INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print); 2222-5234 (Online)
Website: https://www.innspub.net
Email contact: info@innspub.net
Vol. 28, Issue: 3, p. 139-154, 2026

RESEARCH PAPER OPEN ACCESS

Geomatics for forest protection, improved agricultural production and hunger/malnutrition reduction among farm-families in South, South Nigeria

G. O. Nwodo[1], O. J. Ugwu[2], E. U. Onah[3], A. Ugwuoti[3], E. Elijah Ebinne[*3], O. P. Nogheghase[1], S. I. Ogbaa[4], U. E. Ahuchaogu[2], J. I. Ukpabi[4], C. P. Owuamalam-Chidi[4], C. O. Osuagwu[5], M. O. Igwenagu[6], O. E. Mbakaogu[7], J. U. Chikaire[8]

[1]*Department of Geomatics, University of Benin, Benin City, Edo State, Benin*
[2]*Department of Surveying and Geoinformatics, Federal University of Technology, Owerri, Imo State, Nigeria*
[3]*Department of Geoinformatics and Surveying, University of Nigeria, Nsukka, Enugu State, Nigeria*
[4]*Department of Urban and Regional Planning, Federal University of Technology, Owerri, Imo State, Nigeria*
[5]*Department of Agricultural Economics, University of Agricultural and Environmental Sciences, Umuagwo, Imo State, Nigeria*
[6]*Department of Computer Information Systems, Prairie View A&M University, Texas, United States*
[7]*Department of Agribusiness, Federal University of Technology, Owerri, Imo State, Nigeria*
[8]*Department of Agricultural Extension, Federal University of Technology, Owerri, Imo State, Nigeria*

Key words: Characterization, Sequestration, Carbon, Shea parkland, Ivory Coast

Received: February 26, 2026 **Accepted:** March 10, 2026 **Published:** March 15, 2026

DOI: https://dx.doi.org/10.12692/ijb/28.3.139-154

ABSTRACT

This study examined spatial tools for forest protection, agricultural production and hunger/malnutrition reduction in South-South Nigeria. A total of 450 farmers were interviewed with questionnaires and oral discussions. Data collected were analyzed descriptively. Results showed that the geomatics tools for improvement include Geographic Information System (GIS) (91.1%), remote sensing (94.4%), global positioning system (GPS) (97.4%) and others. The agricultural production challenges faced include the use of geomatics tools such as poor knowledge of soil conditions (M= 2.50), unreliable rainfall (M= 2.74), pest/disease outbreak (M= 2.61), land degradation/declining soil productivity (M= 3.81) among others. Geomatics reduces hunger and malnutrition and improves agriculture by production of land suitability maps (M= 3.41), identification of appropriate fertilizers to apply (M= 3.25), identification of drought-prone areas (M = 3.25), provision of weather forecasts (M= 2.91), detection of pests/diseases (M = 2.30) among other roles. It supports forest protection by forest mapping (M = 3.50), monitoring deforestation (M= 3.45), detection of fire outbreaks (M = 3.05), biodiversity conservation (M= 2.84), illegal logging and law enforcement (M= 3.10), and urban encroachment on forest areas (M= 3.45) among other roles. The challenges faced include limited awareness and capacity building (84.4%), weak extension services (87.5%), high cost of technology (91.1%), inadequate infrastructure (94.4%) among others. To address the challenges, the following measures are suggested: use of GIS for site-specific management (87.5%), farm-level decision support systems (94.4%), encourage early warning systems and capacity building/awareness programmes (95.5%).

***Corresponding author:** E. Elijah Ebinne ✉ elijah.ebinne@unn.edu.ng
https://orcid.org/0000-0003-9991-0361

Author:
G. O. Nwodo: https://orcid.org/0000-0002-6418-772X

INTRODUCTION

Geomatics is an interdisciplinary domain that brings together geographic information systems (GIS), remote sensing, global navigation satellite systems (GNSS), and spatial data analysis. This field has become vital for advancing sustainable environmental management and agricultural development. Over recent years, the use of geomatics technologies has increased notably, particularly in tackling global issues like deforestation, reduced agricultural efficiency, and food insecurity. These issues are especially acute in developing areas such as Sub-Saharan Africa, where factors like population growth, environmental degradation, and climate fluctuations place immense stress on both natural resources and food systems.

Forests are essential for supporting rural livelihoods and ensuring food security, particularly in regions like South-South Nigeria, known for its rich biodiversity and dense tropical rainforests.

These forests deliver crucial ecosystem services including soil protection, water management, climate regulation, as well as supplying food, medicinal resources, and fuelwood to rural communities. They also enhance nutrition directly by offering wild food sources and indirectly by bolstering agricultural productivity (Nwokeabia, 2002). Research indicates that closer access to forests correlates with improved dietary diversity and nutritional status among rural residents, illustrating the connection between forest conservation and human health (Rasolofoson *et al.*, 2018).

However, Nigeria's forests are increasingly at risk due to deforestation, illegal logging, agricultural expansion, and infrastructure development. The drive to enlarge cropland, essential for meeting escalating food demands, has emerged as a significant factor contributing to land-use transformations in Nigeria from 2000 to 2020, frequently leading to the degradation of forest ecosystems (Chiaka *et al.*, 2024). This situation creates a complex dilemma where initiatives aimed at boosting agricultural yields might concurrently undermine the ecological systems essential for ensuring long-term food security.

In South-South Nigeria, agricultural activities are mainly performed by smallholder farmers, who depend on traditional farming methods and are particularly susceptible to environmental and economic uncertainties. While the region has substantial agricultural potential, productivity remains low due to challenges like ineffective soil management, limited access to modern farming technology, insufficient infrastructure, and climate-related vulnerabilities. As highlighted by various global and regional reports, hunger and malnutrition persist as critical issues, with millions across Africa facing difficulties in accessing adequate and nutritious food (Rahut, 2023). According to the Food and Agriculture Organization (FAO), food security implies having regular access to adequate, safe, and nutritious food essential for a healthy life (FAO, 2023).

Geomatics presents cutting-edge solutions that effectively merge the protection of forests with agricultural growth and strategies for ensuring food security. Utilizing remote sensing and Geographic Information Systems (GIS), geomatics allows for the real-time tracking of changes in forest coverage, identification of illegal activities, and evaluation of lands suitable for farming.

It plays a crucial role in precision agriculture, enabling farmers to make the most of resources including water, fertilizers, and pesticides, thus boosting crop yields while reducing negative environmental impacts. Furthermore, geospatial technologies enhance decision-making processes by offering accurate, timely spatial data crucial for planning, resource distribution, and policy development (Chukwuma *et al.*, 2024).

The role of geomatics in managing agricultural and environmental concerns is especially significant in South-South Nigeria, where the relationship between forests, agriculture, and rural economies is notably intricate. By promoting sustainable land-use strategies, geomatics can help reconcile the conflicting needs of agricultural development and forest preservation. This approach not only improves agricultural productivity but also strengthens food security and alleviates hunger and malnutrition among farming communities. Consequently, embracing geomatics-driven methods is a vital step toward fulfilling sustainable development objectives related to zero hunger, climate resilience, and the well-being of terrestrial ecosystems.

Despite the wealth of natural resources and favorable climate in South-South Nigeria, the region continues to grapple with serious issues including forest degradation, low agricultural yields, and ongoing hunger and malnutrition among farming families. These challenges are deeply interconnected, often exacerbating each other and perpetuating a cycle of environmental decline and food insecurity. A significant concern is the swift pace of deforestation and degradation of forest areas in the region. Forests are being cleared to make way for agricultural growth, urban expansion, and industrial development, all of which occur without sufficient oversight or sustainable practices. This results in a loss of biodiversity, disruption of critical ecosystem services, and heightened vulnerability to climate change. As forest ecosystems deteriorate, their ability to enhance agricultural productivity diminishes, negatively impacting food supply and the livelihoods of local populations. Additionally, the lack of effective monitoring mechanisms hampers policymakers' and stakeholders' capacity to identify and address environmental changes promptly.

Furthermore, the productivity levels among smallholder farmers are alarmingly low. Many use traditional farming techniques that depend heavily on rain-fed systems and lack mechanization, leading to subpar yields and inefficient resource utilization. Farmers often struggle to access reliable information regarding soil conditions, weather forecasts, and best farming practices, further complicating decision-making and diminishing overall agricultural efficiency. Although Nigeria possesses considerable agricultural potential, the failure to effectively harness this capability has contributed to the persistent issue of food insecurity (Chiaka *et al.*, 2024). Hunger and malnutrition continue to pose significant challenges for rural households in South-South Nigeria, especially among farming families who, despite producing food, often struggle to access diets that are balanced and nutritious. Food insecurity in this area is influenced by not just inadequate food production, but also issues tied to food access, distribution, and utilization.

Economic limitations faced by many rural households restrict their ability to buy a variety of nutritious foods, resulting in poor dietary conditions and heightened vulnerability to malnutrition. This scenario reflects broader trends across Sub-Saharan Africa, where a considerable portion of the population still suffers from hunger and insufficient nutrition (Rahut, 2023).

Moreover, the use of geomatics technologies to tackle these issues remains rather limited in the region. While geospatial tools have shown effectiveness in monitoring environmental shifts and enhancing agricultural decision-making, their implementation in Nigeria faces challenges such as high costs, lack of technical skills, insufficient infrastructure, and low awareness among involved parties. As a result, the full potential of geomatics to bolster forest conservation, improve agricultural productivity, and mitigate hunger and malnutrition has yet to be achieved.

Additionally, there is a notable absence of integrated strategies that bring together forest conservation, agricultural development, and food security initiatives. Current policies and programs often deal with these matters separately, failing to acknowledge their interconnectedness. For example, initiatives aimed at agricultural expansion may disregard the necessity of forest conservation, while those focused on forest protection might not sufficiently take into account the livelihoods of local communities. This disjointed approach diminishes the impact of interventions and hampers sustainable development efforts.

In light of these issues, there is an urgent need for innovative and holistic solutions that utilize geomatics technologies to address the intricate relationships among forest ecosystems, agricultural production, and food security. Such solutions should aim to bolster stakeholders' capacity to leverage geospatial data for informed decision-making, encourage sustainable land-use practices, and enhance access to resources and information for smallholder farmers.

Addressing these challenges is crucial for fostering sustainable agricultural development, safeguarding forest resources, and alleviating hunger and malnutrition among farming families in South-South Nigeria.

This research is essential due to the pressing need to tackle the interconnected issues of forest degradation, agricultural inefficiency, and food insecurity in South-South Nigeria with innovative, sustainable solutions. Geomatics serves as a robust framework for effectively linking environmental monitoring, agricultural planning, and food security assessment. The significance of this study lies in its contribution to environmental sustainability; forests are crucial for ecological stability and agricultural support. Utilizing geomatics technologies, such as remote sensing and GIS, enables the monitoring of deforestation and land-use changes, fostering effective conservation efforts. Moreover, enhancing agricultural productivity for smallholder farmers is vital. Geomatics facilitates precision agriculture through accurate soil and climate mapping, allowing farmers to optimize resources and improve yields. Given agriculture's role in rural economies, boosting productivity is necessary for alleviating poverty.

This study also tackles the imperative issue of food security. By employing geospatial technologies, reliable data on food availability and accessibility can guide targeted interventions to combat hunger and improve nutrition (Chukwuma *et al.*, 2024). Additionally, the findings provide valuable insights for policy formulation and decision-making, aiding government and organizational efforts towards sustainable development. Lastly, it expands academic knowledge by connecting geomatics with forestry, agriculture, and nutrition, underscoring the importance of interdisciplinary approaches in addressing complex challenges.

The main objective of this study is to examine the role of geomatics in forest protection, improved agricultural production, and hunger/malnutrition reduction among farm families in South-South Nigeria. The specific objectives are to: a). identify geomatics technologies in forest protection, improved agriculture and hunger/malnutrition reduction in South-South Nigeria; b). examine perceived agricultural production challenges of respondents in South South, Nigeria; c). ascertain perceived geomatics applications in forest protection in the study area; d). identify geomatics role in improved agriculture for reducing hunger and malnutrition among farm families; e). identify the challenges limiting the adoption of geomatics technologies in the region; f). propose strategies for enhancing the use of geomatics in sustainable environmental and agricultural development.

MATERIALS AND METHODS

The South South, Nigeria, commonly referred to as the Niger Delta, is one of the nation's six geopolitical zones. It comprises six states: Akwa Ibom, Bayelsa, Cross River, Delta, Edo, and Rivers. This area is defined by an extensive system of rivers, creeks, mangrove swamps, and tropical rainforests, establishing it as one of West Africa's most ecologically rich regions. The South-South region holds strategic significance owing to its plentiful natural resources, especially crude oil and natural gas, which play a crucial role in bolstering Nigeria's national income and foreign exchange reserves (Nwilo and Badejo, 2006). From an economic standpoint, the oil and gas sector heavily dominates the region, with significant operations based primarily in states like Rivers and Delta. However, despite its resource wealth, South-South Nigeria grapples with notable socio-economic issues, such as poverty, high unemployment rates, and underdevelopment. This discrepancy is frequently linked to challenges like ineffective governance, environmental degradation, and the unequal allocation of oil revenues (Ikelegbe, 2013). The activities associated with oil exploration have caused major environmental concerns, including oil spills, gas emissions, and a decline in biodiversity, adversely impacting agriculture and fishing, the main livelihoods for many rural inhabitants. The ethnic makeup of South-South Nigeria is diverse, featuring groups including the Ijaw, Itsekiri, Urhobo, Efik, Ibibio, and Edo peoples. This variety fosters a vibrant cultural heritage, showcased through various festivals, traditional structures, and local government practices. Nevertheless, the region has been marred by social unrest and conflicts, often related to resource management, environmental injustices, and the marginalization of youth (Watts, 2008). Agriculture continues to be a significant sector in this region, even as it faces substantial environmental challenges. Commonly grown crops include cassava, yam, oil palm, and plantain, while fishing remains an essential economic activity for coastal communities. Recently, there has been a growing emphasis on sustainable development strategies, such as employing geomatics technologies for environmental oversight, agricultural planning, and managing disaster risks. In infrastructure and development, South-South Nigeria has seen some advancement, especially in urban areas like Port Harcourt and Uyo. Nonetheless, many rural regions still suffer from a lack of essential services, including reliable roads, healthcare facilities, and access to clean water. Initiatives by the government and agencies like the Niger Delta Development Commission aim to tackle these issues, although the pace of progress has been inconsistent.

The quantitative aspect utilizes structured surveys directed at farmers, while the qualitative component encompasses key informant interviews and field observations to gain a richer understanding of the applications and challenges associated with geomatics. This dual approach facilitates a well-rounded exploration of both measurable results and the surrounding contextual dynamics. The study targets farm families, encompassing smallholder farmers, households reliant on forest resources, and agricultural stakeholders within carefully chosen rural communities across the region. These participants are directly engaged in agricultural practices and resource management, making them ideal for evaluating the effects of geomatics technologies including Geographic Information Systems (GIS), remote sensing, and Global Positioning Systems (GPS). A total of 450 participants are included in this research, employing a multistage sampling strategy. Initially, three states are selected intentionally due to their pronounced environmental vulnerabilities and agricultural difficulties. Subsequently, local government areas (LGAs) are randomly chosen within each selected state. Lastly, communities and households are identified through systematic and simple random sampling methods, ensuring a representative sample while minimizing biases. Data gathering is achieved through a combination of primary and secondary sources. Primary data consists of structured questionnaires, interviews, and firsthand field observations. The questionnaires are crafted to collect information regarding farmers' awareness and utilization of geomatics tools, agricultural practices, forest management, and the status of food security. Additionally, interviews with agricultural officers, community leaders, and environmental specialists contribute further insights. Secondary data are sourced from governmental publications, scholarly articles, satellite imagery, and pre-existing geospatial databases. For data analysis, descriptive statistics, including frequencies, percentages, and mean values, are utilized to condense and summarize the responses.

RESULTS AND DISCUSSION

Geomatics tools for forest protection, agricultural production, and hunger/malnutrition

Several geomatics tools exist, as shown in Table 1. A good number of them are very common, while others are not common to many users. However, they exist as important tools for technology, human empowerment, and better livelihoods. These tools include Geographic Information System (91.1%), Global Positioning System (94.4%), Remote Sensing (94.4%), Unmanned Aerial Vehicles (88.8%), Global Mapper (51.1%), Spatial Data (92.2%), Landsat Program Imagery (71.3%), among many more. Geomatics tools-including technologies like Geographic Information Systems (GIS), Remote Sensing (RS), Global Navigation Satellite Systems (GNSS), and Unmanned Aerial Vehicles (UAVs)-are essential in promoting forest conservation, boosting agricultural efficiency, and tackling issues related to hunger and malnutrition. These tools facilitate the gathering, examination, and representation of spatial data, which in turn aids in making informed decisions and managing resources sustainably. When it comes to forest conservation, geomatics tools are extensively utilized for tracking deforestation, assessing forest decline, and monitoring biodiversity. Techniques such as satellite imagery and remote sensing allow for the continuous observation of changes in forest cover, prompt identification of illegal logging activities, and evaluation of wildfire threats. GIS platforms enable spatial evaluations of forest ecosystems, equipping policymakers and conservationists to formulate effective management strategies. For example, time-series data from satellites can highlight deforestation trends in tropical areas, enabling timely corrective measures (FAO, 2020). UAVs also contribute by offering high-resolution imagery for targeted forest monitoring, enhancing oversight and enforcement capabilities. In agriculture, geomatics tools play a pivotal role in enabling precision farming. The integration of GIS and GNSS systems helps farmers analyze soil characteristics, observe crop health, and maximize the effective use of resources such as water, fertilizers, and pesticides. Remote sensing technology aids in evaluating vegetation metrics, like NDVI, that reflect crop health and stress levels. This data empowers farmers to make informed decisions that lead to better yields while minimizing environmental repercussions (Zhang *et al.*, 2019). Furthermore, geomatics tools support climate-resilient agriculture by providing essential data on weather forecasts, drought conditions and flood risk assessments, which are vital for mitigating agricultural losses. These tools also serve a critical function in addressing hunger and malnutrition by strengthening food security frameworks. Spatial analyses assist in pinpointing at-risk populations, mapping food supply chains, and observing trends in food production. Government bodies and humanitarian agencies employ GIS to devise effective food aid logistics and target support in areas suffering from food scarcity. For instance, merging satellite information with socio-economic data can create early warning mechanisms for famine and food crises (WFP, 2021). Additionally, using geomatics for agricultural monitoring ensures a steadier food supply by lowering the risks of crop failures and boosting productivity. In developing areas, such as sub-Saharan Africa, the implementation of geomatics tools can markedly enhance resilience to environmental and socio-economic difficulties. Nevertheless, challenges such as high expenses, limited technical skills, and insufficient infrastructure can obstruct broader adoption.

Agricultural production challenges of respondents

Table 2 showed the agricultural production challenges the respondents face. With a discriminating mean (M) index of 2.50, the following challenges emerged: poor knowledge of soil condition/land suitability (M= 2.50), unreliable rainfall/climatic variability (M= 2.74), pest and diseases outbreaks (M= 2.61), inefficient use of farm inputs (M= 3.62), land degradation and declining soil productivity (M= 3.81), poor access to timely agricultural information (M= 3.50), inadequate irrigation/water management (M= 3.41), weak farm/land use planning (M= 2.94), lack of early warning opportunities (M= 2.88), and weak/ineffective extension advisory and delivery services (M= 2.91). Agricultural production in numerous developing areas, including Nigeria, is confronted with various obstacles such as climate fluctuations, land deterioration, inefficient use of resources, pest infestations, and limited access to timely information. These challenges considerably diminish farm output and jeopardize food security.

Table 1. Geomatics tools for forest protection and hunger/malnutrition reduction

Geomatics tools	*Frequency	Percentage
Geographic Information System (GIS)	410	91.1
Remote Sensing	425	94.4
Global Positioning System (GPS)	425	94.4
Unmanned Aerial Vehicles (UAVs)	400	88.8
ArcGIS	290	64.4
QGIS	310	68.8
Google Earth	324	72.0
ERDAS Imagine	394	87.5
ENVI	281	62.4
Global Mapper	230	51.1
SNAP (Sentinel Application Platform)	245	54.4
AgisoftMetashape	249	55.3
Spatial Database	415	92.2
Open Data Kit	244	54.2
Landsat Program Imagery	321	71.3
SW Maps	250	55.5

*Multiple responses

Table 2. Agricultural production challenges faced by respondents

Agricultural/Farm Challenges	Mean	SD
Poor knowledge of soil condition/land suitability	2.50	0.67
Unreliable rainfall/climatic variability	2.74	0.71
Pest and diseases outbreak	2.61	0.64
Inefficient use of farm inputs	3.62	0.96
Land degradation/declining soil productivity	3.81	1.05
Poor access to timely agricultural information	3.50	0.91
Inadequate irrigation/water management	3.41	1.01
Weak farm/land use planning	2.94	0.84
Lack of early-warning opportunities	2.88	0.74
Weak/ineffective extension/advisory services	2.91	0.60

Accepted mean = 2.50

Nevertheless, advancements in geomatics-an interdisciplinary domain that blends geospatial technologies—provide viable solutions to many of these issues. One significant hurdle is climate variability, which results in erratic rainfall and extreme weather phenomena. Tools within geomatics, including Remote Sensing and Geographic Information Systems, enable farmers and policymakers to observe weather trends, predict droughts or floods, and schedule agricultural activities effectively. Satellite imagery can deliver real-time insights into soil moisture levels, crop health, and rainfall patterns, thus enhancing decision-making (FAO, 2018). Land degradation, characterized by soil erosion and nutrient depletion, presents another serious challenge. By utilizing GIS-based spatial analysis, geomatics assists in pinpointing degraded regions and bolstering precision farming practices. This allows farmers to apply fertilizers, manage irrigation, and implement soil conservation efforts more effectively by targeting specific areas rather than treating entire fields uniformly (Gebbers and Adamchuk, 2010). Additionally, inefficient resource management, especially regarding water and fertilizers, constrains productivity. Geomatics promotes precision agriculture through the integration of GPS-guided systems and geospatial mapping. Innovations like the Global Positioning System facilitate accurate mapping of fields and allow variable-rate application of inputs, minimizing waste and enhancing yields. This not only boosts economic efficiency but also supports environmental sustainability (Zhang *et al.*, 2002). The emergence of pests and diseases also poses a significant risk to crops. Geomatics tools can monitor and predict pest proliferation using spatial modeling and remote sensing insights. Early warning systems founded on geospatial data enable prompt actions, reducing crop losses and reliance on excessive pesticide applications (Atzberger, 2013).

Furthermore, limited access to timely and precise agricultural information remains a major challenge for farmers. Geomatics incorporates mobile platforms and geospatial databases to spread localized information regarding weather forecasts, soil conditions, and market opportunities. This empowers farmers to make well-informed decisions, particularly in rural areas where traditional information networks are lacking (World Bank, 2017). In summary, geomatics is vital in tackling significant agricultural production challenges by enhancing monitoring capabilities, optimizing resource management, enabling early warning systems, and improving the flow of information. Its integration can notably increase productivity, foster sustainable farming practices, and strengthen resilience against various environmental and economic shocks.

Geomatics application in forest protection

Table 3 showed the many ways spatial technologies protect our forest for improved farm productivity and hunger reduction. These ways include forest mapping and resource inventory (M= 3.50), monitoring deforestation and forest degradation (M= 3.45), land use/land cover change analysis (M= 2.98), forest fire detection/management (M= 3.05), biodiversity conservation and habitat monitoring (M= 2.84), illegal logging and law enforcement (M= 3.10), environmental impact assessment (M = 3.43), carbon monitoring and climate change mitigation (M = 3.30), decision support system for forest management (M= 3.25), studying slopes and topography (M= 2.97), estimating forest biomass (M= 2.97), measuring tree heights and canopy structures (M= 3.04), and enhancing early-warning system (M = 3.39), and detecting and preventing illegal encroachment and zoning (M= 3.45). Geomatics, which includes tools like Geographic Information Systems (GIS), Remote Sensing (RS), Global Navigation Satellite Systems (GNSS), and spatial data analysis, has become crucial for safeguarding forests and managing the environment sustainably. Forest ecosystems face growing threats from deforestation, unlawful logging, climate change, and changes in land use. To address these challenges, geomatics offers sophisticated approaches for monitoring, analyzing, and managing forest resources with enhanced precision and effectiveness (Longley *et al.*, 2015). One prominent use of geomatics in forest conservation is through forest monitoring and change detection.

Table 3. Geomatics applications in forest protection

Application in forest protection	Mean	SD
Forest mapping and resource inventory	3.50	0.84
Monitoring deforestation / forest degradation	3.45	0.91
Land use and land cover change analysis	2.98	0.78
Forest protection & management	3.05	1.01
Biodiversity conservation & habitat monitoring	2.84	0.80
Illegal logging and law enforcement	3.10	1.25
Environmental impact assessment	3.43	1.06
Carbon monitoring & climate change mitigation	3.30	0.92
Decision support system for forest management	3.25	0.87
Studying slopes and topography	2.97	0.83
Estimating forest biomass	2.97	0.64
Measuring tree heights and canopy structures	3.04	1.07
Enhancing early warning systems	3.39	1.03
Detecting illegal encroachment and zoning	3.45	0.54

Accepted mean = 2.50

Remote sensing technologies, especially satellite imagery from agencies like the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA), facilitate ongoing surveillance of forest cover across extensive areas. This information enables the identification of patterns related to deforestation, unauthorized land encroachment, and forest deterioration over time. Methods such as the Normalized Difference Vegetation Index (NDVI) and Land Use/Land Cover (LULC) classification are commonly applied to evaluate vegetation health and measure changes within forest areas. By employing time-series analysis, geomatics assists in recognizing trends that support prompt interventions (FAO, 2020).

Another vital application involves forest inventory and biomass estimation. GIS and remote sensing technologies aid in delineating forest boundaries, assessing species diversity, and analyzing structural traits. LiDAR (Light Detection and Ranging) and high-resolution satellite imagery are effective for gauging tree height, canopy cover, and above-ground biomass. These data are crucial for evaluating carbon stocks and implementing climate change strategies, including REDD+ (Reducing Emissions from Deforestation and Forest Degradation) initiatives (Asner *et al.*, 2012). Additionally, GNSS technology enhances the accuracy of field data collection by accurately locating sample sites, allowing this data to be integrated into GIS systems for thorough analysis of forest resources.

Geomatics is crucial for detecting forest fires and managing disasters effectively. Monitoring systems that use satellites can identify thermal anomalies and issue alerts in near real-time regarding forest fires. With spatial data supporting early warning systems, authorities can act swiftly, minimizing harm to forest ecosystems and surrounding communities. Furthermore, geomatics facilitates the modeling of areas at risk for fires by examining factors like vegetation types, landscape features, and climatic conditions. This predictive capability is essential for enhancing disaster preparedness and reducing risks (Chuvieco *et al.*, 2014). In biodiversity conservation, geomatics tools are utilized to create habitat maps, track wildlife movements, and evaluate the health of ecosystems. Habitat suitability models powered by GIS play a critical role in identifying key conservation zones and biodiversity hotspots. By merging spatial data with ecological information, forest managers can establish protected regions and corridors that favor species survival. Additionally, remote sensing aids in recognizing habitat fragmentation and directing restoration initiatives (Turner *et al.*, 2003).

Geomatics also has a significant impact on policy development, planning, and enforcement. Government bodies and environmental organizations leverage spatial data to formulate evidence-based policies and management strategies for forests. Decision support systems driven by GIS help pinpoint areas of high risk, oversee protected territories, and enforce regulations concerning forest usage. For instance, satellite imagery can uncover illegal logging activities, prompting authorities to respond quickly. Moreover, participatory GIS methods empower local communities by integrating them into the processes of forest monitoring and decision-making, thereby enhancing governance and accountability.

Another exciting development is the integration of unmanned aerial vehicles (UAVs), or drones, in forest protection efforts. UAVs deliver high-resolution imagery and real-time data for monitoring small-scale forest areas, especially in hard-to-reach locations. They play a vital role in detecting unlawful activities, evaluating storm damage, and aiding reforestation endeavors.

When UAV data is combined with GIS platforms, it significantly improves the accuracy and promptness of forest assessments (Paneque-Gálvez *et al.*, 2014). However, applying geomatics for forest protection does encounter various challenges, especially in developing nations. These challenges include the high costs of advanced technology, a lack of technical know-how, inadequate infrastructure, and limited access to quality data. Fortunately, the growing availability of open-source GIS software (such as QGIS) and free satellite data from organizations like NASA and ESA is beginning to address these issues. Building capacity and providing institutional support are vital for fully realizing the potential of geomatics in safeguarding forests.

Geomatics roles in hunger/malnutrition reduction

Table 4 showed that geomatics plays a powerful, often under-appreciated role in hunger and malnutrition reduction. With an accepted mean (M) response of 2.50, geomatics play the following hunger/malnutrition reduction roles: production of land/soil suitability maps (M= 3.41), identification of appropriate fertilizer to apply (M= 3.35), identification of drought-prone areas (M= 3.25), identification of location-specific climatic advisory services (M= 3.04), and early detection of crop stress (M= 3.14), mapping of diseases/pests infestation hotspots (M= 3.30), monitoring of crop/animal pests/diseases (M= 2.90), mapping out soil conservation/restoration areas (M= 2.85), monitoring land use/land cover changes (M= 2.77), mapping of surface ground-water potentials (M = 3.05), supports land layout/designs (M= 2.97), track changes in land (M= 2.84), provision of weather records (M= 2.91), detection of erosion salinity (M= 2.89), monitors deforestation (M= 2.74), and detects areas needing nutrient application (M= 3.01). Hunger and malnutrition continue to be significant global issues, especially in sub-Saharan Africa and certain areas of Asia, where countless individuals experience food insecurity each year (FAO, IFAD, UNICEF, WFP and WHO, 2023).

Table 4. Geomatics roles in hunger/malnutrition reduction

Geomatics roles	Mean	SD
Production of land/soil suitability maps	3.41	0.94
Identification of appropriate fertilizer to apply	3.35	0.84
Identification of drought-prone areas	3.25	0.74
Provision of location-specific climate advisory services	3.04	1.05
Early detection of crop stress	3.14	1.01
Mapping of infestation hotspots	3.30	0.91
Monitoring of crop/animal pests/diseases	2.90	0.83
Mapping out soil conservation/restoration areas	2.85	0.77
Monitoring land-use/land cover changes	2.77	0.64
Mapping of surface & groundwater potential	3.05	0.65
Supports land layout/designs	2.97	0.51
Track changes in farmland	2.84	0.63
Provision of weather records	2.91	0.53
Detection of erosion, salinity	2.89	0.52
Monitors deforestation & encroachment	2.74	0.45
Detects areas needing nutrient application	3.01	0.65

Accepted mean = 2.50

Conventional methods for addressing hunger generally include food distribution, agricultural subsidies, and nutrition initiatives. However, the incorporation of geomatics—the discipline focused on the collection, storage, processing, and dissemination of geographic information—holds considerable promise for enhancing food security outcomes (Miller and Goodchild, 2015).

By utilizing tools such as Geographic Information Systems (GIS), Remote Sensing (RS), Global Navigation Satellite Systems (GNSS), and spatial data analytics, geomatics facilitates a deeper comprehension, strategic planning, and oversight of the elements affecting food production, distribution, and accessibility. A crucial way geomatics aids in the fight against hunger is through its support for agricultural planning and management via spatial analysis. Satellite-derived remote sensing data enables ongoing assessment of land conditions, plant health, and soil moisture, thereby providing vital insights into crop growth cycles and stress factors like drought (Zhang *et al.*, 2022). For instance, Normalized Difference Vegetation Index (NDVI) maps produced from satellite images can reveal areas with diminishing biomass, helping agronomists and policymakers to pinpoint regions likely to experience low yields well ahead of harvest time.

Additionally, GIS-generated soil property maps, combined with field data, can identify where interventions for soil fertility are most crucial, improving the accuracy of fertilizer use and minimizing waste (Gebbers and Adamchuk, 2010). These implementations enhance the efficiency and output of agricultural systems, which directly influences food availability. In addition to production, geomatics tools also boost decision-making processes related to food distribution and logistics. Spatial modeling can optimize supply chains by mapping essential infrastructure such as roads, storage facilities, markets, and transportation networks. By uncovering connectivity gaps and travel times, GIS aids in directing resources to the areas where they are most needed, ensuring that food aid reaches at-risk populations more swiftly and cost-effectively (D'Haese *et al.*, 2020). During emergency situations, such as those following natural disasters, geospatial data can assist humanitarian organizations in identifying the safest and quickest routes, ultimately enhancing the delivery of critical supplies and reducing disruptions within food systems.

Access to food is a critical area where geomatics has demonstrated significant influence. By merging socioeconomic information with geographical data, we can pinpoint food deserts—regions where residents have limited access to affordable and nutritious food (Beaulac *et al.*, 2009). Policymakers have the opportunity to implement strategies like mobile markets or encourage retail development in these underserved areas, thereby addressing nutritional inequalities through targeted planning informed by GIS analysis. In urban settings, spatial statistics can uncover patterns of inequality by linking food access with factors such as income, education, and demographics, which helps shape equitable policy initiatives (Morland *et al.*, 2002). The integration of geomatics greatly enhances policy formulation and oversight. There is a growing trend among governments and development organizations to incorporate spatial data into national food security plans. This approach enables them to forecast the potential effects of policy decisions under different climatic and socioeconomic scenarios.

For example, scenario modeling allows stakeholders to assess how climate change might influence future food yields and determine which regions may be most at risk of reduced production. Such insights contribute to building resilience, such as promoting drought-resistant crops within vulnerable communities (Rosenstock *et al.*, 2019). Additionally, GIS tools improve monitoring and evaluation by facilitating near-real-time assessments of program impacts. Spatial dashboards can display vital indicators like malnutrition rates, variations in food prices, and crop performance across different regions, aiding in adaptive management and ensuring accountability. By incorporating crowdsourced and participatory GIS, the process of data collection becomes more decentralized and enriches local knowledge. Smallholder farmers and community members can utilize mobile apps to share geotagged information about crop health, water availability, and food shortages. This grassroots approach not only deepens the data's specificity but also guarantees that local insights contribute to broader analyses (Sieber and Johnson, 2015). Such participatory strategies enhance community involvement and empower people to seek interventions based on concrete evidence rather than mere assumptions (Battersby and Peyton, 2014).

Institutional/Technical barriers to use of geomatics for forest protection, improved agricultural production and hunger/malnutrition reduction

Table 5 revealed that several challenges affect the use of geomatics. These include limited awareness and capacity building (84.4%), weak extension services (87.5%), limited government support (82.2%), poor institutional coordination (89.1%), high cost of technology (91.1%), inadequate infrastructure (94.4%), complexity of tools (70.6%), limited access to high-resolution data (98.0%), and maintenance/technical support (77.7%). Geomatics, which involves the gathering, analysis, and interpretation of geographical data through tools like Geographic Information Systems (GIS), Remote Sensing (RS), and Global Navigation Satellite Systems (GNSS), offers considerable potential for improving environmental conservation, boosting agricultural efficiency, and enhancing food security. Nevertheless, the actual implementation of geomatics technologies faces a multitude of institutional and technical hurdles that limit their effectiveness, particularly in developing nations. One of the major institutional challenges hindering the adoption and sustainable use of geomatics technologies is the absence of supportive policy frameworks and regulatory guidance that prioritize geospatial data within national developmental strategies (Khadka and Bhatta, 2020). Numerous governments lack comprehensive plans for incorporating geomatics into forest monitoring or agricultural management, leading to inconsistent execution and overlapping efforts among different agencies.

Table 5. Institutional/Technical barriers to use of geomatics for forest protection

Institutional/Technical barriers	*Frequency	Percentage
Limited awareness and capacity building	380	84.4
Weak extension services	394	87.5
Limited government support	370	82.2
Poor institutional coordination	401	89.1
High cost of technology	410	91.1
Inadequate infrastructure	425	94.4
Complexity of tools	318	70.6
Limited access to high-resolution data	441	98.0
Maintenance / technical support	350	77.7

*Multiple responses

Additionally, constrained funding and resource distribution limit the ability to acquire modern technology and create the necessary data infrastructure for widespread applications (Mbuli *et al.*, 2022). These financial limitations are further exacerbated by poor institutional coordination among forestry departments, agricultural ministries, and disaster response agencies, often resulting in isolated data and ineffective decision-making. Another significant institutional obstacle is human resource capacity. The successful utilization of geomatics relies on skilled professionals who can analyze intricate datasets. However, many regions encounter a deficit of qualified personnel due to a lack of educational opportunities and inadequate investment in training initiatives (Nguyen *et al.*, 2021). Even in areas with trained experts, the phenomenon of brain drain, where skilled individuals migrate to better-funded institutions or countries, further undermines local capabilities.

Significant technical challenges continue to hinder the effective use of geomatics. One notable issue is the accessibility and quality of data. In many low-income countries, high-resolution satellite imagery and pertinent geospatial datasets can be prohibitively expensive or difficult to obtain. This limitation adversely affects timely and precise land cover analysis and crop surveillance (Zhang *et al.*, 2023). Furthermore, discrepancies in data formats and software ecosystems complicate the process of sharing and integrating information, which impedes collaborative initiatives across different sectors (Shiferaw *et al.*, 2020). In rural areas, restricted internet access and inadequate computing infrastructure exacerbate these issues, making it difficult to utilize cloud-based GIS solutions and real-time analytics necessary for precision agriculture and forest fire monitoring. Another challenge pertains to the reliability of remote sensing in certain environments. For instance, consistent cloud cover can obstruct optical satellite images, significantly hampering efforts to monitor tropical forests (Kerekes, 2021). Although radar and LiDAR technologies can address some of these challenges, their high expense and complexity limit their broad implementation. The ramifications of these institutional and technical obstacles significantly affect food security and efforts to alleviate hunger. Without effective geomatics systems in place, governments find it challenging to monitor crop conditions, anticipate yield declines, or respond proactively to instances of food scarcity. Likewise, forest degradation driven by illicit logging or climate change may remain unnoticed, threatening essential ecosystem services that are crucial for sustainable agriculture and livelihoods.

Table 6. Geomatics–based strategies to reduce hunger/malnutrition

Geomatics-based strategies	*Frequency	Percentage
Use GIS for site-specific management	304	67.5
Build farm-level decision support system	425	94.4
Encouraging early-warning / risk monitoring	410	91.1
Land use planning & soil conservation	420	93.3
Targeted extension/advisory services	449	99.7
Access to high-impact geospatial data	394	87.5
Capacity building/awareness programme	430	95.5
Improve market system with GIS	441	98.0

*Multiple response

Geomatics-based strategies to reduce hunger/ Malnutrition

Table 6 indicates that challenges to the use of geomatics could be overcome by the following strategies: Use of GIS for site-specific management (67.5%), build farm-level decision support system (94.4%), encouraging early warning / risk monitoring (91.1%), land use planning/ soil conservation (93.3%), targeted extension/advisory services (99.7%), access to high-impact geospatial data (87.5%), capacity building/awareness programme (95.5%), and improve market system with GIS (98.0%). Geomatics is an integrated set of technologies, including Geographic Information Systems (GIS), Remote Sensing (RS), Global Navigation Satellite Systems (GNSS), and spatial modeling. These tools are invaluable for monitoring, planning, and managing natural resources effectively. By strategically applying geomatics, we can make significant strides in addressing hunger and malnutrition, improving agricultural yield, and safeguarding forest ecosystems by providing timely spatial information for informed decision-making. A key approach is leveraging remote sensing and GIS in precision agriculture. Satellite and aerial imagery facilitate the observation of crop health, soil moisture, and nutrient levels across vast agricultural areas (Basso *et al.*, 2020). When this information is combined with weather and soil data, farmers and policymakers can pinpoint regions with suboptimal productivity and implement targeted measures like specific fertilizer application or optimized irrigation. This method not only enhances crop performance but also conserves resources, which bolsters food availability and reduces expenses for smallholder farmers (Gebbers and Adamchuk, 2018). These advancements directly help in diminishing the prevalence of hunger and malnutrition by stabilizing and improving access to food supplies. Furthermore, geomatics plays a crucial role in early warning systems aimed at food security. Analyzing satellite data over time enables the detection of drought trends, pest invasions, or extreme weather occurrences, giving authorities the chance to predict crop failures and enact preventative strategies-such as emergency food distribution or adaptive farming recommendations—before conditions worsen (Thornton *et al.*, 2019). In addition, GIS-based vulnerability mapping can identify communities at a heightened risk of food insecurity, allowing for targeted nutritional programs and resource allocation to counteract malnutrition effectively.

In the field of forestry, geomatics serves as an essential tool for monitoring and safeguarding forest ecosystems. Employing earth observation technologies allows for near-real-time evaluations of changes in forest coverage, thus facilitating the swift identification of deforestation and illegal logging (Hansen *et al.*, 2013). By analyzing spatial data related to forest loss alongside socio-economic factors, stakeholders can make informed decisions for conservation efforts and advocate for the enforcement of sustainable land management practices (Lawrence *et al.*, 2021). Moreover, the incorporation of LiDAR (Light Detection and Ranging) data significantly improves assessments of forest structure and biomass, enhancing the precision of carbon stock estimations and bolstering climate change mitigation strategies. Another important application of geomatics lies in land use and land cover (LULC) modeling. By tracking developments such as agricultural expansion, urban sprawl, and forest degradation, geomatics contributes to sustainable landscape planning that seeks to harmonize agricultural growth with ecosystem preservation (Turner *et al.*, 2021).

For instance, spatial decision support systems can help in targeting areas for agroforestry initiatives that integrate tree cultivation with crop farming-promoting soil health, bolstering food security, and safeguarding biodiversity at the same time. To fully leverage the advantages of geomatics technologies, it is crucial for governments and organizations to focus on building capacity, creating data-sharing platforms, and offering open-access geospatial information. Enhancing the technical skills of local communities ensures the successful integration of spatial analysis into agricultural and conservation endeavors. Additionally, open data initiatives help make important geospatial resources accessible, empowering smallholder farmers, NGOs, and community planners to base their choices on data-driven insights (Elwood *et al*., 2020).

CONCLUSION

This research highlights the significant role that geomatics can play in promoting sustainable development across South-South Nigeria. By facilitating accurate monitoring of forest resources, geomatics tools can aid in effective forest conservation, diminish environmental degradation, and bolster ecosystem resilience. In the agricultural sector, advances in GIS, remote sensing, and GPS technology lead to improved land management practices, optimized resource usage, and enhanced crop production. These improvements ultimately contribute to greater food availability for farming households. Additionally, utilizing spatial data in food security and nutritional strategy planning enables more focused actions to alleviate hunger and malnutrition, especially among at-risk families. However, the uptake of geomatics is hampered by various institutional and technical challenges, such as limited infrastructure, insufficient training opportunities, and a lack of awareness among local agricultural practitioners. Overcoming these obstacles requires investment in capacity building, supportive policies, and collaboration among stakeholders to unlock the full potential of geomatics in the area. In summary, this study emphasizes that when implemented effectively, geomatics can serve as an impactful resource for enhancing environmental sustainability, agricultural efficiency, and nutritional health, thus helping to create resilient and food-secure rural communities in South-South Nigeria.

REFERENCES

Asner GP, Clark JK, Mascaro J. 2012. High-resolution mapping of forest carbon stocks in the Colombian Amazon. Biogeosciences **9**, 2683–2696.

Atzberger C. 2013. Advances in remote sensing of agriculture: context description, existing operational monitoring systems and major information needs. Remote Sensing **5**(2), 949–981.

Basso B, Cammarano D, Ritchie JT. 2020. Remote sensing applications in precision agriculture. Journal of Agricultural Science **12**(3), 45–60.

Battersby J, Peyton S. 2014. The geography of urban food insecurity in Cape Town, South Africa. South African Geographical Journal **96**(1), 1–23.

Beaulac J, Kristjansson E, Cummins S. 2009. A systematic review of food deserts, 1966–2007. Preventing Chronic Disease **6**(3), A105.

Chiaka JC, Zhen L, Xiao Y, Hu Y, Wen X, Muhirwa F. 2024. Spatial assessment of land suitability potential for agriculture in Nigeria. Foods **13**(4), 568.

Chukwuma EC, Afolabi OOD, Okonkwo CC, Olamigoke OO, Okonkwo CE. 2024. Application of geospatial technology and decision model in the development of improved food security index. Scientific Reports **14**, 30204.

Chuvieco E, Giglio L, Justice C. 2014. Global characterization of fire activity: toward defining fire regimes from Earth observation data. Global Change Biology **20**(2), 345–365.

D'Haese M, Vandeplas A, Speelman S, Van Campenhout B. 2020. A GIS-based approach to improve food distribution networks in rural areas. Journal of Spatial Science **65**(2), 243–259.

Elwood S, Goodchild MF, Sui DZ. 2020. Prospects for open access geospatial data. Transactions in GIS **24**(1), 1–20.

FAO, IFAD, UNICEF, WFP, WHO. 2023. The state of food security and nutrition in the world 2023. Food and Agriculture Organization of the United Nations.

FAO. 2018. The state of food and agriculture: migration, agriculture and rural development. Food and Agriculture Organization of the United Nations.

FAO. 2020. Global forest resources assessment 2020. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2023. Food security definition and concepts. Food and Agriculture Organization of the United Nations.

Gebbers R, Adamchuk VI. 2010. Precision agriculture and food security. Science **327**(5967), 828–831.

Gebbers R, Adamchuk VI. 2018. Precision agriculture and food security. Science Advances **4**(8), eaar1379.

Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova S, Tyukavina A, Townshend JR. 2013. High-resolution global maps of forest cover change. Science **342**(6160), 850–853.

Ikelegbe A. 2013. The politics of oil resource conflicts in the Niger Delta region of Nigeria. African Studies Review **56**(1), 123–143.

Kerekes J. 2021. Remote sensing limitations in tropical environments. International Journal of Remote Sensing **42**(6), 2150–2167.

Khadka R, Bhatta B. 2020. Challenges and opportunities in the integration of GIS in environmental management. Journal of Geospatial Science **8**(2), 123–135.

Lawrence D, Saha S, Sanchez M. 2021. Linking satellite data and forest conservation policy. Environmental Research Letters **16**(4), 045015.

Longley PA, Goodchild MF, Maguire DJ, Rhind DW. 2015. Geographic information science and systems. Wiley.

Mbuli TR, Chirwa PW, Moyo S. 2022. Institutional constraints to geospatial technology adoption in sub-Saharan Africa. African Journal of Science, Technology, Innovation and Development **14**(1), 45–57.

Miller HJ, Goodchild MF. 2015. Data driven geography. GeoJournal **80**, 449–461.

Morland K, Wing S, Roux AD. 2002. The contextual effect of the local food environment on residents' diets: the Atherosclerosis Risk in Communities study. American Journal of Public Health **92**(11), 1761–1768.

Nguyen LT, Tran DT, Pham HT. 2021. Capacity building for GIS applications in agriculture: barriers and strategies. Journal of Agricultural Informatics **12**(3), 78–89.

Nwilo PC, Badejo OT. 2006. Impacts of oil spills along the Nigerian coast. Association for Environmental Health and Sciences Journal **8**(2), 95–100.

Nwokeabia OD. 2002. Forestry and food security in Nigeria. Food and Agriculture Organization.

Paneque-Gálvez J, McCall MK, Napoletano BM. 2014. Small drones for community-based forest monitoring. Remote Sensing **6**(12), 12885–12912.

Rahut DB. 2023. Agricultural practices and food security in developing countries. Sustainable Agriculture Studies.

Rasolofoson RA. 2018. Impacts of forests on children's dietary diversity. Frontiers in Sustainable Food Systems.

Rosenstock TS. 2019. The future of food and agriculture: Trends and challenges. Annual Review of Environment and Resources **44**, 431–463.

Shiferaw A, Tesfaye K, Belay K. 2020. GIS data integration challenges in multi-sectoral planning. Geoinformatics Journal **6**(1), 89–102.

Sieber R, Johnson PA. 2015. Place, participation and geographic information: a historical exploration of public participation GIS (PPGIS). In: Craglia M, McLaren R, Weiner D (Eds), Spatially enabled society, Springer, 41–66.

Thornton PK, Ericksen PJ, Herrero M, Challinor AJ. 2019. Climate variability and food security risk. Annual Review of Environment and Resources **44**, 117–144.

Turner BL, Lambin EF, Reenberg A. 2021. The emergence of land change science for sustainable landscape planning. Proceedings of the National Academy of Sciences **118**(7), e2018177118.

Turner W, Spector S, Gardiner N. 2003. Remote sensing for biodiversity science and conservation. Trends in Ecology and Evolution **18**(6), 306–314.

Watts M. 2008. Blood oil: The anatomy of a petro-insurgency in the Niger Delta, Nigeria. Foucault Studies **5**, 50–80.

World Bank. 2017. ICT in agriculture: Connecting smallholders to knowledge, networks, and institutions. World Bank Publications.

World Food Programme (WFP). 2021. Hunger map and early warning systems. Rome: WFP.

Zhang C, Kovacs JM. 2019. The application of small unmanned aerial systems for precision agriculture: A review. Precision Agriculture **20**(2), 1–20.

Zhang N, Wang M, Wang N. 2002. Precision agriculture: A worldwide overview. Computers and Electronics in Agriculture **36**(2–3), 113–132.

Zhang X. 2022. Remote sensing and crop yield estimation: a review. Agronomy **12**(3), 550.

Zhang Y, Zhao L, Wang X. 2023. Access to satellite imagery and its impact on precision agriculture adoption. Remote Sensing Letters **14**(4), 367–379.