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The Role of IoT (Internet of Things) Technologies in enhancing precision Agriculture Practices for food security in Nigeria

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Abstract – The growing demand for food in terms of quality and quantity has increased the need for industrialization and intensification in the agriculture field. Internet of Things (IoT) is a highly promising technology that is offering many innovative solutions to modernize the agriculture sector. The Internet of Things (IOT) has become important to almost every area of life due to the huge advantages it possesses. Nigeria currently is eager to employ various IOT applications to ease the difficulties farmers encounter by using smart farming to usher in precision Agriculture. This is very necessary as majority of Nigerian populace depend hugely on agriculture. The aim of the study was to assess the role of IoT Technologies to enhance precision agriculture and enjoy the benefits, including food security in Nigeria. It is important that all farm management practices will be meticulously planned, monitored, and controlled before planting to storage and distribution stage using precise Agritech. Precision Agriculture in Nigeria is an unavoidable farming system for Nigeria farmers to efficiently manage their farm, thereby combating the issue of food security as the nation's population increases daily, and with the prediction that the world's population is expected to climax 9.8 billion by 2050.

The methodology adopted is a desk methodology. This is because it involves collection of secondary data. Data is basically collected from existing resources preferably because of its low cost advantage as compared to a field research. The study indicated that precision agriculture technologies play a crucial role in enhancing farm productivity by enabling more efficient and effective farming practices. These technologies, which include GPS (Global Positioning System)-guided equipment, remote sensing, and data analysis, allow farmers to precisely monitor and manage their crops and soil. By using GPS and GIS (Geographic Information Systems), farmers can create detailed maps of their fields, identifying variations in soil types and nutrient levels. Remote sensing technologies, such as drones and satellites, provide real-time data on crop health, helping to detect issues like pest infestations and water stress. IoT-based agricultural monitoring solutions have been identified based on the sub-domains to which they belong. The identified sub-domains are soil monitoring, air monitoring, temperature monitoring, water monitoring, disease monitoring, location monitoring, environmental conditions monitoring, pest monitoring, and fertilization monitoring. Further, the IoT paradigm improves human interaction in the physical world through low-cost electronic devices and communication protocols. IoT also monitors different environmental conditions to create dense and real-time maps of noise level, air, water pollution, temperature, and damaging radiations. Data collected from these different environmental parameters by the devices is transmitted to the user by trigger alerts or sending recommendations to authorities via messages.

Definition of Concepts

Smart Farming: This can be referred to as the application of modern information and communication technologies techniques/skills into agriculture in order to achieve higher productivity [3]. Smart farming or smart agriculture can provide the farmer with daily updates with respect to the soil, crop health, and energy consumption level within the farm [31].

Smart Irrigation: It uses controllers to monitor weather and soil conditions, state of evaporation and plant healthiness while adjusting watering schedules to maintain and moderate the required water on a smart farm. Smart irrigation is targeted of agricultural crops all year round [23].

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Livestock Detection Management: IOT is used to track the location of livestock, identify the livestock, check for their healthiness, locations and when properly deployed, it can solve the herders/farmers clashes [17].
Weather Monitoring: This involves the systematic approach of measuring the atmosphere and climate, including variables such as temperature, moisture, wind velocity and barometric pressure using IOT [32].
Nutrient Management: This involves the smart monitoring of soil nutrients level using IOT for effective crop production [20].
Machines for Routine Operations: This involves optimization of routes for drivers' assistance and reducing the harvest and treatment of crops [4].
PA (Precision Agriculture): is a new advanced method in which farmers provide optimized inputs such as water and fertilizer to enhance productivity, quality, and yield [5]
Integrated Food Security Phase Classification (IPC). IPC is the global standard for measuring food insecurity of hunger. The different phases of hunger using this scale include (IPC Phase1,2,3,4 and 5)[29]

Keywords – [nternet of things (IoT); devices/sensors; agricultural applications; communication protocols, Precision Agriculture, GPS(Global Positioning System), GIS (Geographical Information System), IDPs (Internally Displaced Persons)

1. Introduction

Nigeria in recent years have been faced with a lot of challenges, especially insecurity issues. This scenario affected famers greatly leading to acute food shortage and astronomical increase in prices of food stuff. Farming however, will be made easy to address this problem with precision agriculture. Precision agriculture in Nigeria has been in continuum development to tackle the variability of soil and crop conditions on farmland or field to ensure that farmers are enabled with technologies that increase profits while reducing risks. It is in continuous use to check the problem of misuse of agricultural land, inconsistency, and unsustainability while increasing productivity. It is important that all farm management practices will be meticulously planned, monitored, and controlled before planting to storage and distribution stage using precise Agritech. Precision Agriculture in Nigeria is an unavoidable farming system for Nigeria farmers to efficiently manage their farm, thereby combating the issue of food security as the nation's population increases daily, and with the prediction that the world's population is expected to climax 9.8 billion by 2050 [9].
Internet of Things involves how network of physical devices, vehicles, home appliances, and other items embedded with sensors, software, being connected to allow themselves to collect, exchange, and act on data among themselves for smart farming and timely decisions. It encompasses interconnected devices that communicate with each other and the cloud. These devices are intelligent as they are equipped with sensors, actuators and processing power that can send and receive data via the internet, physical objects, such as appliances, machines, and sensors. IoT facilitates remote monitoring and control, provides data driven decision making, increased efficiency and automation, improved safety and security, hence enhancing the consumer's experiences. IoT technology provides tools for environmental monitoring to ensure precision in Agriculture practices. Precision Agriculture is a systematic technique of applying the right amount of input (fertilizer, pesticide, water, crop, etc.) at the right location, at the right time in a way that optimizes farm returns and minimizes chemicals and protects the environment.[9]
This in turn enhances efficiency, productivity, and sustainability, ensuring food security. Thus PA (Precision Agriculture) is a new advanced method in which farmers provide optimized inputs such as water and fertilizer to enhance productivity, quality, and yield [5]

It is expected that that the increased use of the internet of things technological will bring a wide range of benefits for organizations, especially farmers in Nigeria. One of the major benefit of this innovation will be ability to give producer and consumer services in real time. Internet of Things (IoT) technology provides enabling tools to provide the expected benefit through its innovative technologies and giving a way to enhance the user's perception and ability by modifying the working environment as it offers multiple solutions in different domains such as healthcare, retail, traffic, security, smart homes, smart cities, and agriculture. IoT deployment in agriculture is considered the ideal solution because it requires continuous monitoring and control. In the field of agriculture, IoT is used at different levels in the agriculture industrial production chain [1]. The main applications of IoT in agriculture are Precision Farming, Livestock, and Greenhouses, which are grouped into different monitoring domains. All these applications are monitored with the help of different IoT-based sensors/devices by using wireless sensor networks (WSNs) that helps the farmers collect relevant data through sensing devices. Some IoT-based setups analyze and process the remote data by applying cloud services, which helps the farmers make better decisions. Nowadays, with the advancement of current technology, environment monitoring solutions offer additional facilities in terms of management and decision making. IoT management devices monitor elements such as wind, soil, atmosphere, and water over a large area. The Internet of Things is helping to create smart farms where every process can be monitored to reduce waste and improve agricultural productivity.

IOT Technologies include Wireless communication (Wi-Fi, Bluetooth, cellular), Sensor Technologies (temperature, motion, pressure), microcontrollers and microprocessors, cloud computing and data analytics, Artificial Intelligence and machine learning. The Iot continues to expand, transforming industries and revolutionizing the way we live and work. Application of IoT in Precision Agriculture involves [28]:

1. Soil Moisture Monitoring: Sensors measure soil moisture, enabling optimal irrigation scheduling.

2. Crop Monitoring: Sensors and drones monitor crop health, growth, and development.

3. Weather Station: Real-time weather data informs irrigation and planting decisions.

4. Precision Irrigation: Automated systems optimize water usage.

5. Livestock Monitoring: Track health, behavior, and nutrition.

6. GPS-enabled Farm Equipment: Optimizes planting, spraying, and harvesting.

7. Smart Greenhouses: Climate control, automated watering, and monitoring.

8. Crop Yield Prediction: Machine learning algorithms predict yields.

IoT-based agricultural monitoring solutions have been identified based on the sub-domains to which they belong. The identified sub-domains are soil monitoring, air monitoring, temperature monitoring, water monitoring, disease monitoring, location monitoring, environmental conditions monitoring, pest monitoring, and fertilization monitoring. Further, the IoT paradigm improves human interaction in the physical world through low-cost electronic devices and communication protocols. IoT also monitors different environmental conditions to create dense and real-time maps of noise level, air, water pollution, temperature, and damaging radiations [9,10]. Besides, data collected about different environmental parameters is transmitted to the user by trigger alerts or sending recommendations to authorities via messages [**30**].

Sustainable agricultural practices will help to meet immediate societal needs while protecting land and other natural resources for future generations.

2. Statement of Problem

Nigeria had in recent times been experiencing acute food shortage due to insecurity occasioned by the activities of terrorists, bandits, bad government policies resulting in very high hikes in prices of essential food due to low food supply. The negative impart, though general in the country, but seem higher in Northern Nigeria. Food assistance needs therefore will remain high across the country, but especially in northern Nigeria [29]

Conflict, including armed attacks, kidnapping incidents, and IED explosions, was generally higher in July to December 2023 than in the first half of 2023 or in July to December 2022 and continues at elevated levels in January and February 2024 (Figure 1). Banditry, kidnapping, and cattle rustling in the northwest and north central states, and insurgency attacks and kidnapping in the northeast, have significantly impacted engagement in most livelihoods, particularly access to farmland during the main season harvest. The conflict has also resulted in significant household and productive asset losses, displacement, widespread fear, and limited mobility in the worst-affected areas of the north.

Conflicts had continued to drive widespread Crisis which may lead to (IPC Phase 1,2, 3, 4,5) outcomes in the country especially in the Northeast, North West, and North Central Nigeria**.** This protracted existence of the conflicts in the North and escalating attacks of herdsmen with farmers in the East, oil spillage to water and farmlands in the south have greatly disrupted livelihood activities, thereby limiting access to income-generating activities, driving population displacement, and constraining food access.

FEWS NET estimates that between 17 and 18 million people will need humanitarian assistance in the June to August 2024 lean season [30]. Of highest concern includes the population in inaccessible areas, the displaced population in garrison towns, and the IDPs in camps in the Northeast. If the macroeconomic crisis persists, with inflation hitting a nearly 30-year high and the continued devaluation of the Nigerian naira, households across the country will face increased prices for basic necessities, as the states are still struggling to implement the approved minimum labor wages. This minimum wage may not be able to keep up with the rising inflation and acute food shortage thereby driving widespread Stressed (IPC Phase 2) outcomes.

Hence, there is need for food assistance to Nigeria as a country especially the Northern part by enhancing precision agricultural farming through adoption of IoT (Internet of Things) technologies

3. Literature Review

Revolutionizing Precision Agriculture farming in Nigeria

Precision agriculture has made farming easy in recent time. Precision agriculture in Nigeria has been in continuum development to tackle the variability of soil and crop conditions on farmland or field to ensure that farmers are enabled with technologies that increase profits while reducing risks. It is in continuous use to address the problem of misuse of agricultural land, inconsistency, and unsustainability while increasing productivity. Precision Agriculture in Nigeria is just an unavoidable farming system for Nigeria farmers to efficiently manage their farm, thereby combating the issue of food security as the nation's population increases daily, and with the prediction that the world's population is expected to climax 9.8 billion by 2050 [28].
For Precision Agriculture in Nigeria to be effective the following Technological Tools and Knowledge are required:

Precision Agriculture

Precision Agriculture is a systematic technique of applying the right amount of input (fertilizer, pesticide, water, crop, etc.) at the right location, at the right time in a way that optimizes farm returns and minimizes chemicals and protects the environment.

Yield Monitors

Maximum harvest consideration should be at the planning stage of farm activities. This is because the resultant effect of pre-planting activities, growth, and development cycles would be evident during harvest. To monitor these stages, some precision technologies should be incorporated. These technologies include crop yield measuring devices installed on harvesting equipment which have the capability of indicating yield (kg/ha), weight, ha/hour, hectare worked, grain moisture content. The system work by providing information on crop yield at regular intervals by time or distance..

Global Positioning System (GPS)

This is a network of satellites that transmit precise satellite time and location information to ground receivers. It is used to get the location of yield data collected within one to three meters on the field..

Geographical Information System (GIS)

This is an integrated open-source computer software system that is used to collate, store, analyse and display spatially received geographical information from Global Positioning System (GPS) and yield monitors in a map-like form.

Variable Rate Technology

This system works with precise geographical information received about the field condition and the need for crop, nutrient, and water of each grid location. The nutrient, environmental condition, or water need is formulated and programmed in a precise and controllable way into farm field and equipment.

The controllable way makes fertilizer applicator with VRT system provide a means by which required fertilizer applications are made only in amounts and locations where they are needed.

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Remote Sensors

This is an inbuilt system in farm equipment that detects temperature, light, pH, oxygen, moisture, etc from the soil, crops, and environment. They are used before planting to the storage stage to detect certain problems and by that solution can be made and maintained throughout the processes.

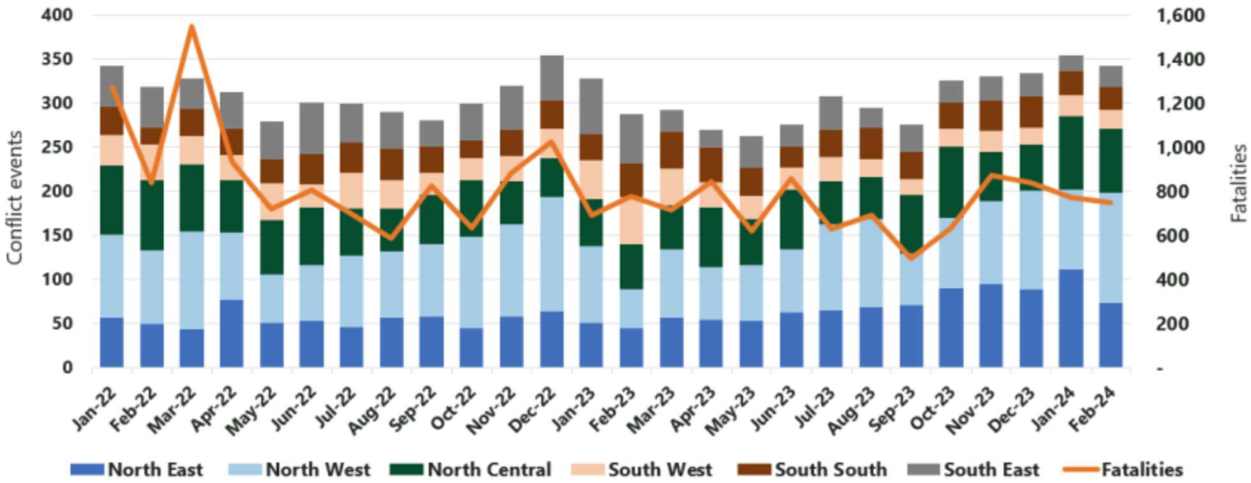
Remote sensing can help in detecting small problem areas caused by pathogens and diseases which can inform optimized time and quantity for fungicide applications. Other sensored equipment are soil moisture sensor, digital light sensor, portable soil sampler, etc. The on-site data generated is processed and then added to the GIS database.

Computer Hardware and Software

Through the knowledge of data analytics, a computer is required to analyse the data collected by yield monitors and GPS as this will be transformed into readable formats such as maps, graphs, charts, or words for decision making. Other emerging technologies outside IoT in precision agriculture in Nigeria and all over the world is the application of Agricultural Robots (Agbots) and Drones.

Current National Overview

The surging economic crisis since mid-2023, especially after the takeover of the current government in May 29, 2023 has been a key driver in the growing levels of insecurity in Nigeria. Beyond increased engagement in opportunistic petty theft and criminality, financially motivated armed actors, bandits in the northwest and insurgents in the northeast, unemployed educated youths in the East and South are increasingly adopting kidnapping for ransom as a more economically lucrative income source. The insensitive removal of fuel subsidy with its attendant hike in fuel price had impacted negatively on food prices. Amid this, the continued depreciation of the Nigerian Naira (NGN) had also heightened the cost-of-living.



Source: FEWS NET/ACLED [29]

Figure 1. **Conflict events and fatalities in Nigeria from January 2022 to February 2024, by region**

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Stages of food security crisis

Mert Er [28] in March 18, 2024, working in world food program, had a look at the stages of hunger ranging from having sufficient food right through to the most extreme form of hunger opined that Climate change and global economic instability combine to create hunger crises in countries. He stated that about 42.3 million people around the world stand on the brink of famine, as conflict, across the globe increases. Famine is defined according to and what stages they are before people reach a catastrophic level of hunger. The"Richter scale" defined these stages as The Integrated Food Security Phase Classification (IPC). IPC is the global standard for measuring food insecurity, of hunger. The different stages of hunger using the scale include:

1.No/minimal food insecurity (IPC Phase 1)

In a situation of no or minimal acute food insecurity, people are able to meet their essential food and non-food needs without engaging in atypical and unsustainable strategies to access food and income. In this phase, less than 5 percent of the population is malnourished and people have a stable income.

2) "Stressed" acute food insecurity (IPC Phase 2)

This phase sees people having minimally adequate food consumption but able to afford some essential non-food items without engaging in stress-coping strategies. They have unsustainable incomes, face difficulties meeting their basic needs and have to make some changes to support their non-food needs.

3) "Crisis" acute food insecurity (IPC Phase 3)

This phase sees families either facing food consumption gaps alongside acute malnutrition, or only just able to meet their food needs resorting to crisis coping strategies like selling off essential livelihood assets. There are limited food choices and people must go to extreme lengths to get the calories they need.

4) "Emergency" acute food insecurity (IPC Phase 4)

In this stage, families face large food consumption gaps alongside very high acute malnutrition rates and excess deaths, or are able to overcome food consumption gaps only by selling off the few assets they have left. Loss of income at this stage is irreversible.

5) "Catastrophe" or "Famine" (IPC Phase 5)

This is the most severe phase of hunger. It is shameful that in a world of plenty, famine still exists. It means a complete lack of access to food and other basic needs. Families face an extreme lack of food and other basic needs even after all possible coping mechanisms have been put in place. Starvation, death, destitution and extremely critical levels of acute malnutrition are evident.

From these stages of food insecurity scenarios, most Nigerians are in IPC phase 2 especially in the Southern part of the country while most of the states in the North are speedily accelerating to phase 3. An urgent action need to be taken to reverse this trend by the government of the day. The fastest way will be through adoption of precision Agriculture using technological tool of IoT to ensure food security for the population.

State-of-the-Art IoT Agricultural Solutions in the Market

According to the report of Finistere Ventures, more than 2 billion dollars have been invested around the globe in AgTech, which is expected to increase in the coming years [**11**]. As IoT is gaining importance in different applications of smart farming, almost all of the top technology firms are investing and supporting this technology in their own way to develop innovation in the agriculture field. Firms and ministry of Agriculture in Nigeria have also keyed in this solution. **Table 1** represents the different IoT agricultural solutions proposed by the top technologies firms.

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Table 1. Available solutions and initiatives regarding IoT in agriculture.

Industries	Initiatives and Solutions
Samsung	Samsung takes the initiative in the field of IoT by providing its Samsung Data Systems (SDS) IoT Platform, which connects the multiple IoT devices and communication protocols such as Modbus, Zigbee, Bluetooth Low Energy (BLE), MQTT, and LoRaWAN [**11**].
AeroFarms	AeroFarms provides indoor farming solutions by analyzing data related to plants into data through big data, imaging, and artificial intelligence technologies [**19**].
Microsoft	Microsoft also works on data-driven farming techniques by resolving the issues from cloud to sensor [**12**]. The Bosch technology firm provides different sensors analytics techniques and IoT-based data management techniques to monitor the crop productivity and diseases [**6**].
R- Style Lab	R- Style Lab is the top IoT software-providing company that offers multiple software solutions such as predictive maintenance, drone's inspections, and crop/animal monitoring solutions, and it provides some embedded software that can easily be integrated into portable trackers [**13**,**14**].
IBM	IBM has provide an AI-based service called Watson Decision, which is best solution to improve the sustainability, harvesting, and quality of smart farming by using IoT and AI technologies [**15**].
Intel	Intel has been developed an IoT-based platform Infiswift, which helps increase the efficiency of agricultural solutions through advanced connected services [**16**].
Google	Google has suggested a vision for advanced agricultural so3lutions by joining the MIT Media Lab Open Agriculture Initiative to provide a healthier food system [**26**].

4 Benefits of IoT in Precision Agriculture in Nigeria

Even though Nigeria is blessed with so much land, several rivers and most of the crops and vegetables can grow favorably well on these soils, there is need to plan to automate planting, storage and distribution of agricultural products using IOT techniques.

Some of the benefits of adopting IoT include:

a. Increased food production: Due to insecurity and its attendant issues, Nigeria has experienced an increase in hunger and poverty. Smart farming has the tendency to perform optimization of smart farming to include accurate planting, pesticides and herbicides application, watering and harvesting. This in turn will lead to increased food production and security, hence reducing hunger in Nigeria.

b. Conservation of Water and Proper Usage of Abundant Rivers: IOT sensors has the huge ability to detect weather conditions and moisture contents of soils. This means that watering of crops can only be done when soils lack the adequate moisture for crop growths. This ensures accurate and timely amount of moisture needed for crop growth thereby conserving water usage in dry seasons. Smart irrigation of farms will help to provide food all year round for Nigerians. Unfortunately, smart irrigation has not been adopted properly in Nigeria to make a proper usage of the abundant natural rivers all over Nigeria. This will be achieved with IoT.

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c. Real Time Monitoring and Insight into Production: Farms in Nigeria are most times physically managed. As such, decision making about such farms is usually slow. IOTs have the capability to assist farmers to perform real time monitoring of farms in terms of visualizing what happens on such farms and taking real time decisions remotely and timely.

d. Operation Cost Reduction: When the clearing of bushes, tillage of the land, planting of seedlings, application of herbicides/insecticides, clearing of weeds, and harvesting of crops is automated with the aid of IOTs devices, the cost of operating an entire farm will be greatly reduced.

e. Improved Livestock Farming: The health and wellbeing of animals can be well monitored with the help of IOTs. Furthermore, the clashes between herders and farmers in Nigeria can be reduced by the deployment of IOT. This can be achieved by tracking the movements of livestock to monitor and check for encroachments. Cattle rustling will be more conveniently traced and offenders punished.

f. Monitoring of Agricultural Equipment/Machinery: Farming equipment can be effectively managed in Nigeria using IOTs based on production rates, labour effectiveness, and failure prediction. Hence, shortage of agricultural equipment and machinery can be minimized and these equipment/machineries could be effectively used on different farms routinely to achieve more bountiful harvest.

5. Open Issues and Challenges

Some of the open issues and challenges associated with implementation of IoT applications include:

Security

Security issues arise at a different level of IoT-based agricultural systems, which need to be addressed. Due to low security, users face many difficulties such as loss of data and other on-field parameters. In the agriculture field, IoT devices are at risk due to physical interference such as attack by animals and predators or modification in physical address [34,7]. Moreover, due to low energy consumption and limited memory, it is hard to implement sophisticated and complex algorithms. The precision farming services such as IoT-enabled location information and location-based services are exposed to hackers that may use this information for device capturing [6,34,25]. Attackers attack the IoT device and take out cryptographic implementations. Other communication layers also undergo some vulnerable denial-of-service (DoS) attacks and wireless signal blocking [34]. Major security threats to the cloud infrastructure are hijacking attacks, session hijacking, database issues, and denial of service attack [34].

Cost

While deploying IoT in agriculture, several cost-related issues arise such as setup and running costs. The setup costs consist of hardware costs such as IoT devices/sensors, base station infrastructure, and gateways. Moreover, running costs includes an uninterrupted subscription for the management of IoT devices, the exchange of information among other services, and centralized services that provide information/data collection [11].

Lack Knowledge of Technology

Poor understanding of technology is the main barrier among the farmers who are living in rural areas. This problem is common in developing countries, where most farmers are uneducated [8]. The implementation of IoT in agriculture is a big challenge, because a lot of investment is required in farmer’s training before deploying IoT infrastructure.

Reliability

In the field of agriculture, IoT devices are deployed in an open environment due to which harsh environmental conditions may cause communication failure and the humiliation of deployed sensors. Therefore, it is important to ensure the physical safety of deployed IoT devices/sensors to protect them from severe climate conditions [2].

Scalability

A large number of IoT devices and sensors are deployed in the agriculture field, due to which an intelligent IoT management system is required for the identification and controlling of each node [1].

Localization

There are many factors that need to be considered while deploying devices/sensors. Such devices should have the ability to provide functionality and support to the rest of the world without deploying additional devices with overhead configuration [3]. Moreover, it is important to select the best deployment position so that devices can communicate and exchange information without any interference.

Interoperability

There are billions of IoT devices, standards, and protocols that are needed to interoperate. Interoperability involves semantic, syntactic, technical, and organizational policy. Semantic interoperability is the ability to deal with the interpretation of content exchanged among humans. Syntactical interoperability is related to data formats, such as java script object notation (JSON), data interchanged electronically, extensible markup language (XML), and variables separated by a comma. Technical interoperability is associated with the development of infrastructure, protocols, and hardware/software components that enable the IoT devices' communication. Organizational interoperability is related to policies for communicating and transferring data effectively across the different geographic regions and infrastructure.

6. Food Security Outlook in Nigeria

The most likely scenario from February to September 2024 is based on the following national-level assumptions [29]:

The country's poor **macroeconomic conditions** are expected to continue deteriorating through the outlook period – despite the **World Bank** projections of 3.3 percent growth in GDP in 2024 – due to continued low revenue generation and poor revenue utilization. The demand for foreign currency will likely remain high, driving devaluation of the NGN through at least September 2024. Annual headline inflation is expected to continue trending upward through September 2024, primarily driven by the depreciation of NGN and the high cost of food, fuel, and transportation.

The price of petrol is expected to remain stable at elevated levels. The commencement of production by Dangote refinery is unlikely to impact domestic fuel prices during the projection period since the global price of petrol remains high, further exacerbated by the devaluation of the NGN.

Conflict associated with the insurgency in northeastern Nigeria is likely to persist through September 2024 at levels similar to those in 2023.

Violence associated with banditry and kidnapping, particularly in the northwest and north-central, is expected to slightly increase in 2024, driven in part by deteriorating economic conditions. Kidnapping had been on the increase in the southeast and southwest.

Farmer/herder conflict in the north and south of the country is expected to increase starting with the rainy season in June as available routes for livestock movement become limited, in-line with normal seasonal trends.

Rains are forecasted to start normally in March in southern areas and May/June in the north. Early rainfall performance between March and May will likely be slightly below average in the south. In the north, precipitation from June to September is anticipated to be average. The harvest from the 2024 dry season farming activities is expected to be below average due to lower than normal engagement and constrained purchasing power of the middle and better-off households to purchase fuel, inputs, and labor.

Main season (2024) farming activities are anticipated to start on time, with land preparation in February/March in the south and April/May in the north. Due to low household purchasing power for inputs/hiring labor and the sustained high levels of conflict, main season farming – including land preparation and area planted – is likely to be below last year and average in the surplus-producing north. The main season harvest will commence normally in late September with early maturing maize, millet, and yams.

Agricultural labor associated with main season farming is anticipated to follow seasonal trends, with demand increasing starting in March in the south and May in the north for land preparation. However, labor supply will outpace the below-average demand due to reduced purchasing power of farmers and reduced area planted. Agricultural labor wages are expected to be above average.

Retail prices of locally produced staple foods are expected to increase through the projection period and peak in the lean season (July and August), remaining well above the five-year average across all monitored market trend. Prices are expected to decline slightly with the start of the main season harvest in late September, following seasonal trends. Domestic demand is anticipated to remain elevated through the projection period

Formal cross-border trade, both import and export, is expected to be average to above average throughout the outlook period due to the depreciation of the NGN relative to USD, though slightly constrained by the persisting insecurity along some northern corridors. However, **informal cross-border trade** activities are expected to be above last year's and average levels through September. Currency depreciation will likely decrease the trade of livestock.

The domestic flow of goods, including staple foods from surplus-producing areas in the north to deficit-producing areas in the south, is expected to remain below average due to impacts of persisting conflict exacerbated by high fuel and transportation costs. Trade disruptions are expected to continue in conflict-affected areas, while goods will likely move more freely in less-affected areas. Market supply is expected to decline progressively through the lean season until September, when the early main season harvest stock will become available. However, transportation costs will remain atypically high due to increased fuel costs.

Livestock movement from northern to southern pastures will likely start in February, as is typical. However, migration will likely be below average due to the persisting farmer/herder conflict, cattle rustling, and increased kidnapping. In the central and southern areas, pastoralists who migrate will have relatively limited access to pasture due to the volatile security environment, open grazing bans, and prosecution for kidnapping. Livestock that migrated will return from southern and central states to homesteads in the north in June. Pastoral movement from neighboring countries will be below normal, and herds will be below average in the country due to the persisting conflict.

Livestock prices will likely be higher than last year and above average through September due to conflict, bans on open grazing, border closure with the Niger Republic, and depreciation of the NGN limiting livestock production and inflows. In July, livestock prices are expected to peak due to increased demand and favorable livestock body conditions improved by wet season pasture availability.

Poor households will continue relying heavily on non-agricultural labor, including casual labor, petty trading, firewood/charcoal sales, and self-employment. Income from these sources is likely to remain slightly above average, though will not increase at pace with the increase in staple food prices.

Labor migration from rural conflict-affected areas to less conflict-affected areas – both rural and urban – is expected to be similar to last year and above average as households continue exploring options to increase food and cash income, further increasing labor supply.

International remittances will likely be higher than last year and the average through September 2024 due to depreciation of the NGN. Meanwhile, domestic remittances will likely be near or below last year's and the average due to the poor domestic economic conditions.

7. USING IoT TO SUSTAIN FOOD SECURITY IN NIGERIA

In view of the importance of IoT in agriculture, the challenges to practicing farmers in Nigeria, the following recommendations are made to enhance food security especially to average and below average households:

1.Internet facilities should be made available for the rural farmers

2.Adult literacy to the practicing farmers should be encouraged and provided

3.Computers, i-phones and other network-connecting media given to farmers should be loaded with user-friendly software written in mother tongue of the farmers of that locality

4.Simple but explanatory flow chart for mode of the connecting media should be made available to the farmers as well as continuous training and sensitization awareness program

5.Solar energy as alternative source of power for charging phones, laptops etc should be made available to avoid possible negative effects of incessant power failures

6.The farmers' children should be integrated into the training and application of IoT in their area to further enhance continuity

7.Extension agents should be well articulated in the field and accessible to the farmers for trainings and clarifications

8. CONCLUDING REMARKS

The global food challenge necessitates that farmers positioned with state of the art technologies – IoT in order to find better means of feeding the population which is growing with a geometric progression. With internet of things, agricultural practices is made modern and easy, it improves operational efficiency, drives productivity, creates new revenue sources and, ultimately, makes sustainability synonymous with higher profits.

However, Nigerian agriculture must be worked on through provision of modern internet-based equipment/facilities and trainings to obtain improved productivity to address food security threats in Nigeria.

9. CONTRIBUTION TO KNOWLEDGE

Based on the importance and application of Internet of Things to agriculture, it is recommended that Nigerian farmers:

1. Should have access to facilities and trainings on internet of things that relate to precision agriculture. The training should be made available in the farmers' local language

2. Should be taught to read and write in their local language

3. Alternative source of power like solar energy should be in place standby.

4. Most importantly, Government policies should support and aid the extension agents through trainings, incentives for successful execution of projects and transportation means to interior villages.

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