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Applications of remote sensing technology in agriculture: A review of contributions to food security challenges and strategies in developing countries

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Abstract

In the agricultural sphere, particularly in developing countries where food security is still a major concern, remote sensing technology has also surfaced as an important tool. In this review, the usages of remote sensing in agricultural areas and its contributions to food security are surveyed; The overall framework is illustrated dynamically by indicating available image platforms that were instrumental for agriculture application paradigms. This research identifies certain areas where some selected case studies and existing literature are reviewed to serve as proof that remote sensing technology has been tremendously impactful. Areas like crop monitoring, yield prediction, or natural resource management have been very well reported by the literature review process adopted. This field analysis of related studies used highly sophisticated RS sensor data. The challenges like data availability, technological limitations, and socio-economic factors have been discussed besides the strategies, for instance, capacity building, policy interventions, and prospects for technological advancements. These results underscore the vitality and adoption of remote sensing technologies in agricultural practices and policies which is the key driver of improved food security in developing countries.

Keywords: Remote sensing; Agriculture; Food security; Developing countries; Applications; Challenges; Strategies

1. Introduction

Agriculture is the backbone of many Least Developed Countries (LDC) economies, which serves as a substantive source of livelihood for huge sections of their people and constitutes large percentages of Gross Domestic Product (GDP), the national revenue stream [1]. However, the agriculture space is besieged by numerous problems manifested due to climate variability, shrinking resources, and mounting population pressures. A major danger that these difficulties represent, generally in countries of low agricultural productivity: is due to be acknowledged for operating a menace to global food security [2].

The answer to these hurdles encountered is remote sensing technology integration. Remote sensing technology uses sensors placed on satellites, drones/UAVs, or aircraft to capture information from the Earth´s surface and atmosphere without direct physical contact [7]. With its ability to acquire high spatiotemporal and spectral resolution data at regional scales, the Sentinel program has been able to monitor agricultural landscapes of large areas in great detail, providing information ranging from crop health status, soil parameters estimates, water availability or land cover/use [6].

This paper focuses on the vast extension of remote sensing technology and its possible application to agriculture in developing countries. Specifically, this research will focus on the use of remote sensing technology in agriculture (drought monitoring, precision farming, etc.), how it has affected food security globally or how it can help promote it;

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challenges faced during application, implementation and possible ways out that could be embraced so as not to prevent its potential benefits from being enjoyed.

The application of remote sensing mapping in agriculture could vary from crop monitoring, identification, and detection of pests and diseases, assessment of soil health conditions, or even yield prediction through natural resource management, as observed by [5]. Such applications are useful in guiding farmers and policy makers with the information necessary to make well-informed decisions that will help optimize resource utilization vis-à-vis farm production.

Many challenges prevent the efficient use of remote-sensing technology to realize its potential within developing countries. The scarcity of data, limited technological infrastructure, complexity cost and lack of technically adept manpower are leading hindrances of remote sensing technology for advanced agricultural purposes [4]. Socio-economic factors also contribute to the challenges faced by smallholder farmers, and also resource constraints in communities, create limited awareness, as well as capacity constraints.

Given these challenges, comprehensive strategies are needed to address all the barriers to improve the use of remote sensing technology in agriculture. Broad-based strategies could include long-term capacity-building programmes, focused investments in infrastructure and technology, policy initiatives to facilitate knowledge propagation and transfer of technologies across the regions, and developing public-private partnerships (PPP) between government agencies/academic institutions/industry stakeholders [4,3].

Given the imperatives of solving these challenges and tapping into the promise of remote sensing, developing countries can improve agricultural productivity while minimizing resource consumption leading to improved food security for millions. This paper aims to extend the discussion on utilizing remote sensing technology as a transformative instrument in agriculture and development, promoting the enhancement of sustainability and resilience amidst changing global conditions

2. Methodology

A systematic methodology consisting of a thorough review of agricultural remote sensing literature is implemented, resulting in this study providing a picture that reflects on the applications and contributions as well as challenges and strategies using examples mainly from developing countries. Academic journal articles, research papers, conference proceedings, books, and reports are vital assets.

Further, this study also integrates learning from case studies and examples across regions of the world. They also provide concrete examples of the application and effects of new technologies for remote sensing in agriculture, thereby offering important lessons on leverage within real ecosystems which, are as diverse as the challenges faced. Case studies were selected based on considerations of diversity, agroecological relevance, and quality (related to data available for remote sensing applications) such as indicators adopted in each context.

This work is a product of opinions and reports gathered from environmental organizations, and stakeholders, proficient in remote sensing technology & agricultural development. International institutions such as the Food and Agriculture Organization (FAO), are introduced to complement this literature review with other viewpoints that address these issues. Similarly, the World Bank and regional agricultural research institutions are important sources of information on data, analysis reports, and policy recommendations about the application of remote sensing in agriculture.

This research paper is based on an analysis and discussion of the synthesis of literature review study results, findings from case studies; and expert opinions. Amalgamating information from multiple sources, the approach aimed at offering a holistic appraisal of the vitality of remote sensing technology, for agriculture and food security; why its uptake presents challenges; residual strategies that can be applied to augment or modify prevailing adoption behaviours.

In conclusion, the methodological framework utilized in this study aims to guarantee rigor, completeness, and relevance when studying agricultural remote-sensing technology within developing countries. This article contributes to knowledge and evidence-based policy, practice in agriculture development by synthesizing various sources of evidence.

Relying on a case study of East African countries, the author supports this assertion by using real-world examples to demonstrate how remote sensing technologies can be realized and deliver social benefits in an agricultural context while discussing the challenges and constructive experiences from different sectors. The choice of case studies provided an optimized geographic representativeness, diversity in agricultural typologies, and available RS application datasets.

3. Application of Remote Sensing Technology in the Agricultural Sector through Case Studies from East Africa

3.1. Case 1

Rekha Bommanahal Chief of the Soil Health and Plant Nutrition Division at ICRISAT shared from Kenya: Enhancing crop monitoring & management "In Kenya, it is already in practice for Crop Monitoring Matters with smallholder farming using technologies like remote sensing. In a study by [16], farmers can assess their crop health and vegetation dynamics using satellite imagery to plan irrigation scheduling, pest management decision-making for disease control purposes, and fertilizer application. Farmers used this information to improve resource efficiency resulting in improved agricultural productivity, across different agroecological zones ranging from highlands (area with above 1500m elevation) through the arid/semi-arid regions.

3.2. Case 2

FAS: Tanzania: Mapping Land Use and Land Cover Changes Satellite imagery has been used to map land use/land cover change in the United Republic of Tanzania, providing insight into changing agricultural patterns and landscape dynamics. [15]. Observed land cover change using satellite imagery to identify those regions that have experienced deforestation, urban expansion, and agricultural encroachment. The results aided farmers in land use planning initiatives and guided policy actions promoting sustainable agricultural practices to prevent land degradation. This research underscored the value of remote sensing for tracking land cover change over a broad range of geographic areas, both near margins and in more terrestrial locations such as Tanzania's savannas.

3.3. Case 3

Uganda is applying Remote Sensing in soil moisture assessment to increase water management. Remote Sensing technology such as satellites, has made it possible to understand the soil moisture levels towards an optimal water management strategy within areas with agricultural activities. [17], estimated soil moisture content across various agroecological zones, such as humid highlands to semi-arid regions using satellite-based remote sensing data streams between 2016 and 2023. Farmers could then use this information to irrigate crops more precisely and efficiently, saving water resources while boosting their yields. The study revealed the need for remote sensing applications to combat water scarcity and climate variability in the agricultural sector, of Uganda.

3.4. Case 4

Ethiopia: Remote sensing has greatly contributed to monitoring crop yield and food security prediction over the years. A study by [14], used a combination of satellite imagery and machine learning algorithms to forecast crop yield outcomes in major staple crops — maize, wheat, and teff. These predictions are intended to serve as an early warning system for identifying potential food crises, allowing action in due time through measures such as urgent assistance or support programs related to agriculture. It was proof of concept that clearly illustrated the sensitivity, and societal value of remote sensing for food security monitoring and response in diverse agro-climatic regions, from highlands to lowlands.

The study attempts to represent applications and impacts that are diverse across agricultural settings expressed through various cases. Remote sensing in agroforestry processes such as crop monitoring, water management, land-use changes, and, yield prediction, underscores its potential as a tool that can enhance the region's productivity and sustainability.

Findings drawn from the above case studies of East African countries reveal numerous applications in agriculture such as crop monitoring, pest and disease identification, soil analysis, and yield prediction. The significant role played by these applications in increasing agricultural productivity, efficient management of resources, and weather-induced risks has been discussed. Barriers hindering the adoption of remote sensing in developing countries, prescriptions, the uptake Capacity-building, policy support, public-private partnerships, and technological innovations are among the measures identified as vital to address these challenges.

4. Prospects of Remote Sensing Applications in East African Agriculture

4.1. Crop Monitoring

Remote sensing technology allows real-time assessment of crop health, and their growth dynamics over vast agricultural land mosaics. The deleterious effect of stress on growth and yield is mitigated by delivering the right quantity of supplementary irrigation for the complete growing season [24]. ORIZA IRRIGATION LLC recommends a vigorous analysis between satellite imagery, and vegetation indices to reveal areas where there are severe farm problems which advice on actions such as crop spray, or treatment needs, enabling different actions ITICAL REVIEW OF RELATED LITERATURE The technological development has helped farmers today define settlement, recommend practices such as proper-irrigation scheduling, and applications of nutrients using better-improved data from remote sensing methods like LANDSAT – TM funded programmes. This proactive crop monitoring methodology enhances productivity by taking timely action and optimal utilization of resources.

4.2. Pest and Disease Detection

Early detection and monitoring of pests and diseases in crops is an important task where remote sensing plays a critical role. Farmers put in place interventions by detecting anomalies associated with pest invasion or disease outbreaks through spectral signatures and thermal imagery analysis thus, reducing potential losses [16]. Remote sensing technology leverages pest and disease control as an effective tool that reduces potential yield losses in plants.

Soil Analysis — Non-invasive soil analysis remotely senses the condition of soils and can reveal properties such as their chemical composition, acidity, alkalinity (pH), fertility level, etc. Incorporation of multispectral and hyperspectral data can provide a broader understanding of soil variables including moisture content, nutrient density & quality, pH value & texture which are useful for landscape management practices such as land planning in agriculture [17]. The information enables farmers to go for specific site management and precision farming, which increases resource use efficiency in the extreme cases of nutrient utilization, where soil health is also a benefit.

4.3. Yield Prediction

Remote sensing-based models can provide established information on how the yield of crops such as wheat can be predicted and anticipated by farmers or policymakers to plan out future crop production levels. Satellite imagery, weather data, and machine learning algorithms with plantation prediction models can be used to create an early warning system for predicting the increased likelihood of food crises. These tools could also help decision-makers make the right decisions, [14]. Predicting yield in advance is useful for ensuring food security by administering timely interventions and allocating resources.

4.4. Farm Productivity, Resource Efficiency, and Climate Risk Immunization Contributions

East Africa's significant agricultural productivity improvements, better resource use efficiency, and risk mitigation from crop failure due to climate variability are of utmost importance. It helps farmers make the right and timely decisions for better maintenance of their crops by offering them information about crop health, soil conditions, and weather requirements among other things. This helps in guiding precision agriculture methodologies. A positive result could be increased crop yields, resource use efficiency, improved resilience to climate variability, enhanced food security, and necessary livelihoods in the region [15].

4.5. Challenges and Approaches for Ubiquitous Adoption

While remote sensing technology provides an enormous range of benefits, its adoption in developing countries such as East Africa is still surrounded by hurdles. Some of the main bottlenecks that act as barriers to integrating remote sensing technologies into agricultural practices are limited accessibility to data–technology, poor infrastructure, and human resources [4]. To address these challenges, targeted strategies are required:

4.6. Capacity Building

Training and capacity-building programs are essential for increasing the technical expertise in remote sensing technologies and their applications, i.e., farmers, investigators, and extension workers. The training effort should be directed toward understanding the data interpretation, image processing techniques, and use of remote sensing tools for agricultural decision support [17].

4.7. Policy Support

The adoption of remote sensing technologies is voted low in the pyramid, however, it deserves a higher category because no service could be developed if there were no satellite or drone images at our disposal. Enabling the environment through governments and policymakers plays a big role. Appropriate actions that involve policy development supportive of remote sensing for agriculture, regulations, and incentives together with facilitation with a focus on access to data and technology infrastructure [3].

4.8. Public-Private Partnerships

To make the most out of public resources, and harness expertise and technology, remote sensing technologies, should be adopted on a large scale with cooperation among government agencies, research institutions, private sector stakeholders, and civil society organizations in agriculture. Potentially, there is value in public-private partnerships ranging from knowledge-sharing, technology transfer, and solution experience perspective [4].

4.9. Technological Innovations

Further developments in the remote sensing area, especially low-cost sensors [4]., unmanned aerial vehicles (UAVs), and mobile applications are crucial to lowering the barriers to the implementation of changing needs and will also foster access to these tools.

In conclusion, these strategies are intended to guide East African countries in ensuring the effective use of RS technology, for sustainable agricultural development and food security by integrating crop and its management knowledge, enhancing resource utilization efficiency; minimizing yield loss due to climate variability, and ultimately helping region promote sustainable agriculture.

4.10. Main Observation and Relevance of Remote Sensing in Dealing with Food Safety Challenges

In developing countries, remote sensing is making invaluable contributions to resolving food security challenges via timely and accurate information to aid in decision-making for agricultural practices. Based on the study of satellite photos and data from other remote sensing systems, several important conclusions were obtained to determine such a useful tool for agricultural activities. Information technology based on optimization in our sphere improves farming practices significantly, thus optimizing resource management processes and effectiveness in agriculture development.

4.11. Enhance Agricultural Practices

With remote sensing technology, data can be captured in advance to aid farmers and policymakers in monitoring plant health, pest detection, and soil conditions like never before. The status allows stakeholders to enforce intervention i.e. valuable effects including precision irrigation, pest control, and soil fertility management which can help increase crop yields, and reduce losses [22]. Remote sensing technology helps rationalize agricultural practices and thus supports more effective evidence-based decision-making that improves productivity and food availability.

4.12. Resource Management Optimization

Remote sensing technology in agriculture expedited better natural resource management (water, soil, and land). Remote sensing provides information on soil moisture, water availability, and changes in land cover that stakeholders can use to improve resource utilization [17]. Soil-moisture data can be used to improve irrigation, allowing site-specific management that conserves water resources and minimizes environmental impacts by farmers. At the same time, remote sensing information supports land use planning efforts, promoting sustainable management practices, and reducing the degradation of terrestrial lands [15].

4.13. Encouraging Sustainable Growth

The importance of remote sensing technology for sustainable development in developing countries is that it can allow for more informed decision-making and a higher level of resilience when facing issues related to the environment. Remote sensing plays a crucial role in monitoring key drivers of deforestation, land degradation, and habitat loss to help identify priority areas for conservation intervention [15]. Remote sensing aids in monitoring the impacts of climate change on agricultural productivity through the development and implementation of adaptation strategies [14]. Remote sensing technology contributes to achieving sustainable development goals viz., poverty alleviation, environmental conservation, and food security.

4.14. Unique Challenges Demand Tailored Approaches

It is important to note that the challenges and opportunities of remote sensing technology adoption are not equal regionally, and vary among different communities. However, though the benefits of remote sensing are substantial, there do exist barriers like low data and technology access levels, lack of infrastructure, and capacity hurdles which need focus through measure-driven mechanisms [4]. Strategic capacity building, technology and infrastructure investments, and policy interventions must also be area-specific/context-specific. Remote sensing initiatives need to be linked with local knowledge and participatory approaches.

4.15. Complimentary Intervention Synergies

It can and should be integrated with other agriculture interventions to magnify their impact. For instance, the fusion of remote sensing data with agronomic modeling methods results in decision support tools that provide farmers with tailored advice for crop management [22]. Similarly, remote sensing can enhance conventional agricultural extension services through the necessary data and tools for advisory service providers [17]. Complementary strategies to yield the benefits from remote sensing technology while integrating other components of an agroecological system will be better devised in conjunction with best practice outcomes.

5. Conclusion

Remote sensing technology, therefore, can play a crucial role in providing unique solutions for food security challenges faced by developing countries, based entirely on sustainable agricultural practices and more efficient resource utilization. Tailored approaches that address the specificities of different regions and communities are required to break down these barriers and maximize gains from remote sensing interventions. In the farming community, through learning to take advantage of synergies between it and other agricultural interventions in developing countries. Remote sensing can help create broad-based strategies that not only, make food security sustainable but, also lead to a move toward better agricultural practices for farmers.

Remote sensing technology is a game-changing tool, which can revolutionize agriculture and thus, pave the way for enhanced food security in the developing world. Remote sensing as a discipline has its limitations such as, technological, institutional, and socio-economic hindrances, however, the benefits derived from it outweigh these limitations. In this discussion, one will see the evidence that focuses on how important remote sensing is, to improve productivity in agriculture, support resources management, and be successful against the adverse impacts of climate change on food security. By using remote sensing advantages efficiently and strategically, new doors for agriculture development can be opened in developing countries with a greater adaptive capacity. Barriers to remote sensing adoption can be addressed further through proactive measures such as capacity building, policy support, public-private partnerships, and technological innovations. Overcoming these barriers will guarantee access to remote sensing tools, equitably. Make them more useful for agricultural practice within food systems.

The integration of remote sensing technology use in farming practices requires interlinkages and joint investment between governments, policymakers, researchers, and stakeholders. This requires a concerted effort to ensure policies are developed and implemented, infrastructure investment is made in the technology employed, and knowledge-sharing initiatives are in place. Developing countries cannot enjoy the full benefits of remote sensing technological opportunities without concerted efforts.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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