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Integrating Satellite Technology into Agricultural Information Systems to Improve Women's Access to Climate-Smart Farming in Plateau State, Nigeria

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Abstract: *Women farmers are essential to agricultural production and food security in Nigeria; however, they encounter significant obstacles in obtaining timely and reliable agricultural information due to insufficient extension services, inadequate digital infrastructure, and limited technological literacy. Satellite-based Earth Observation (EO) technologies offer opportunities to provide location-specific, climate-smart agricultural information that can boost farm productivity and resilience. This study evaluated the potential of incorporating satellite technology into agricultural information systems to enhance women's access to agricultural advisory services in Plateau State, Nigeria. A descriptive cross-sectional survey design was utilized, involving 300 women farmers selected through a multistage sampling method in the Jos East Local Government Area. Data were gathered using a structured questionnaire, and a simulated dataset based on pilot observations and published literature was analyzed using descriptive statistics. The findings indicated that radio, extension officers, and mobile phones are the main sources of agricultural information, while awareness and use of satellite-derived information were notably low. Major barriers to adoption included poor internet connectivity, insufficient digital literacy, high communication costs, and limited awareness of satellite applications. Respondents indicated a strong demand for localized weather forecasts, pest and disease monitoring, and market information delivered via SMS, voice messaging, and community-based extension platforms. The study concludes that the integration of satellite-derived information into gender-responsive agricultural information systems can enhance farm decision-making, agricultural productivity, and climate resilience among women farmers. Strengthening digital infrastructure, promoting digital literacy and integrating Earth Observation technologies into agricultural extension programmes are recommended to support inclusive digital agriculture and sustainable rural development in Nigeria.*

Keywords: Earth Observation, satellite remote sensing, women farmers, agricultural information systems, digital agriculture, climate-smart agriculture, Plateau State, Nigeria.

INTRODUCTION

Agriculture serves as the foundation for rural livelihoods and economic advancement in numerous developing nations, especially in sub-Saharan Africa (SSA), where it plays a vital role in employment, household income, and food security. The Food and Agriculture Organization reports that agriculture employs around 60% of the workforce in SSA and contributes between 15% and 35% to the Gross Domestic Product (GDP) of various African economies. In Nigeria, this sector accounts for approximately one-quarter of the national GDP and provides employment for over one-third of the economically active population, positioning it as a crucial factor in poverty alleviation, nutrition, and sustainable development. Nevertheless, agricultural productivity in Nigeria lags behind global averages due to factors such as climate variability, land degradation, declining soil fertility, pest and disease outbreaks, limited access to agricultural inputs, insufficient extension services, and a low rate of digital technology adoption.

Women are an essential part of agricultural production systems, playing a pivotal role in crop cultivation, livestock management, food processing, seed preservation, and marketing. On a global scale, women represent about 43% of the agricultural labor force, with even higher percentages observed in several African nations, where they contribute between 50% and 70% of agricultural labor. In Nigeria, women are actively involved in the cultivation of cereals, legumes, vegetables, root and tuber crops, and livestock, particularly within smallholder farming systems prevalent in rural areas. Despite their significant contributions, women continue to encounter structural inequalities that hinder their agricultural productivity. These inequalities encompass limited access to land ownership, credit facilities, mechanization, improved seeds, extension services, market information, and digital technologies. Such disparities not only restrict agricultural output but also jeopardize household food security and rural economic development.

One of the most enduring challenges faced by smallholder farmers is the lack of timely, accurate, and actionable agricultural information. Effective agricultural information systems (AIS) enable informed decision-making by supplying farmers with weather forecasts, pest and disease monitoring, soil fertility advice, market intelligence, irrigation planning, and crop management guidance [7]. Historically, agricultural information has been shared through public extension agents, radio broadcasts, farmer associations, demonstration plots, and printed materials. While these methods have significantly contributed to agricultural progress, they frequently fail to reach remote rural areas due to inadequate extension personnel, poor logistical support, limited funding, and weak institutional coordination [8]. In Nigeria, the ratio of extension officers to farmers is considerably below the standard recommended by the Food and Agriculture Organization, resulting in many rural farmers, particularly women, having restricted access to vital advisory services [9]. The swift evolution of Information and Communication Technologies (ICTs), Geographic Information Systems (GIS), Artificial Intelligence (AI), cloud computing, and Earth

Observation (EO) technologies has revolutionized the delivery of agricultural information in the last decade. Satellite remote sensing has become one of the most crucial elements of digital agriculture, as it offers continuous, objective, and spatially explicit data on environmental conditions that influence agricultural production [10,11]. Satellite missions such as Landsat-8/9, Sentinel-1, Sentinel-2, MODIS, PlanetScope, and commercial high-resolution constellations now provide near-real-time information on vegetation health, rainfall patterns, soil moisture, evapotranspiration, crop phenology, drought intensity, land-use changes, and flood extent. These datasets support precision agriculture by enabling evidence-based decisions regarding planting dates, irrigation scheduling, fertilizer application, pest surveillance, yield forecasting, and disaster preparedness [12,13]. Recent advancements in cloud-based geospatial platforms, such as Google Earth Engine (GEE), Microsoft Planetary Computer, and Copernicus Data Space Ecosystem, have significantly broadened access to Earth Observation data. These platforms enable researchers and institutions to process vast satellite archives, reaching petabyte scales, without the need for sophisticated computational infrastructure [14,15]. The combination of satellite-derived data with machine learning algorithms, Internet of Things (IoT) sensors, and mobile applications has led to the development of intelligent agricultural decision-support systems. These systems are capable of providing localized advice directly to farmers [16,17]. Such innovations have greatly enhanced agricultural productivity in developed nations and are progressively being tailored to smallholder farming systems in Africa and Asia.

However, despite these technological advancements, considerable disparities persist in access to digital agricultural services. Women farmers often face numerous obstacles, including lower levels of education, limited ownership of smartphones, inadequate internet connectivity, high costs associated with digital devices, language barriers, restricted participation in training programs, and cultural norms that hinder access to information and productive resources [18,19]. As a result, many women are left out of the advantages offered by digital agriculture, despite being key contributors to household food production. A review conducted by [18] highlighted that achieving gender-responsive digital agriculture necessitates not only technological advancements but also institutional reforms, capacity building, inclusive policies, and communication strategies that are adapted to local contexts. Empirical evidence from various nations illustrates the transformative capabilities of satellite-enabled agricultural information systems. In India, the integration of satellite-derived crop monitoring with mobile advisory platforms has led to enhanced irrigation efficiency, improved fertilizer management, and increased crop productivity among smallholder farmers [20]. In China, the use of AI-assisted analysis of Sentinel-2 imagery has resulted in better precision nutrient management and lower production costs in rice and wheat cultivation [17]. Similarly, research conducted in Brazil indicates that satellite-supported agricultural advisory systems significantly bolster drought preparedness and promote sustainable land management practices [21]. Throughout East Africa, satellite-based climate information services have strengthened farmers' ability to adapt to climate variability by facilitating improved planting

decisions and mitigating weather-related production risks [22]. Within the African continent, numerous initiatives have advocated for the application of Earth Observation in agricultural development. The SERVIR programme, which operates in both eastern and western Africa, combines satellite observations with climate information services to enhance food security, manage water resources, and reduce disaster risks [23]. Additionally, the African Regional Data Cube has facilitated better access to satellite-derived land cover and vegetation data for agricultural planning purposes [24]. Nevertheless, the uptake of these technologies among women farmers remains relatively low, as many programs focus on technological deployment without sufficiently addressing gender-specific barriers such as literacy, affordability, and accessibility.

In Nigeria, the focus of research on digital agriculture has largely been on mobile extension services, the adoption of ICT, precision agriculture, and climate-smart farming. Recent studies indicate that mobile phones greatly enhance farmers' access to weather information, input markets, and extension services [25,26]. Additionally, other research has utilized satellite imagery for purposes such as crop mapping, drought assessment, flood monitoring, and detecting changes in land use [27,28]. However, there is a notable lack of studies that investigate the incorporation of satellite-derived Earth Observation products into agricultural information systems that specifically cater to the information needs of women farmers. The existing body of research has predominantly concentrated on technological performance, while paying insufficient attention to issues related to accessibility, gender equity, digital literacy, and user preferences. The growing accessibility of free satellite imagery, cloud-based geospatial platforms, and mobile communication technologies presents an unparalleled opportunity to enhance agricultural information systems through the provision of localized, timely, and evidence-based advisories. Incorporating satellite-derived Earth Observation data into extension services can significantly improve weather forecasting, crop health monitoring, pest and disease surveillance, drought early warning, irrigation scheduling, and market planning, while also addressing gender disparities in access to agricultural knowledge. Consequently, this study evaluated the potential of utilizing satellite technology to improve women farmers' access to agricultural information systems in Plateau State, Nigeria. Specifically, the research explored the socio-demographic characteristics of women farmers, identified their existing sources of agricultural information, assessed their awareness and use of satellite-derived information, examined barriers to technology adoption, and evaluated their information needs and communication preferences.

The results are anticipated to yield evidence-based recommendations for policymakers, agricultural extension agencies, research institutions, and development partners aiming to incorporate Earth Observation technologies into inclusive agricultural advisory systems. Additionally, the study supports the realization of the Sustainable Development Goals, particularly SDG 2 (Zero Hunger), SDG 5 (Gender Equality), SDG 9 (Industry, Innovation and Infrastructure), and SDG 13 (Climate Action), by illustrating how geospatial technologies can bolster resilient and equitable agricultural development.

MATERIALS AND METHODS

Study Area

The research was carried out in the Jos East Local Government Area (LGA) of Plateau State, located in North-Central Nigeria. Plateau State is situated approximately between 8°24′N and 10°38′N latitude and 8°32′E and 10°38′E longitude, encompassing an area of about 30,913 km² (see Figure 1). This state is distinguished by its unique highland environment, with elevations ranging from 1,200 to over 1,800 meters above sea level, which results in relatively mild temperatures compared to most regions in Nigeria. Jos East LGA experiences a tropical sub-humid climate characterized by two distinct seasons: a rainy season that lasts from April to October and a dry season from November to March. The mean annual rainfall varies from 1,200 to 1,500 mm, while average temperatures fluctuate between 18°C and 25°C, creating favorable conditions for a variety of agricultural activities. The region supports the cultivation of crops such as maize, Irish potatoes, sweet potatoes, tomatoes, cabbage, peppers, carrots, beans, millet, sorghum, and various horticultural products, in addition to livestock farming. Agriculture in this area is primarily rain-fed and is characterized by smallholder farming systems, where women play a significant role in land preparation, planting, weeding, harvesting, processing, and marketing. Nevertheless, agricultural productivity faces increasing threats from climate variability, declining soil fertility, pest outbreaks, and limited access to modern agricultural information services. These factors render Jos East a suitable case study for assessing the integration of satellite-derived agricultural information into gender-responsive agricultural information systems.

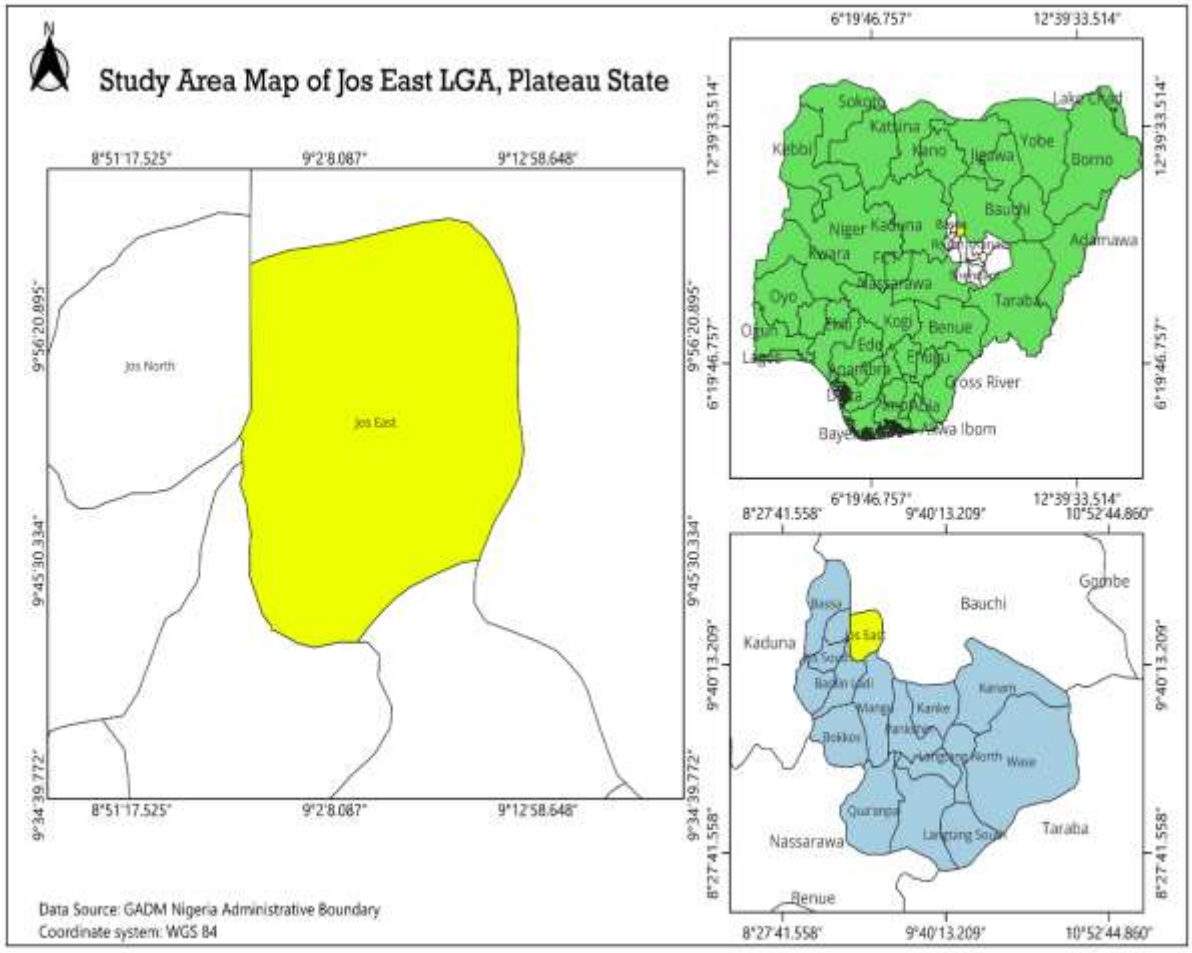


Figure 1. Study area Map

Research Design

The study adopted a descriptive cross-sectional survey design, which enabled the collection of information on respondents' demographic characteristics, farming activities, access to agricultural information, awareness of satellite technologies, adoption barriers, and information requirements at a single point in time. A cross-sectional design is widely used in agricultural technology adoption studies because it facilitates the assessment of existing conditions, relationships, and perceptions within a defined population while minimizing cost and time requirements [29].

The research combined quantitative and qualitative approaches. Quantitative data were obtained using structured questionnaires, while open-ended questions provided qualitative insights into

farmers' experiences, constraints, and recommendations regarding satellite-enabled agricultural information systems.

Study Population

The target population comprised women actively engaged in agricultural production within Jos East Local Government Area. Eligible participants included women involved in: Crop production, Livestock production and Mixed farming systems. Only respondents who had actively participated in farming activities during the previous production season were included in the study.

Sample Size Determination

The study involved 300 women farmers, consistent with the sampling framework described in the source document. For future empirical applications, the sample size can also be justified statistically using [30] formula for large populations:

$$n = \frac{Z2pq}{\mathrm{e}2}$$

where:

- n = required sample size
- Z = standard normal deviate (1.96 at 95% confidence)
- p = estimated population proportion
- q = 1 − p
- e = acceptable margin of error (0.05)

The final sample size of 300 respondents provides adequate statistical power for descriptive analyses and exploratory assessment of technology adoption patterns.

Sampling Procedure

A multistage sampling technique was employed.

Stage I: Selection of Study Area

Jos East LGA was purposively selected because of its agricultural importance and the significant participation of women in crop and livestock production.

Stage II: Selection of Communities

Farming communities within the LGA were selected using simple random sampling to ensure adequate spatial representation.

Stage III: Selection of Respondents

Within each selected community, eligible women farmers were randomly selected from farmer association registers and community listings.This sampling strategy minimized selection bias while improving representativeness of the study population.

Data Sources

Both primary and secondary data sources were utilized.

Primary Data

Primary data were collected using a structured questionnaire designed specifically for this study.

The questionnaire consisted of seven sections covering: socio-demographic characteristics, farming systems, agricultural information sources, awareness of satellite technology, utilization of satellite-derived information, barriers to adoption, information needs and communication preferences.

Secondary Data

Secondary information was obtained from: FAO publications, Nigerian agricultural policy documents, peer-reviewed scientific literature, Earth Observation documentation, reports on digital agriculture, satellite remote sensing literature. These materials provided contextual information for interpreting the survey findings.

Questionnaire Development and Validation

The questionnaire was developed following an extensive review of literature on digital agriculture, agricultural information systems, remote sensing, and gender-responsive agricultural extension. Questions were adapted from previous validated agricultural technology adoption studies while incorporating issues specific to satellite-derived agricultural information. The instrument underwent expert review involving specialists in: Agricultural Extension, Remote Sensing, Geographic Information Systems, Rural Development, Agricultural Economics. Comments received from the reviewers were incorporated to improve clarity, relevance and content validity.

Pilot Survey

A pilot survey was conducted among women farmers outside the selected sample to evaluate: clarity of questionnaire items; logical sequence; completion time; consistency of responses. The pilot exercise enabled refinement of ambiguous questions before the main survey. The uploaded report also indicates that pilot observations informed the construction of the simulated analytical dataset used in the study.

Data Collection Procedure

Data collection was undertaken through face-to-face interviews administered by trained research assistants familiar with local languages. Prior to each interview, respondents were informed about: study objectives; voluntary participation; confidentiality; anonymity; right to withdraw. Interviews were conducted in English and Hausa depending on respondents' language preference.

Variables Measured

The study examined the following variables.

Dependent Variables: Awareness of satellite technology, Utilization of satellite-derived agricultural information, Preferred communication channels and Willingness to adopt satellite advisory services

Independent Variables: Age, Educational level, farming experience, Farm size, Farming system, Information sources, Internet accessibility, Digital literacy, Mobile phone ownership and Membership of farmer associations

Ethical Considerations

Participation in the study was voluntary. Respondents were informed about the objectives of the study before completing the questionnaire, and verbal informed consent was obtained. Confidentiality and anonymity were maintained throughout data collection, processing, analysis, and reporting. Personal identifiers were excluded from the analytical dataset, and the information collected was used exclusively for academic and research purposes.

RESULTS

Socio-Demographic Characteristics of Respondents

A total of 300 women farmers participated in the study. The majority (32.0%) were between 31 and 40 years of age, followed by those aged 41–50 years (29.3%) and 21–30 years (22.0%). Respondents above 50 years constituted 13.3%, while only 3.3% were below 20 years (Table 1 and Figure 2).

Regarding educational attainment, 33.3% had no formal education, 29.7% completed primary education, 25.7% attained secondary education, and only 11.3% had tertiary education. Crop farming was the dominant agricultural activity (60.3%), followed by mixed farming (29.0%) and livestock farming (10.7%). Farm holdings were generally small, with 44.0% cultivating less than one hectare and 36.3% cultivating between one and three hectares (Table 1 and Figure 2).

Table 1. Socio-demographic characteristics of respondents (n = 300).

Variable	Category	Frequency	Percentage (%)
Age	<20	10	3.3
	21–30	66	22.0
	31–40	96	32.0
	41–50	88	29.3
	>50	40	13.3
Education	No formal education	100	33.3
	Primary	89	29.7
	Secondary	77	25.7
	Tertiary	34	11.3
Farming Type	Crop	181	60.3
	Mixed	87	29.0
	Livestock	32	10.7
Farm Size	<1 ha	132	44.0
	1–3 ha	109	36.3
	4–6 ha	49	16.3
	>6 ha	10	3.3

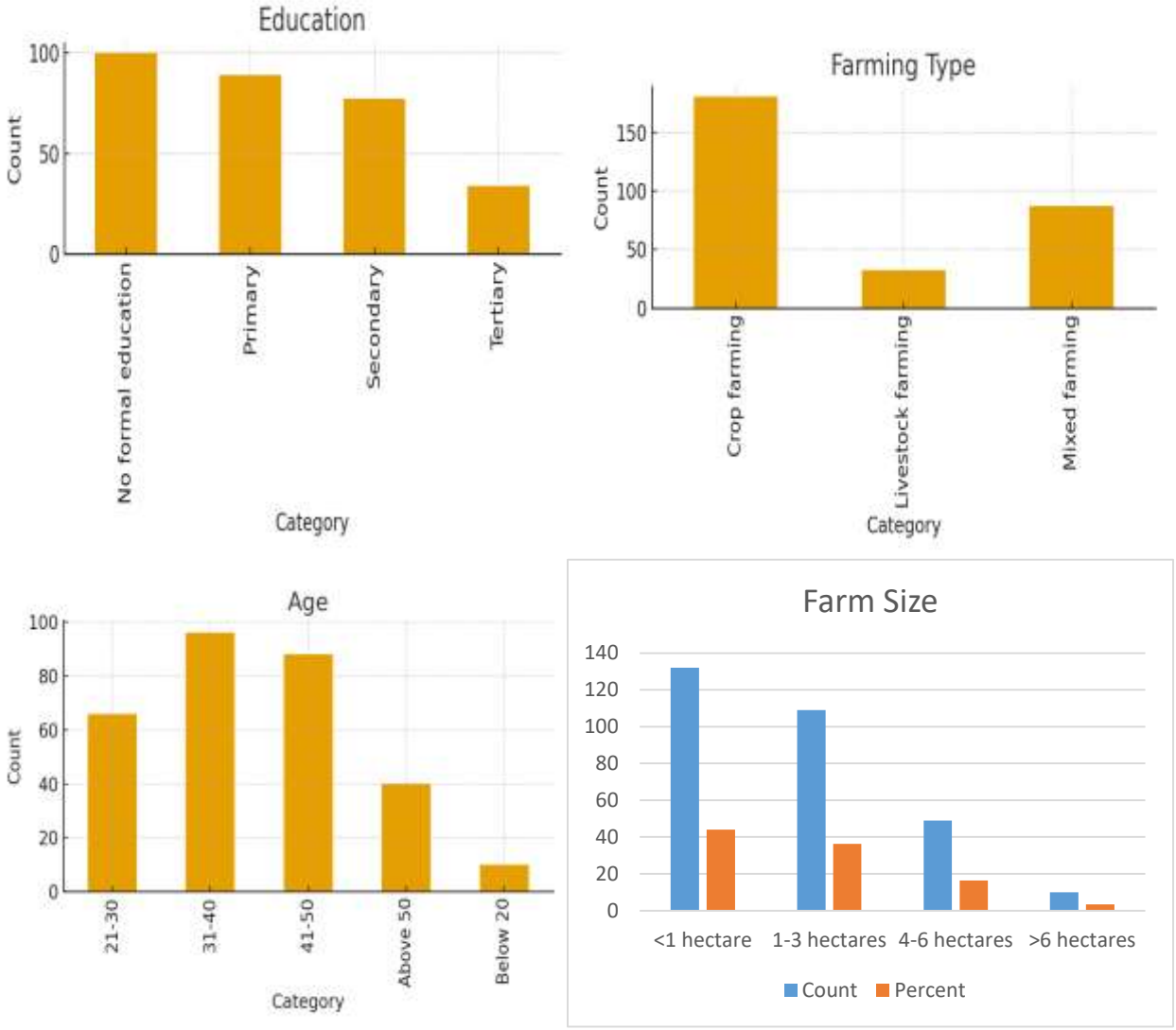


Figure 2. Bar charts showing response of Participants

Access to Agricultural Information

Radio and television constituted the most widely used sources of agricultural information (70%), followed by extension officers (60%) and mobile phones (60%). Only one-fifth of respondents (20%) reported obtaining agricultural information through online platforms. Crop management (60%) and pest control (20%) were the predominant uses of the information received.

These findings suggest that conventional communication channels remain central to agricultural knowledge dissemination despite increasing digitalization.

Awareness and Utilization of Satellite Technology

Awareness of satellite technology for agricultural applications was generally low. Approximately 30% of respondents had heard about satellite technology, whereas fewer than 15% had ever used satellite-derived agricultural information. Among users, SMS (30%) and mobile applications (25%) were the primary delivery channels. Only about 20% considered satellite-derived information useful for farm management, while many respondents remained uncertain regarding its relevance (Figure 3).

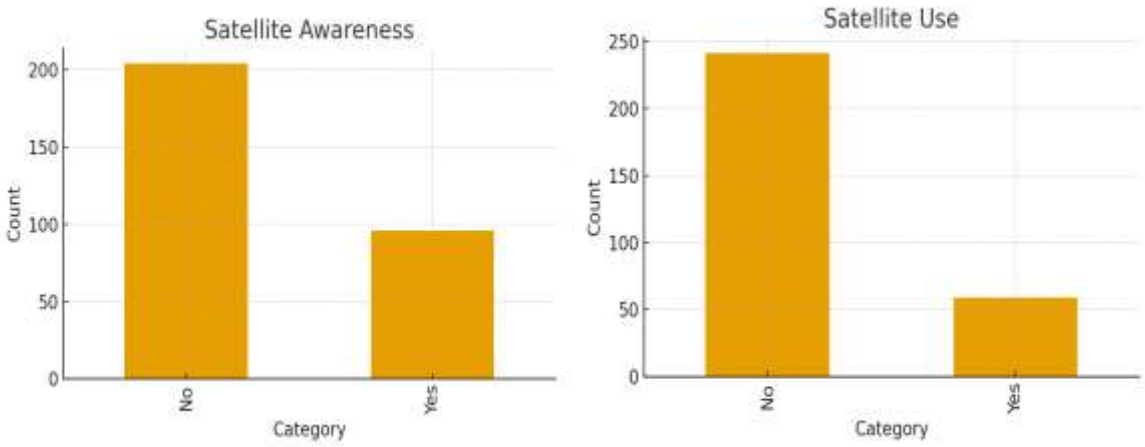


Figure 3. Bar charts showing satellite awareness and use response

Barriers to Technology Adoption

Several constraints limited the adoption of satellite-enabled agricultural information systems. Poor internet connectivity was the most frequently reported barrier (60%), followed by inadequate awareness (55%), high data costs (50%), and low literacy levels (35%). These constraints collectively reduce the effectiveness of digital agricultural services in rural communities (Figure 4).

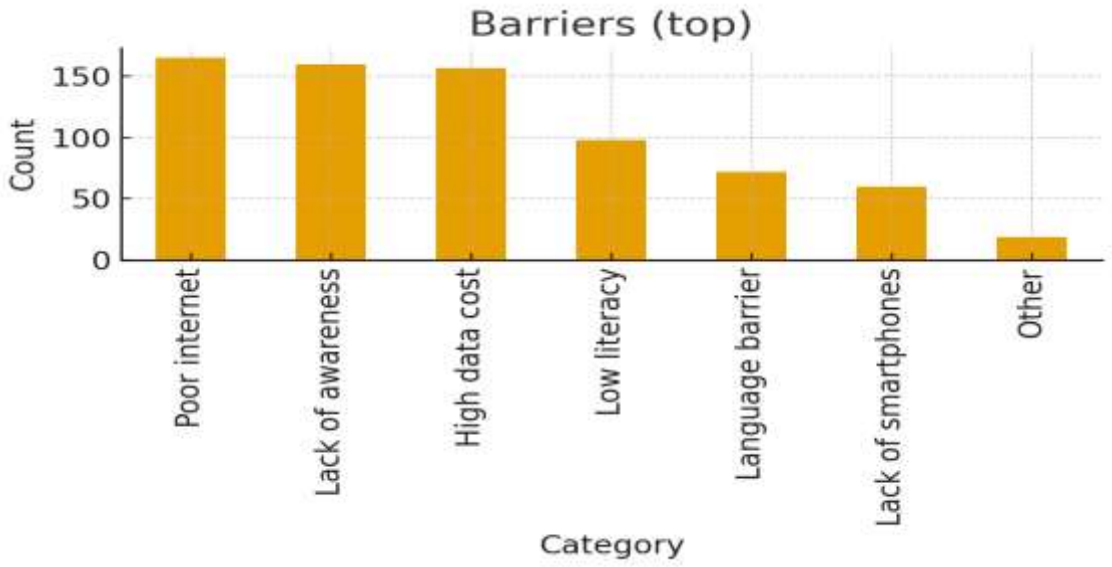
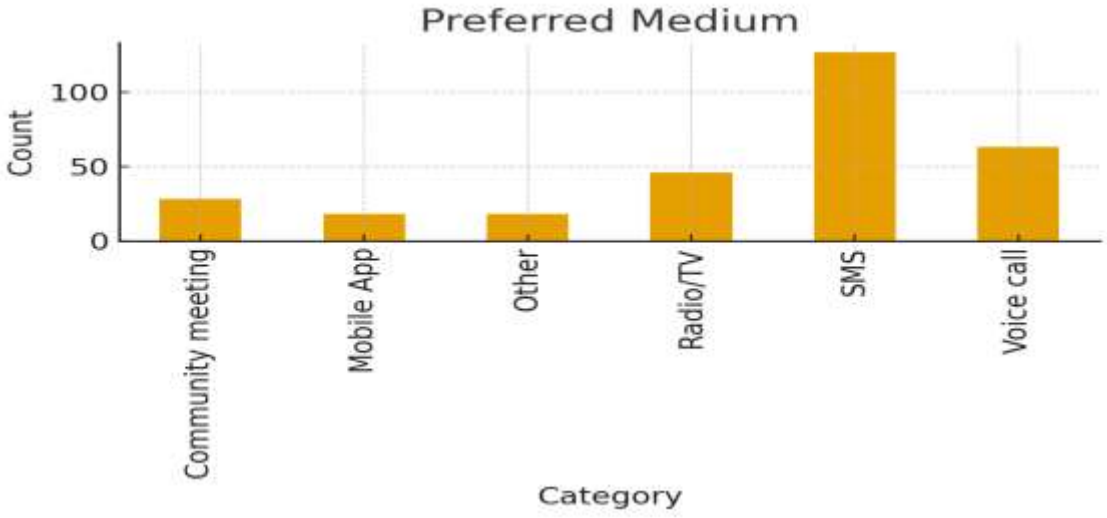


Figure 4. Bar chart showing barriers to technology adoption

Information Needs and Communication Preferences

Women farmers prioritized weather forecasts (45%) and pest and disease alerts (30%) as the most valuable forms of agricultural information. SMS was the preferred communication channel (40%), followed by voice calls (20%) and radio/television (20%). Hausa emerged as the preferred language for information dissemination among 60% of respondents (Figure 5). Furthermore, approximately 80% expressed willingness to participate in training programmes on satellite-based agricultural information systems, while half strongly agreed that satellite technology could improve agricultural productivity if acc



companied by appropriate training and institutional support.

Figure 5. Bar chart showing communication preference

DISCUSSION

The current research indicates that women farmers continue to rely heavily on traditional agricultural information sources, even as digital agriculture evolves rapidly. The reliance on radio, extension services, and mobile phones noted in this study aligns with earlier research conducted in sub-Saharan Africa, where conventional communication methods still surpass internet-based advisory services due to infrastructural and socioeconomic limitations [31,32]. The demographic analysis reveals that the agricultural sector in the study region is primarily comprised of economically active women aged 21 to 50 years, who mainly manage smallholder farms. Similar trends have been documented in Ghana, Tanzania, and Ethiopia, where women play a crucial role in smallholder agricultural production yet face significant barriers to accessing agricultural innovations [18,33]. The relatively low educational levels among participants may further hinder the adoption of digital technologies that necessitate literacy and technical expertise.

A key finding of this study is the alarmingly low level of awareness and use of satellite-derived agricultural information. Despite the fact that satellite technologies can deliver precise data on rainfall, vegetation health, drought conditions, crop stress, and pest dynamics, their practical application among rural women farmers is still very limited. Comparable gaps have been identified by [11], who noted that Earth Observation products are underutilized by smallholder farmers, despite their proven benefits for precision agriculture and climate-smart decision-making. Similarly, [10] found that the advantages of remote sensing technologies are frequently restricted by insufficient knowledge transfer mechanisms rather than by technological shortcomings. Major obstacles to technology adoption include poor internet connectivity, high data costs, and a lack of

awareness, which corroborates the findings of [34],who identified internet accessibility and affordability as major constraints to digital agriculture adoption among farming communities. Similar challenges have also been reported across West Africa, where digital inequalities disproportionately affect women because of lower smartphone ownership, financial limitations and reduced participation in formal extension programmes [35,36].

The high demand for weather forecasts and alerts regarding pests and diseases illustrates the significant role of satellite-derived Earth Observation data in promoting climate-smart agriculture. Variability in weather continues to be a primary source of uncertainty in production for rain-fed farming systems, and timely advisories derived from satellites can greatly enhance decisions related to planting, irrigation scheduling, fertilizer management, and pest monitoring. Recent research indicates that the combination of remote sensing, artificial intelligence, and mobile advisory systems markedly boosts farm productivity and resilience among smallholder farmers [37,38]. The preference for SMS, voice messaging, and communication in local languages underscores the necessity of creating gender-responsive agricultural information systems that are tailored to local contexts rather than being solely technology-driven. Prior studies have highlighted that effective digital agriculture initiatives require not just technological advancements but also institutional backing, digital literacy, language adaptation, and inclusive extension services [18,39]. Therefore, incorporating satellite-derived information into current agricultural extension programs could significantly enhance information accessibility while mitigating gender disparities in the adoption of agricultural technologies. The overall findings indicate that satellite technology serves as a feasible means to enhance agricultural information systems for women farmers in Plateau State.

Nevertheless, to fully harness this potential, it is essential to invest in rural digital infrastructure, implement targeted capacity-building programs, foster stronger collaboration among research institutions, extension agencies, and policymakers, and create user-centered digital advisory platforms that cater to the unique needs of women farmers.

CONCLUSION

This study investigated the potential of leveraging satellite-derived Earth Observation (EO) technologies to improve women farmers' access to agricultural information systems in Plateau State, Nigeria. The findings demonstrate that although women constitute a substantial proportion of the agricultural workforce, their access to timely, accurate, and location-specific agricultural information remains limited. Conventional communication channels, particularly radio, agricultural extension officers, and mobile phones, remain the primary sources of agricultural information, while awareness and utilization of satellite-enabled advisory services are still relatively low. The study identified poor internet connectivity, inadequate digital literacy, limited awareness of satellite technology, and high communication costs as the major barriers preventing women farmers from benefiting from modern digital agricultural information systems. Despite

these challenges, respondents expressed strong willingness to adopt satellite-enabled agricultural advisory services when delivered through accessible communication platforms such as SMS, voice messaging, community radio, and local-language extension programmes. The findings further demonstrate that satellite remote sensing has enormous potential to transform agricultural information delivery by providing near real-time information on weather conditions, crop health, soil moisture, pest outbreaks, drought monitoring, and land suitability assessment. When integrated with gender-responsive extension systems, satellite-derived information can substantially improve farm decision-making, agricultural productivity, climate resilience, household food security, and women's socio-economic empowerment.

Overall, the study provides empirical evidence supporting the integration of Earth Observation technologies into agricultural information systems as a strategic pathway towards inclusive digital agriculture and sustainable rural development in Nigeria.

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Conflict of Interest

The authors declare that there are no financial or personal relationships that could have influenced the work reported in this manuscript.

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