

Figure 2.1: Flow chart of the system

2.1.2 Block diagram of the system

The interconnection of the modules that comprise the physical subsystem is depicted in the system's block diagram. The system is composed of the following modules: the DHT22 sensor, soil moisture sensor, soil temperature sensor, and ultrasonic water level; the output modules are the irrigation system controller and water pump; and the data collection, control, and transmission module, which is handled by the Arduino microcontroller board and ESP32. The central power supply module, which consists of the battery, buck converter, charge controller, and solar panel, powers the entire system. The physical integration of the hardware components that makes up the system includes setting up the solar power supply system which involves the connection of the 50W solar panel to the 10A charge controller and then to the 12V DC battery which supplies power to the DC bulk converter followed by the interconnection of the sensing and control components of the system on a permanent circuit board using the circuit diagram developed on the Proteus 8 simulation software as a guide.

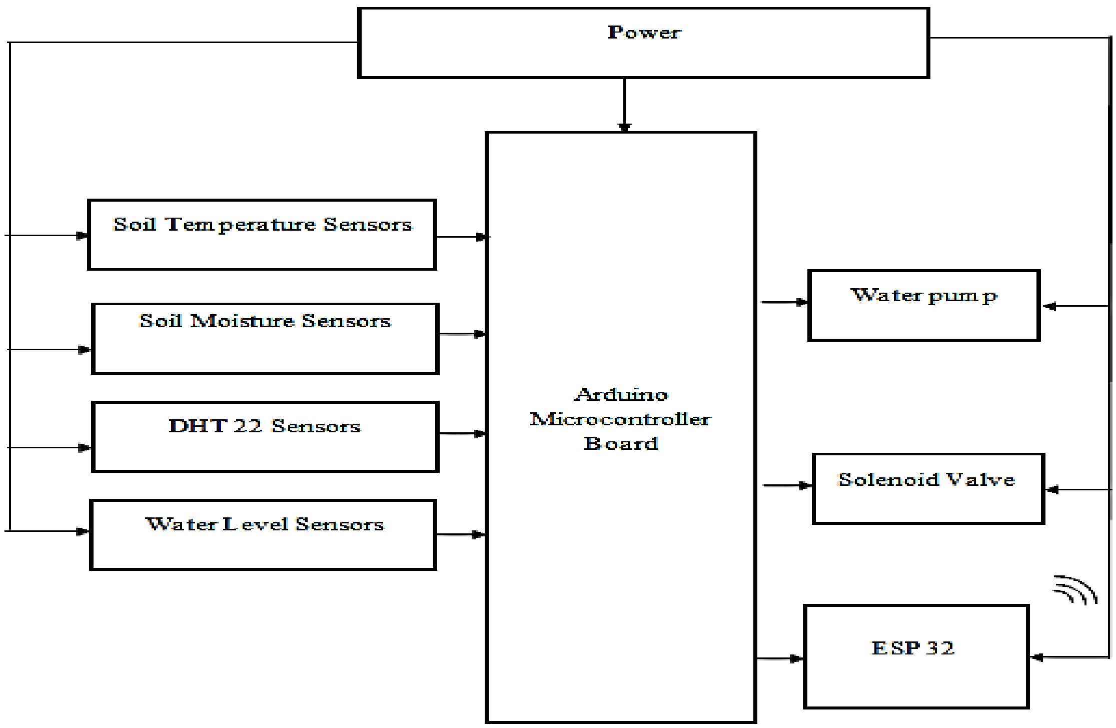

Figure 2.2: Block diagram of the system

2.1.3 Complete circuit diagram

The circuit diagram, sometimes referred to as the connection diagram, shows the connections between the different components of the primary electronics hardware system. Designed to serve as a roadmap for putting the hardware subsystem's component elements together, Proteus 8 simulation software was used to generate the circuit diagram before the physical implementation of the system.

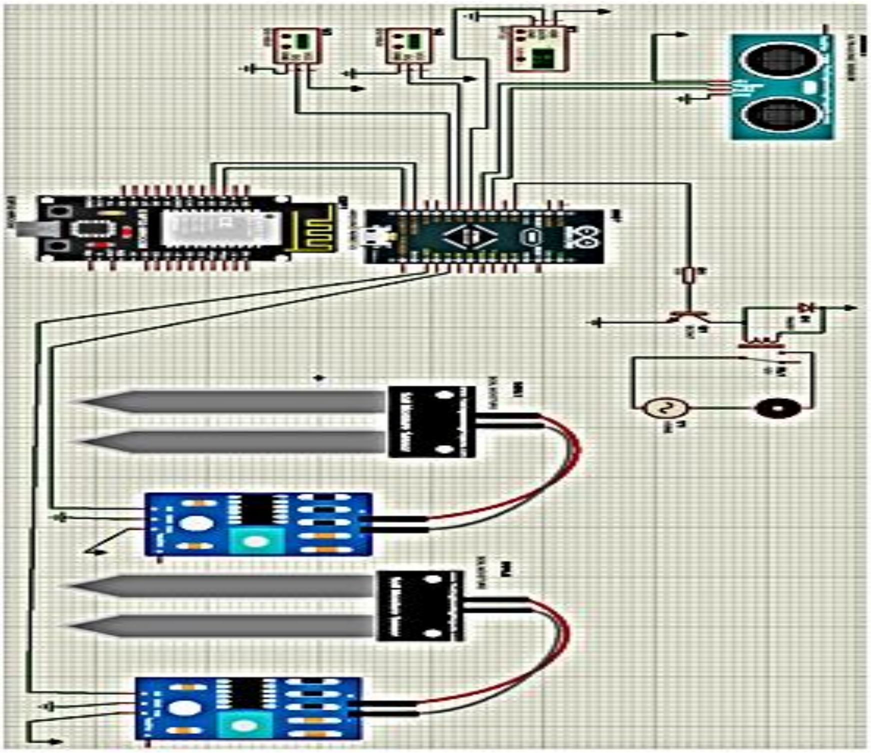

Figure 2.3: Complete circuit diagram of the system

3.0 Method of data collection, transmission and uploading to a database

The microcontroller collects data from multiple sensors (which includes as soil moisture sensor, soil temperature sensor, humidity sensor and ultrasonic sensor) from their respective locations in the farm. These sensors were deployed across a tomato farm in Michael Okpara University of Agriculture, Umudike and were closely monitored for a period of 31 days. The data was collected at every six (6) hours. Each sensor provides data through analog or digital signals. The microcontroller reads data from analog sensors using analog-to-digital (ADC) pins and digital sensors directly from the general purpose input/output (GPIO) pins configured to receive specific signal format. Once the microcontroller reads the raw data, it processes and converts it into usable values. The microcontroller then transmits the data collected and processed to the ESP32 using serial communication protocol, that is, the microcontroller sends the data over a universal asynchronous receiver/transmitter (UART) using the TX/RX pins. The ESP32 then listens to the incoming data and parse it accordingly. After receiving the data from the microcontroller, the ESP32 then connects to Wi-Fi network to transmit data to an online MySQL database from which the data can be displayed in real-time and viewed remotely on a custom web dashboard. In this study, hypertext transfer protocol (HTTP) was used to transmit data to the webserver.

3.1 Estimation of sensor data fusion

Sensor data fusion refers to the process of combining data from multiple sensors to produce more accurate, reliable and useful information than would be possible by using the data from individual sensors separately. This technique is widely used in various fields such as wireless sensor networks, robotics, autonomous vehicles and environmental monitoring. When combining data from multiple sensors (soil moisture, soil temperature, humidity, ultrasonic sensors), a weighted average can be calculated as

$$X_f = \frac{\sum_{i=1}^{n} weighted\ average_i(\sum_{i=1}^{n} w_i x_i)}{number\ of\ days} \quad (1)$$

where X_f = Fused sensor value,

x_i = measurement value from the i-th sensor, w_i = weight assigned to the i-th sensor, n= number of days

Weighted average = $(W_{SM}xX_{SM}) + (W_{ST}xX_{ST}) + (W_H xX_H) + (W_{US}xX_{US})$ (2)

Considering the critical importance of soil moisture, soil temperature and humidity to tomato plant growth, the recommended average weight based on typical agronomic practices are W_{SM}= 0.45, $W_{ST} = 0.25, W_H = 0.15$ and $W_{US} = 0.10$ respectively.

4.0 Results and Discussions

The data collected from the tomato farm in Michael Okpara University of Agriculture, Umudike, Abia State is shown in table 1. This data was extracted from the database.

Soil Mois 1	Soil Mois 2	Soil Temp 1	Soil Temp 2	ENV Temp	Humidity	Water Level	Timestamp
56	80	26.12	26.19	25.30	99.90	31	2024-09-02 06:45:33
56	81	27.87	27.69	26.10	99.90	31	2024-09-02 00:45:37
77	100	30.12	29.63	29.00	95.30	31	2024-09-01 18:45:36
79	100	28.00	27.87	35.60	72.90	30	2024-09-01 12:45:40
75	100	24.81	25.06	23.40	99.90	31	2024-09-01 06:45:38
73	100	26.87	26.69	24.30	99.90	31	2024-09-01 00:45:41
77	100	29.31	28.75	28.40	97.10	30	2024-08-31 18:45:43
50	98	26.25	26.19	25.20	99.90	31	2024-08-30 22:52:07
52	100	27.50	27.69	29.30	95.00	30	2024-08-30 16:52:07
51	100	25.69	26.31	26.80	96.00	31	2024-08-30 10:52:06
52	100	25.44	25.81	25.30	99.90	31	2024-08-30 04:52:08
52	100	26.81	26.94	26.40	99.90	30	2024-08-29 22:52:13
52	100	27.50	28.00	30.10	91.60	30	2024-08-29 16:52:12
52	100	25.94	26.75	32.30	85.60	31	2024-08-29 10:52:32
52	100	26.06	26.31	25.10	99.90	30	2024-08-29 04:52:12
53	100	27.87	27.62	26.40	99.90	31	2024-08-28 22:52:46

The calculated weighted average for the period of the experiment is shown in table 2

Day	**Weighted average**
1	55.22375
2	55.85500
3	64.68875
4	61.19375
5	63.81875
6	63.70500
7	64.64750
8	57.20500
9	58.59875
10	58.56000
11	58.69125
12	57.27875
13	56.97750
14	58.87125
15	58.73125
16	56.71625
17	58.44625
18	57.56625
19	57.78500
20	57.42625
21	61.38875
22	65.47750
23	64.97125
24	65.82500
25	53.63000
26	56.20250
27	57.06125
28	63.01750
29	56.62875
30	58.59875
31	57.76125

The sum of the weighted averages for 31 days as calculated from equation 2 is 1719.7955 and the sensor data fusion value as calculated from equation 1 is 55.48. It is seen that the sensor data fusion value of 55.48 represents an aggregated measure of key environmental parameters such as soil moisture, soil temperature, humidity and ultrasonic sensor readings obtained from the tomato farm for a period of 31 days. This value suggests ideal growing conditions of tomato plants are being maintained and the micro-climate around the tomato plants is healthy with optimal soil temperature, humidity and other factors. The graphs of soil moisture against date, soil temperature against date, humidity against date and water level against date are shown in figures 4, 5, 6 and 7 respectively.

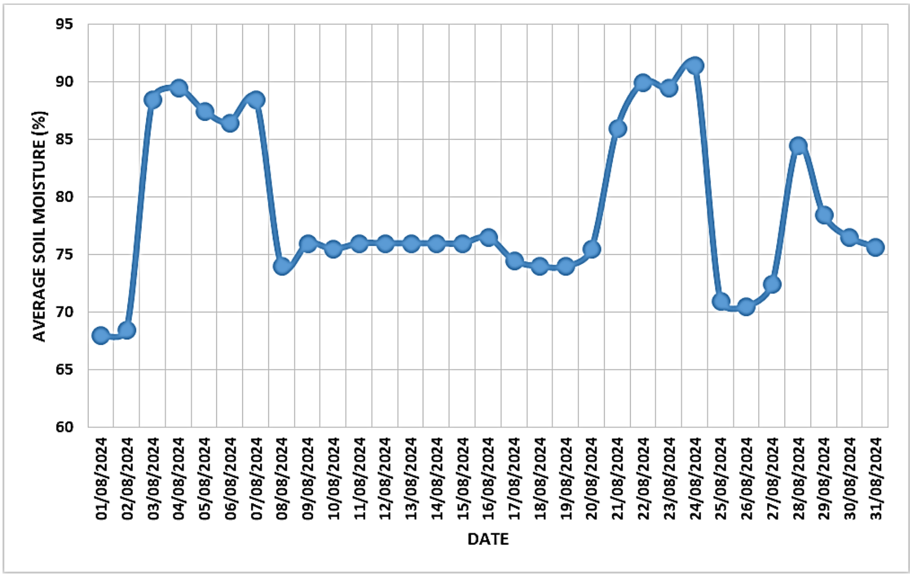

Figure 4.1: Graph of soil moisture against days in August

Tomato crops have specific soil moisture requirements for optimal growth. The acceptable soil moisture range typically falls between maximum soil moisture of 80% to 90% of the soil's field capacity and minimum soil moisture of 50% to 60% of field capacity to avoid stress. It is seen that values obtained from the soil moisture readings fall within the range of acceptable soil moisture, that is the maximum soil moisture and minimum soil moisture. It implies that maintaining soil moisture within this range will result in healthy tomato growth and increase crop production.

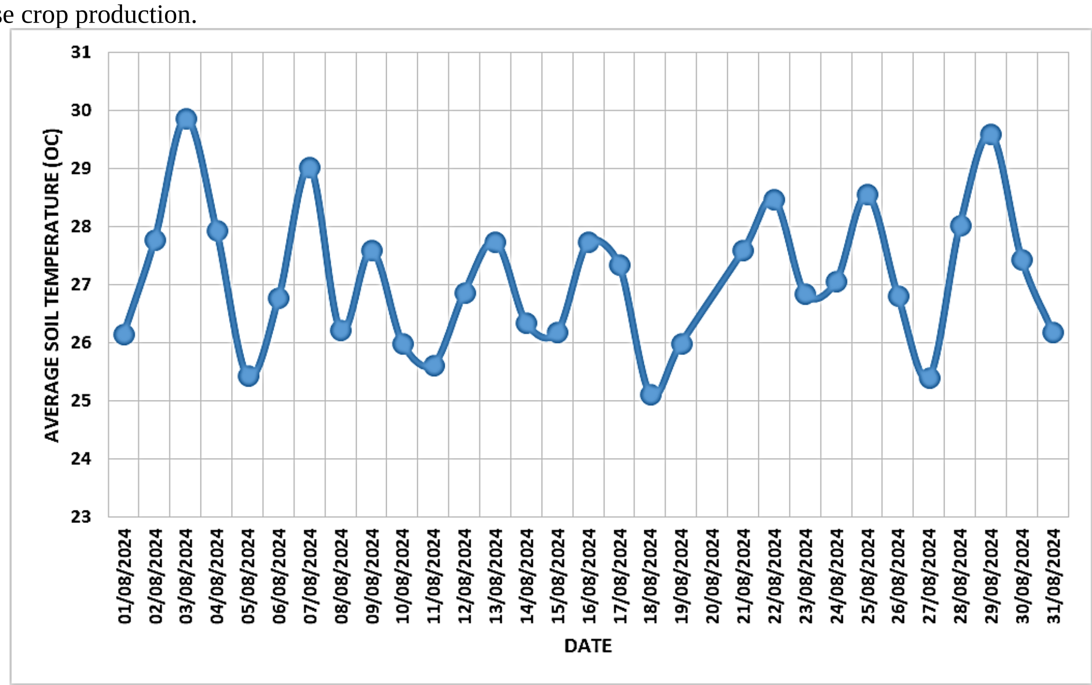

Figure 4.2: Graph of soil temperature against days in August

Tomato plants are sensitive to soil temperature which plays an important role in their growth, development and crop production. The maximum soil temperature of tomato plants is from 30°C to 32°C and the acceptable minimum soil temperature is from 10°C to 15°C. It is observed from the graph that values obtained from soil temperature readings fall within the range acceptable soil temperature, that is the maximum soil temperature and minimum soil temperature. It implies that maintaining soil temperature within this range will result in optimal growth of tomato crops and boost its productivity.

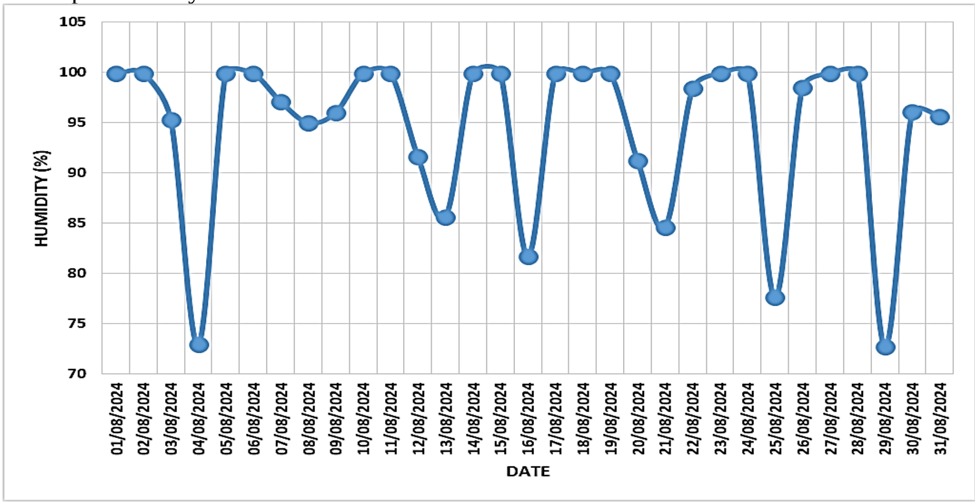

Figure 4.3: Graph of humidity against days in August

The optimal humidity range is critical for tomato plant health and system efficiency. The maximum humidity is around 90-95% relative humidity and the minimum humidity is around 60-65% relative humidity. It is seen that values of humidity obtained from the farm are in line with the maximum and minimum range of humidity which is an indication that maintaining proper humidity will optimize tomato growth while conserving water.

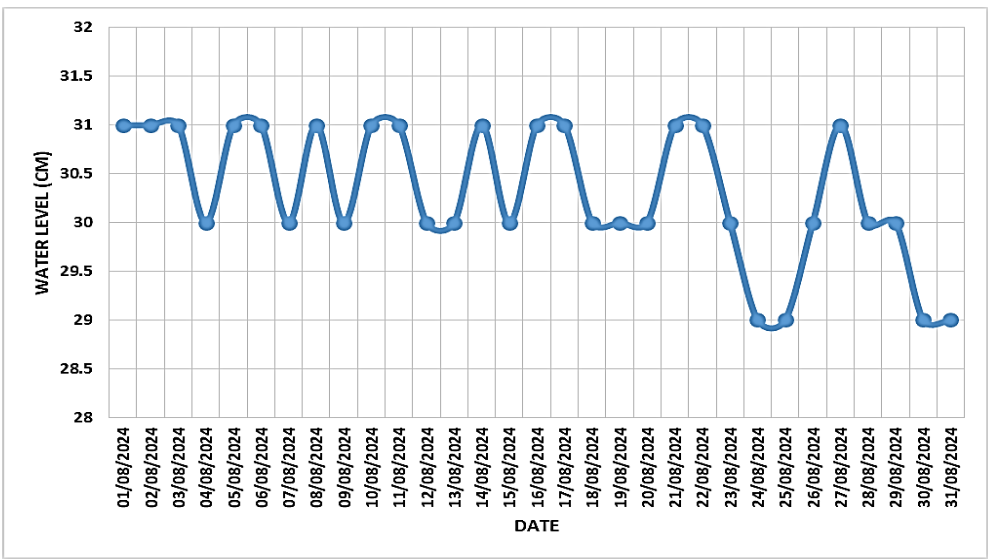

Figure 4.4: Graph of water level against days in August

It can be observed from the graph that the water level sensor maintains almost the same values consistently. It suggests that the water consumption by the tomato crops needs to remain stable which is an indication of optimum water utilization for optimum yield. This can occur if the soil temperature, humidity and crop water demand are steady over time, requiring a system to maintain a consistent water level.

5.0. Conclusion

Wireless sensor networks (WSNs) have proven to be a transformative technology for improving agricultural productivity and sustainability. By enabling real-time monitoring of critical parameters such as soil moisture, soil temperature, humidity and water levels, WSNs empowers farmers with the ability to make informed decisions, automate irrigation and optimize resource use. It was observed that the sensor data fusion value of 55.48 integrates all sensor data over 31 days. This result represents a comprehensive, averaged value that can be used to make more reliable decisions about agricultural practices in Nigeria in order to improve its productivity. It was also observed that the maximum and minimum values obtained from the tomato farm are 90% and 68% for soil moisture, 25.125°C and 29.875°C for soil temperature, 99.9% and 72.70% for humidity and 31cm and 29 cm for water level respectively. These values fall within the acceptable range of these sensors which is an indication of optimal performance of tomato plants. Hence, the use of WSNs in agricultural practices in Nigeria if implemented will optimize irrigation, prevent over-irrigation, ensure efficient water usage and improve crop yields.

6.0 Recommendation

It is recommended that wireless sensor networks should be used in agriculture, especially regions prone to attacks by hoodlums such as kidnappers and Fulani herdsmen.

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