### ****APPLICATION OF REMOTE SENSING AND GIS FOR REAL-TIME CROP MONITORING AND EXTENSION SUPPORT SERVICES****

### ****Abstract****

### **The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) has transformed agricultural monitoring and extension services by enabling real-time, location-specific, and data-driven decision-making. This study explores the conceptual framework, technologies, and practical applications of RS and GIS in monitoring crop health, predicting yield, and delivering adaptive agri-advisories. It highlights the capabilities of satellite imagery, UAVs, hyperspectral and thermal imaging, and their integration within GIS platforms to support sustainable and precision agriculture. The paper reviews notable initiatives such as India’s FASAL project and platforms like GeoFarmer, which demonstrate the effectiveness of geospatial tools in improving farm-level interventions. Furthermore, the study examines the growing role of Artificial Intelligence and Big Data in enhancing the accuracy and reach of extension services. Despite these advances, challenges persist, including high costs, technical capacity gaps, limited rural infrastructure, and the need for better socio-economic data integration. The paper concludes with future directions and policy implications, emphasizing the need for investment in digital infrastructure, training, open-data access, and public-private partnerships to make RS-GIS-based agriculture more inclusive, resilient, and impactful.**

### ****Introduction****

Agriculture remains the backbone of many economies, particularly in developing countries like India, where a large portion of the population relies on it for livelihood. With the increasing challenges of climate change, resource scarcity, and the demand for higher productivity, the need for timely, accurate, and location-specific agricultural information has become crucial. In this context, **Remote Sensing (RS) and Geographic Information Systems (GIS)** have emerged as transformative tools for enhancing agricultural planning, monitoring, and decision-making (Ashour et al., 2021).

Remote sensing technology, through satellite imagery, drone-based surveillance, and spectral sensors, enables the continuous observation of crop health, soil conditions, and climatic variations across large geographic areas (Al-Ismaili, 2021). When integrated with GIS—a system that captures, stores, analyzes, and visualizes spatial data—it becomes possible to create dynamic maps, detect crop anomalies in real-time, and deliver actionable insights to stakeholders.

**Remote Sensing for Crop Monitoring**

The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) in agriculture has significantly advanced the efficiency and precision of crop monitoring and agricultural extension services (Omia et al., 2023). Several studies highlight how RS-GIS technologies have evolved from basic land cover mapping tools into sophisticated systems for real-time, data-driven decision-making in agriculture.

According to **Thenkabail et al. (2007)**, multispectral and hyperspectral remote sensing can accurately detect vegetation health through indices like NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index), enabling early detection of crop stress and yield variability. Similarly, **Doraiswamy et al. (2004)** demonstrated that satellite-based RS data, when integrated with weather and soil models, could reliably estimate crop yield and forecast agricultural productivity across regions. These insights have become foundational in real-time crop monitoring systems.

In the Indian context, projects like **FASAL (Forecasting Agricultural output using Space, Agrometeorology and Land based observations)**implemented by the Ministry of Agriculture and ISRO, have shown successful applications of RS and GIS for monitoring crop acreage and forecasting production. According to **Raju et al. (2010)**, FASAL’s integration of multi-date satellite data with field observations helped generate timely and accurate reports on major crops such as rice, wheat, and cotton, which supported both planning and policy formulation.

The role of GIS in agricultural extension has also been well-documented. **Jat et al. (2008)**reported that GIS-based spatial analysis enables mapping of crop health, soil fertility, and pest incidence zones, thereby guiding site-specific advisory services. **Fazal and Amin (2011)**emphasized that GIS helps in layering data such as rainfall, soil type, and crop type to provide location-specific recommendations for fertilizer and irrigation, enhancing precision farming practices.

Recent innovations include the use of UAVs (drones) for ultra-high-resolution crop imaging. **Sankaran et al. (2015)** highlighted how drone-based monitoring offers flexibility in data collection and improves the detection of fine-scale field variations, which is especially useful for smallholder farms. Moreover,**CGIAR’s GeoFarmer platform** showcases the integration of participatory GIS and mobile-based advisory systems, allowing farmers to receive, validate, and share geo-tagged field-level information in real time.

Despite these advancements, challenges remain in the widespread adoption of these technologies, especially among smallholder farmers. **Tripathi and Singh (2013)** observed that high costs, limited technical literacy, and data accessibility are key barriers. Additionally, there is a need to better integrate socio-economic data with geospatial analytics to enhance the relevance of advisories.

### ****Conceptual Framework of Remote Sensing & GIS in Crop Monitoring****

The conceptual framework for utilizing Remote Sensing (RS) and Geographic Information Systems (GIS) in crop monitoring is founded on a systematic approach that involves the collection, processing, analysis, and application of spatial and spectral data to support real-time agricultural decision-making. This integrated system is designed to enhance the accuracy, timeliness, and efficiency of crop monitoring and extension support, particularly in large and diverse farming landscapes. By combining the strengths of RS and GIS, agricultural stakeholders can gain timely insights into crop conditions, enabling proactive responses to challenges such as drought, pest attacks, or soil degradation. (Duveiller, G., & Defourny, P. (2010)).

Remote sensing refers to the process of acquiring information about the Earth’s surface without physical contact, primarily through the use of satellite imagery, aerial platforms, or drones (Grishin & Timirgaleeva, 2020). In the agricultural context, RS is widely used to monitor vegetation growth, assess soil moisture levels, identify crop stress, and even predict yields. Key features of RS include spectral imagery, where multispectral and hyperspectral sensors capture data across different wavelengths of light to analyze plant health using indices like NDVI (Normalized Difference Vegetation Index), SAVI (Soil-Adjusted Vegetation Index), and EVI (Enhanced Vegetation Index). In addition, RS technologies support temporal monitoring through repeated satellite passes, allowing for time-series analysis of crop development and early detection of anomalies or disease outbreaks. These sensors can be categorized into passive systems, like Landsat and Sentinel-2, which rely on sunlight to capture images, and active systems such as Synthetic Aperture Radar (SAR), which emit their own signals and can function under cloudy or nighttime conditions.

Geographic Information Systems (GIS), on the other hand, are computer-based tools used to capture, manage, analyze, and visualize spatial data. Within crop monitoring, GIS plays a critical role in managing multiple data layers, including remote sensing imagery, soil maps, rainfall data, elevation profiles, and field boundaries (Raihan, 2024). Through spatial analysis, GIS can identify zones of stress, detect patterns in water scarcity, or map nutrient-deficient areas, thus guiding precision agriculture practices (Zhao et al., 2023). Moreover, GIS facilitates informed decision-making by generating thematic maps, risk models, and visual dashboards that extension officers and policymakers can use to deliver targeted advisories and resource interventions (Duveiller, G., & Defourny, P. (2010)).

The integration of RS and GIS is central to real-time crop monitoring. While RS provides continuous, up-to-date data on crop conditions, GIS enables the contextualization and spatial interpretation of that data. Together, these technologies enable the development of early warning systems for threats such as drought, floods, or pest infestations, allowing timely mitigation strategies. They also enhance adaptive extension services by delivering location-specific advice to farmers based on real-time observations. Furthermore, this integration supports sustainable resource management by optimizing the use of inputs like water and fertilizers, reducing waste, and minimizing environmental impacts. Overall, the RS-GIS framework empowers agricultural systems to become more responsive, data-driven, and resilient.

### ****Remote Sensing Technologies and Data Types****

Remote sensing technologies have become essential tools in modern agriculture, enabling real-time and accurate monitoring of crops over vast areas. These technologies rely on sensors mounted on satellites, drones (UAVs), aircraft, or even ground-based platforms to capture data about the Earth's surface without physical contact. The selection of a remote sensing system depends on factors like spatial resolution, revisit frequency, atmospheric conditions, and the specific agricultural application (Zhu, L., et al., 2018).

Satellite-based remote sensing is widely used due to its ability to cover large geographic areas consistently over time. Notable satellites include Landsat (by NASA/USGS), which provides medium-resolution data useful for historical crop trend analysis; Sentinel-2 (by the European Space Agency), which offers high-resolution multispectral data ideal for monitoring vegetation health and chlorophyll content; and MODIS (by NASA), which delivers lower resolution data but with high temporal frequency, making it suitable for large-area seasonal crop assessments. India’s own Resourcesat series also contributes significantly to crop mapping and acreage estimation at the national level.

In addition to satellites, drones or UAVs have gained popularity due to their ultra-high-resolution capabilities and flexibility. These are especially useful for smallholder plots and precision farming, where detailed, site-specific information is needed to manage inputs like water, fertilizers, and pesticides. Aircraft-based sensors serve as an intermediate solution, offering better resolution than satellites and wider coverage than drones, though they are used less frequently due to cost and operational challenges. Ground-based remote sensing, using handheld sensors or field spectrometers, is often used for field validation and for capturing fine-scale variations in crop traits (Zhu, L., et al., 2018).

The data collected through remote sensing can be of various types, each serving different analytical purposes. Multispectral data capture information across several distinct spectral bands such as red, green, blue, and near-infrared, and are widely used for calculating vegetation indices like NDVI (Normalized Difference Vegetation Index), which is a key indicator of plant health. Hyperspectral data go a step further, capturing data in hundreds of narrow spectral bands, allowing for the detection of subtle differences in crop type, nutrient status, and early signs of disease. Thermal infrared data measure land surface temperature and are useful for monitoring crop water stress, managing irrigation, and detecting drought conditions. Radar data, particularly Synthetic Aperture Radar (SAR), represent an active sensing method using microwave energy. SAR has the advantage of penetrating clouds and working under all weather conditions, making it extremely valuable during monsoons or in regions with persistent cloud cover. It is commonly used to assess soil moisture, monitor flood-affected areas, and evaluate crop structure.

**GIS-Based Crop Monitoring and Advisory System**

A Geographic Information System (GIS)-based crop monitoring and advisory system serves as a powerful tool for collecting, managing, analyzing, and visualizing spatial agricultural data to support real-time decision-making. By integrating data from remote sensing platforms, ground observations, meteorological sources, and historical crop databases, GIS enables the spatial mapping of crop conditions, soil types, pest and disease outbreaks, and weather patterns at various scales—from field level to regional or national levels. This spatial intelligence allows agricultural experts and extension agencies to generate location-specific advisories tailored to the needs of individual farmers or communities. GIS platforms support dynamic monitoring of crop growth stages, stress detection, irrigation needs, and yield forecasting, thus enhancing early warning capabilities. These systems can also be linked to mobile applications or SMS services to deliver timely, actionable information to farmers in local languages, including fertilizer recommendations, pest control alerts, and market price trends. Furthermore, GIS-based decision support systems (DSS) help policymakers and planners assess the impact of agricultural interventions, prioritize resource allocation, and design region-specific strategies for climate-resilient and sustainable agriculture. Ultimately, GIS transforms raw spatial data into valuable insights, bridging the gap between technology and grassroots-level agricultural extension.

**Use of Hyperspectral and Thermal Imaging in Crop Stress Monitoring**

Hyperspectral and thermal imaging technologies play a critical role in the early detection and precise monitoring of crop stress caused by factors such as drought, nutrient deficiencies, pests, and diseases. Hyperspectral imaging captures reflectance data across hundreds of narrow and contiguous spectral bands, far beyond the visible range, allowing for the identification of subtle physiological and biochemical changes in plant tissues that are not detectable through conventional imaging. This enables precise discrimination between healthy and stressed vegetation, assessment of chlorophyll content, water status, and nutrient levels, and the detection of disease symptoms at an early stage. Thermal imaging, on the other hand, measures the surface temperature of plant canopies, which increases under water stress due to reduced transpiration. By detecting temperature anomalies, thermal sensors can effectively map irrigation deficiencies and help optimize water management. When integrated with GPS and GIS platforms, hyperspectral and thermal data provide spatially detailed and timely information that supports precision agriculture practices. These technologies are particularly valuable in large-scale monitoring and research, enabling targeted interventions that improve crop health, reduce input costs, and boost productivity while minimizing environmental impact (Zarco-Tejada et al., 2012).

**Integration of AI and Big Data for Agri-Advisory Development**

The integration of Artificial Intelligence (AI) and Big Data is transforming the landscape of agricultural advisory services by enabling data-driven, timely, and personalized recommendations for farmers. Big Data in agriculture encompasses vast and diverse datasets, including satellite imagery, weather forecasts, soil health records, sensor data, market trends, and farmer demographics. AI technologies—such as machine learning, deep learning, and natural language processing—analyze these complex datasets to uncover patterns, predict outcomes, and generate actionable insights. For instance, AI algorithms can forecast crop yields, detect pest outbreaks, predict disease risks, and optimize input usage based on historical and real-time data. These predictive models enhance the precision and reliability of agri-advisories, enabling early warnings and location-specific guidance. Moreover, AI-powered chatbots and voice-based interfaces are increasingly being used to deliver advisories in local languages through mobile apps or SMS platforms, ensuring accessibility even in remote rural areas. The continuous feedback loop between farmer responses and AI systems further refines the accuracy and relevance of recommendations. By integrating AI and Big Data into agricultural extension systems, stakeholders can promote sustainable farming practices, improve productivity, and strengthen climate resilience, ultimately bridging the information gap between scientific knowledge and grassroots-level farming decisions (Mallick, S., et al., 2025).

**Application in Agricultural Extension Services**

The application of advanced technologies such as Remote Sensing (RS), Geographic Information Systems (GIS), Artificial Intelligence (AI), and Big Data analytics has significantly enhanced the reach and effectiveness of agricultural extension services. Traditionally reliant on manual methods and face-to-face communication, extension services have now evolved into tech-enabled platforms that offer real-time, location-specific, and need-based advisories to farmers. Remote sensing and GIS facilitate the monitoring of crop conditions, pest and disease outbreaks, soil health, and weather variability, enabling extension agents to identify issues early and respond promptly. By overlaying spatial data with farm-level information, extension personnel can develop customized intervention plans and disseminate them efficiently through digital platforms (Singh et al., 2023).

AI and Big Data further empower extension systems by automating data analysis, predicting agricultural risks, and generating tailored recommendations. For example, AI-based diagnostic tools can identify crop diseases from farmer-submitted images, while predictive models help anticipate rainfall patterns or pest infestations. These insights can be shared with farmers via mobile apps, SMS alerts, or call centers, enhancing decision-making even in remote and resource-limited areas. Additionally, real-time dashboards and data visualization tools support extension managers in monitoring field activities, tracking progress, and allocating resources effectively. The integration of these technologies ensures not only greater precision and scalability in advisory delivery but also improves transparency, accountability, and farmer satisfaction. Ultimately, the digital transformation of agricultural extension services plays a crucial role in increasing productivity, sustainability, and resilience in the farming sector.

**Challenges and Limitations**

Despite the growing adoption of Remote Sensing (RS) and Geographic Information Systems (GIS) in agriculture, several challenges and limitations hinder their widespread and effective application, especially in the context of real-time crop monitoring and extension services. One of the primary constraints is the high cost of acquiring high-resolution satellite imagery or UAV-based data, which makes it inaccessible for smallholder farmers and underfunded extension departments. Additionally, technical complexity related to data processing, interpretation, and software usage requires specialized training that is often lacking among extension personnel and local institutions. Limited infrastructure, such as inadequate internet connectivity and unreliable electricity in rural areas, further restricts the real-time use and dissemination of geospatial data. Another critical issue is the temporal resolution of satellite data; cloud cover during crucial crop stages can delay or obstruct image acquisition, particularly during the monsoon season. Moreover, while RS and GIS offer strong biophysical monitoring capabilities, they often fail to integrate socio-economic variables, which are essential for tailoring advisories to local realities. Data privacy concerns, lack of policy frameworks, and limited collaboration between research institutions, government agencies, and private sector players also contribute to the slow scaling of these technologies. Lastly, language and literacy barriers in rural areas can prevent farmers from fully understanding or acting upon geo-based advisories unless they are simplified and localized. Addressing these challenges requires a multi-pronged strategy involving investment in capacity building, public-private partnerships, and the development of user-friendly, low-cost, and localized solutions that bridge the digital divide in agriculture.

**Future Directions and Policy Implications**

The future of Remote Sensing (RS) and Geographic Information Systems (GIS) in crop monitoring and extension services is promising, particularly with the rapid advancement of technology and the growing push toward digital agriculture. Future directions involve the integration of AI and machine learning algorithms with RS-GIS platforms to enhance predictive modeling, automate anomaly detection, and improve the accuracy of crop forecasting. The use of real-time mobile-based advisory systems linked to geospatial data will enable hyper-local, timely decision support for farmers, especially during climate-related events. Additionally, cloud computing and open-data platforms can democratize access to satellite imagery and processing tools, making them more accessible to smallholder farmers and local extension agencies. On the policy front, there is a pressing need for governments to establish clear data-sharing frameworks, ensure inter-agency coordination, and promote capacity-building programs that train extension workers and farmers in geospatial technologies. Investment in rural digital infrastructure, including internet connectivity and affordable access to remote sensing tools, is also critical. Policies should also encourage public-private partnerships to innovate and scale location-based agri-advisories. Furthermore, integrating social and economic dimensions into geospatial systems will make advisory services more inclusive and equitable. In summary, proactive policies, capacity development, and technological innovation must go hand-in-hand to ensure that RS-GIS-based crop monitoring becomes an integral, farmer-friendly component of India’s agricultural extension system.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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