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GEOSPATIAL TECHNOLOGIES IN PRECISION AGRICULTURE: APPLICATIONS OF GIS, GPS AND REMOTE SENSING FOR SUSTAINABLE CROP PRODUCTION

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ABSTRACT
In the last century, new farming methods have been introduced, such as the Green Revolution, which has enabled agriculture to keep up with the increasing demand for food and other agricultural goods. But population growth, rising income levels, and increased food demand will probably put more stress on the planet's natural resources. As the detrimental effects of agriculture on the environment become more widely acknowledged, new methods and strategies need to be able to meet future food needs while preserving or lessening the environmental footprint of agriculture. Informed management decisions aiming at increasing crop production could be made with the help of emerging technologies like artificial intelligence (AI), Internet of Things (IoT), big data analysis, and geospatial technology. Precision agriculture is a transformative approach to farming that combines technology and data-driven insights to optimize crop production, reduce environmental impacts and enhance sustainability. It focuses on efficient resource utilization, including nutrients, water, seeds and more. Key components involve Remote Sensing (RS), Global Positioning System (GPS) and Geographical Information System (GIS), enabling farmers to collect and analyze data for better decision-making throughout the farming process, from land preparation to harvest. These technologies improve variable fertilizer management, irrigation scheduling, disease control, weed mapping and yield forecasting. Precision agriculture greatly benefits from the deployment of remote sensing technologies, which also presents new chances to enhance agricultural practices. Geographically, latitude and longitude data can be recorded for field data (slope, aspect, nutrients, and yield) using the global positioning system (GPS). Because of its ability to continuously determine and record the right position, it can build a larger database for the user. Geographic Information Systems (GIS), which can handle and store these data, are needed for the additional analysis. This review will offer you an overview of Remote Sensing technology, GPS, and GIS, and how it might be used for precision agriculture.

KEYWORDS: GPS, GIS, remote sensing, precision agriculture**,** disease and pest management; nutrient management.

INTRODUCTION

The changing climate every year is creating uncertainties in production pattern from a piece of land so is creating concern about the food security. Prediction models are needed to be site specific to give accurate prediction data and give precise information on the benefit data. Improvement in crop yield by performing better in field management decisions, reduction in chemical and fertilizer costs and more efficient application through information technology, permit more accurate farm records increase profit margin and can reduce pollution. Technology has a great role to play in such aspects (Hardi and Modh 2026**)**. "The evolution of agricultural production systems has been significantly influenced by the adoption of technological innovations initially developed for other industries. The Industrial Revolution introduced mechanization and synthetic fertilizers to agriculture, enhancing productivity (Syed et.al., 2024). The Technology Age brought genetic engineering and automation, further transforming agricultural practices. The Information Age offers the potential to integrate these technological advancements into precision agriculture (PA), enabling more targeted and efficient farming methods" (Whelan et al., 1997; Maurya et. al., 2024). Since the mid-20th century, farming has progressed from manual, labor-intensive methods to data-informed, precision agriculture methods. Initial developments in geographic information systems (GIS) in the 1960s and 1970s changed the capture and analysis of spatial data, establishing the foundation for contemporary mapping and resource management for agriculture. At the same time, remote sensing arrived on the scene with the earliest satellites, progressing from primitive imagery to advanced multispectral and hyper spectral sensors, which currently deliver vital information about crop conditions and environmental factors (Mrutyunjay et.al., 2025)

The demand for food globally has risen tremendously and is expected to increase to 59–98% by the year 2050 (Valin et.al., 2014). However, the growing concerns are that the agricultural food production systems are unable to match the high demand, especially in poor nations, causing an intensifying level of food insecurities (FAO,2019**)**. The inefficiency of the food production systems is also one of the reasons for food insecurity (Elahi et. al., 2022**)**. In efforts toward transforming the weak and often inefficient traditional subsistence production practices, sustainable production approaches (Alexandratosand Bruinsma 2012, Misselhorn et.al., 2012) that support production-efficiency-enhancement and better agronomic practices are needed. These include planting climate-resilient crops, high-yielding crop varieties, crop yield forecasting, integrated pest management, as well as integrating biodiversity solutions in sustainable food production systems (Elahi et.al., 2021and Lanyaet.al., 2019) Ultimately, these novel interventions would require comprehensive, up-to-date datasets (spatial and non-spatial) and the adoption of advanced GIS technologies that can synthesize and integrate social, spatial, economic, demographic, and environmental data in agriculture. The output of this synthesis would be evidence-based spatial knowledge that improves our understanding of agriculture sustainability and in supporting better policies and decision making processes. Contemporary advances in Geographic Information Systems (GIS), Remote Sensing (RS), and Geographic Positioning Systems (GPS) technologies present an opportunity to acquire and operationalize high-resolution satellite imagery and digital spatial data (Merchant and Narumalani, 2009). GIS technology provides users with a mixture of geo-spatial information management tools and methods that allow users to collect, store, integrate, query, display, and analyze geospatial data at various scales (Goodchild M.F., 2011). Remote sensing technology acquire images and other information about crops and soil from sensors mounted on different platforms including satellites, airborne remote sensing (manned drones and unmanned aerial vehicles), and ground-based equipment that is then processed by computers to aid agricultural decision-making systems (García-Berná, et.al., 2020 and Weiss et.al., 2020).

In recent times, the increasing complexity associated with agriculture production systems has aroused policymakers' interest in investigating how the spatial aspect "dimension" of agriculture can be exploited using advanced GIS, RS, and GPS technologies to improve agricultural productivity and better production practices (Clay and Shanahan, 2011, Thakur, 2017). The integration of GIS technologies in agriculture has increased the opportunities for the development of even better spatial explicit frameworks that support the creation of dynamic agriculture databases and interactive systems (Nie at. al.,2010, García-Berná et al., 2020**)** used a systematic mapping study to focus on the current trend and what new opportunities in remote sensing techniques offer in agriculture. Their study found increased uptake of RS technologies in the acquisition and extracting of georeferenced data from satellite imagery and unmanned aerial vehicles. Spatial data from these technologies have been applied in several areas including crop growth and yield estimation, cropland parameter extraction, weed and disease detection, and the monitoring of water and nutrients in plants.

Crops health and growth can be monitored using remote sensing by analyzing spectral data obtained from satellites, airborne sensors, or ground-based instruments. This information can help farmers identify areas of their fields that may need additional attention or water, fertilizer, or pest management. Global Positioning Systems or GPS are used to find the exact location of things. Geographic Information Systems or GIS are used to record information on to maps. Remote sensing and GIS work together to gather, store, analyze, and visualize data from virtually any geographic position on Earth. Irrigation and soil moisture monitoring and management are major components of remote sensing in agriculture (Sarvapriya Singh, 2024**)**.Remote sensing and Geographic Information System (GIS) technologies are commonly used for real-time analysis and forecasts of weather, floods, and monitoring crop area sown, lost, or damaged due to floods and rainfall.

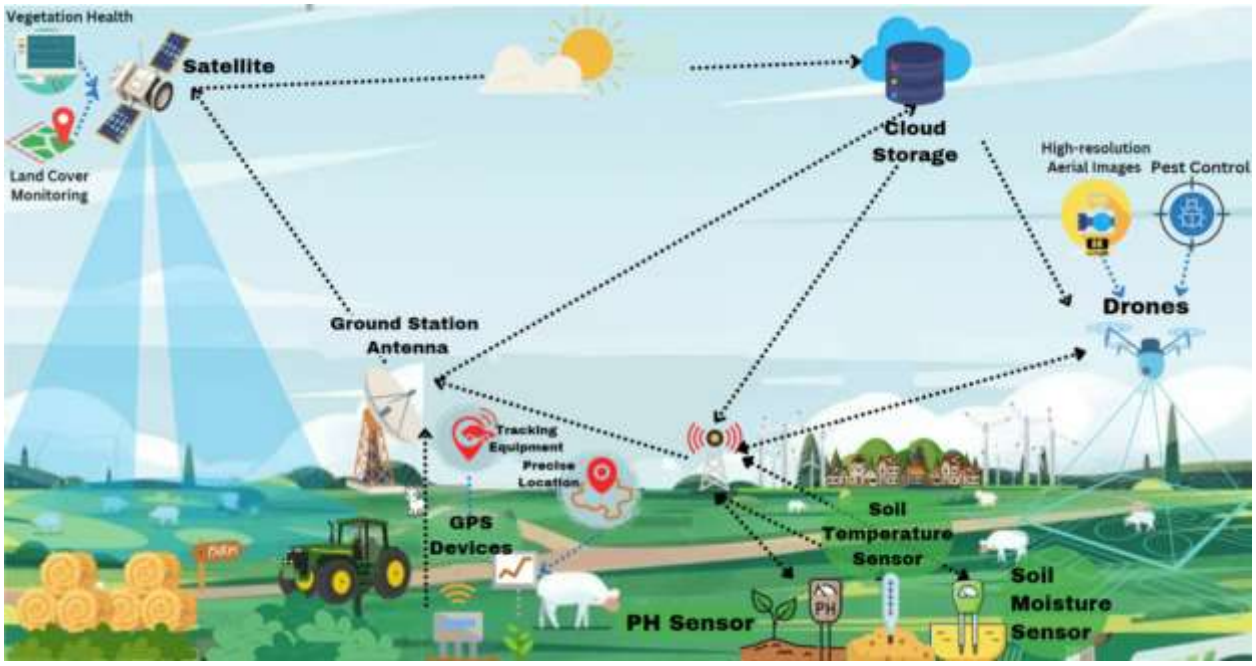


Figure: Overview of GIS application in agriculture

What is a GIS

Maps and other geographical data, as well as other spatial data, can be managed, stored and analysed using a GIS system **(**Sahoo and Giri, 2023**).** GIS is a helpful tool for managing and typically used in GIS applications (Tayari et al., 2015**).** The GIS is regarded as Precision Agriculture's brain. Because GIS can analyse and process large amounts of data quickly, it is crucial for handling and storing location-specific data (Sahuet.al.,2019). Geographic Information System (GIS) is regarded as the brains behind precision agriculture because of its ability to facilitate feature and location data collection, storage, retrieval, and analysis. It also plays a vital part in data-driven solutions, such site-specific management **(**Kumar**,** et.al., 2017). To address theurgent need for PA applications at the field level, many commercial GIS packages, such as the software packages introduced by AGRIS Corporation, Farm Works TM, Agri-Logic, Inc., John Deere Precision Farming Group, Case Corporation, Rockwell International, and RDI Technologies, Inc., have been developed(Ess et al., 1997).Some systems directly interact with DGPS devices or yield sensors to acquire location and yield data in real time.(Runquist et al., 2001)developed a field-level GIS (FIS) containing analytical functions for spatial data analysis in PA research.



Figure: Mapping and visualization in GIS

What is a GPS

Global positioning systems have metamorphosed into a keystone for precision farming practices in India. This section delves deep into the applications of GPS technology, outlining its utility in land surveying, machinery management and efficient field operations. Such precise management drives enhanced productivity, thereby enticing the attention of the global agricultural research community. GPS is a satellite navigation system operated by the US department of defence that provides global 3D location data (latitude, longitude, elevation) in all weather conditions. It helps farmers gather annual soil samples with accuracy for crop monitoring and to evaluate soil variability at various scales. Additionally, it aids in the generation of data about agricultural land, including field boundaries, acreage, roads, irrigation systems, separations and weed and disease-affected areas (Sahu*et al*., 2019).

What is a Remote Sensing

In Remote Sensing (RS), the Earth's surface is seen and monitored using satellite and aerial pictures. This information can be used to determine areas that are under environmental stress, such as water stress and to evaluate the production and health of crops. A farm or collection of farms can have both visible and invisible features measured by remote sensing, which also converts point measurements of continuous spatial data. This method keeps an eye on the dynamic of soil conditions as well as the surface of plant (Tayari et al., 2015). The process of gathering data through remote sensing involves sensors mounted on aircraft or satellites that pick up reflected energy from the Earth (Sahu et. al., 2019). Precision agriculture remote sensing systems, categorized by sensor platform and type, are deployed on satellites, aerial vehicles, and ground-based platforms. Satellite products have been used since the 1970s. Recently, aerial platforms, including aircraft and unmanned aerial vehicles (UAVs), have also found application in precision agriculture. Ground-based platforms, encompassing hand-held, free-standing, and tractor-mounted systems, are referred to as proximal remote sensing systems, situated close to the target surface compared to aerial or satellite-based platforms (Sishodia et. al., 2020). The field of agriculture has witnessed a revolution in crop monitoring and productivityboosting interventions through the numerous methodologies and applications of remote sensing (Sishodia, et.al., 2020, Weiss, et.al.,2020).

D. Precision Agriculture

With the seamless integration of GIS and GPS, Precision Agriculture (PA) is triggering a transformative wave across Indian farmlands. Its immense potential for variable-rate applications, yield monitoring and sustainable crop management is meticulously analyzed. For underscores the socioeconomic and environmental impacts of PA practices in the Indian context, marking it as an essential contribution to the scholarly discourse. By reducing the amount of inputs (such as water, energy, fertilizers, and pesticides) used, precision agriculture increases the quantity and quality of agricultural produce. This improves time efficiency by executing farming practices remotely while also producing benefits for the climate (Udoumoh et. al., 2021).

Among these tools, GPS and GIS serve as foundational elements. The map-based approach involves the collection and storage of data for fertility assessment, while the sensor-based approach offers real-time monitoring and adaptive input application, even without GPS connectivity (Sahu et al., 2019). Precision agriculture, driven by technologies like GPS and GIS, aims to maximize agricultural output while minimizing resource use, reducing environmental impact and ensuring sustainability. It includes variable rate technologies, electronic maps, yield monitors, and guidance systems. Precision agriculture utilizes remote sensing tools like satellites and drones to collect high-resolution field data for informed decision-making. This approach is applicable to various agricultural production systems beyond crop farming, including agronomics, livestock farming, aquaculture and agro forestry(Karunathilake et. al., 2023).

Application of GIS, GPS and remote sensing in precision agriculture

Using GPS, whether built-in to smart phones or handheld devices, allows farmers to map their fields and find more accurate and site-specific solutions to their issues. In addition to field mapping, GIS and remote sensing provide very powerful tools that can be used to monitor crop stages, disease management, yield estimation, soil mapping, weed mapping, and hotspots for disease incidences. These tools are particularly useful when spatial content is linked to other web-based applications. Here are some applications of these technologies-

• Assessment of crop growth stages and crop condition
• Identification of Disease, pest and weeds and its management
• Soil fertility, micro and macro nutrients and site-specific fertilizer application
• Precision conservation • Climate suitability and crop suitability
• Assessment of evapotranspiration (ET)
• Precise space utilization • Micro propagation/tissue culture
• Site specific irrigation, water resource management and crop water stress monitoring. Source: (Sood et. al., 2015; Patel, 2016; Sishodia et. al., 2020; Udoumoh et. al., 2021; Trivedi et. al., 2022).

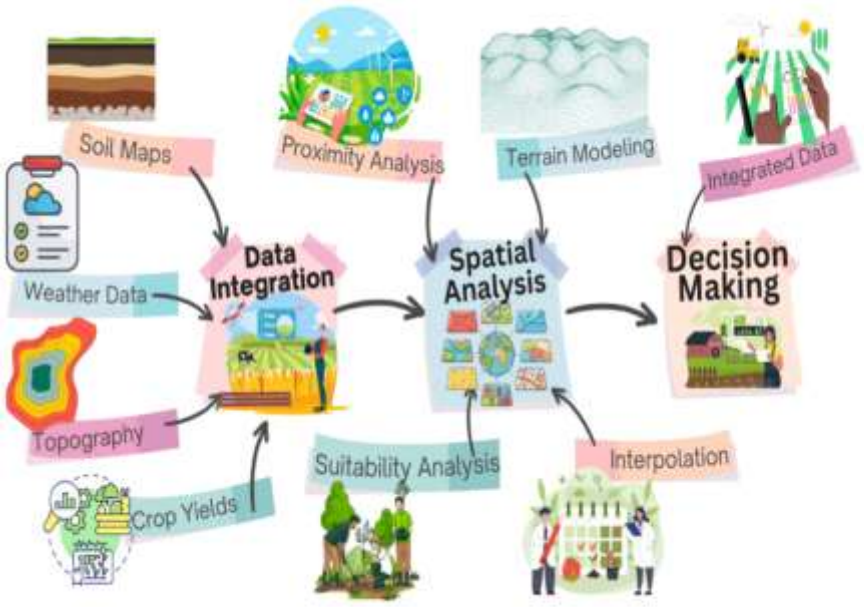


Figure: Data integration and spatial analysis workflow

1. Crop Inventory

In order to identify crops and locations where cropping patterns are changing, remote sensing (RS) and geographic information systems (GIS) are essential tools for conducting crop surveys and mapping (Kingra, et.al., 2016). For a government in a nation where agriculture is the main industry, accurate and timely information on the types of crops planted, their area, and estimated output is crucial. The spectral data is a crucial component of remote sensing data for crop modelling, and it is closely related to canopy parameters, which are indicators of the health and stage of growth of the crop. Crop-specific maps, which are useful to agribusinesses like seed and fertiliser companies, are produced by combining satellite images, survey data, and information on the layout of the land and its owners (farmers). The study of remote sensing can be very helpful in compiling information on various crops. In the literature, several investigations utilising aerial photography and digital image processing methods have been described. It helps to decrease the amount of field data that must be gathered and increases the estimate's precision (Gebeyehu M.N., 2019). In rain-fed locations, agricultural damage, especially to rice-growing regions, is a typical occurrence. Crop yield, damaged crop region, and anticipating moisture stress and flood are common occurrences. A crucial component of production estimation is various crop yield information. Every crop genotype has a specific yield potential that can be met in an experimental field under ideal circumstances. Yet, in the actual world, factors like soil, weather, and cultivation techniques including planting date, irrigation, and fertiliser affect crop output. Moreover, biotic stressors like disease and pests have an impact on crop output. Given that it delivers a rapid, precise, synoptic, and objective estimation of numerous crop characteristics, satellite-based remote sensing is an appropriate substitute for assessing and forecasting crop condition and yield. One crucial tool for yield modeling is data from remote sensing (Dadhwal, VK., 2003).

2. Nutrient and Water Stress

For healthy growth and vitality, plants require sufficient amounts of nutrients, sunlight, and water. Macronutrients are more important than micronutrients as fundamental components in the development of plant cell and tissue. Nutrient and water stress management is one of the most significant domains where we can choose to apply remote sensing and GIS through the application of precision farming. Remote sensing and geographic information systems (GIS) are crucial for site-specific nutrient management, which can lower crop costs and boost fertilizer usage efficiency (Mee, et. al., 2017). By using precise technologies, it may be able to use water wisely in arid areas. Drip irrigation, for instance, can be used in conjunction with data from remotely sensed data, such as the temperature difference between the canopy, to improve water use efficiency by lowering runoff and percolation losses. Nutrient deficit is identified by using multispectral and hyperspectral image analysis. Selecting wavelengths sensitive to various types of nutrients and water stress can be aided by spectral reflectance measurements. (Shanmugapriya et. al., 2019) For effective irrigation water management, crop water stress detection is crucial. In order to assure that crops won't suffer from water stress and will produce yield under limited water conditions, precision agriculture must monitor vegetation water stress using satellite technology. The regional and temporal dynamics of crop development under water stress and its effects on production may be provided through satellite data.

3.Flood Monitoring

The use of remote sensing technology enables measurements, particularly from space, to be made at spatial scales that are far larger than those that can be reached by field-based tools and techniques. To learn more about floods on various temporal and spatial scales, especially in the form of flooded areas, satellite data of inundation have been used. The amount of time it takes to detect and respond to flood emergencies has been cut in half because to automated spacecraft technology. Using satellite images of floods is crucial to show their potential, advance our knowledge of flood dynamics, and even speculate on their potential utility (Schumann et.al. 2018). Using a remote sensing approach, it is possible to increase the spatial coverage of river discharge estimates on a global scale. Several surface water hydraulic characteristics of large rivers, such as average river width over a specific reach length, water surface slope, water surface elevation, and channel morphology, can be measured or evaluated from remote-sensing data (Sun et.al., 2022).

4. Land Use and Land Cover

The identification of surface features at different sizes and their hierarchical classification are involved in land use/land cover mapping, which is important in the study of worldwide change. Environmental challenges caused by human activity, such as deforestation, biodiversity loss, and global warming, have a considerable impact on land use and land cover. As a result, the data on land use and land cover that is currently available can offer important input for decisions regarding environmental management and future planning. Growing socioeconomic status and population have an unplanned and uncontrollable impact on how land is used and covered. Poor management of agricultural, range, and forest areas often causes land use and cover changes, resulting in major environmental challenges such as floods and landslides. To identify changes, satellite imagery maps of land use and land cover were pixel by pixel compared (Reis S.,2008). Land cover refers to naturally occurring surface features (such as trees, hills, rivers, and so on), whereas land usage refers to features that have been altered by humans (urban, rural settlement, canal, orchards, etc.). In all geographical research, mapping of land use and land cover has always been crucial since it contains the fundamental details of features already present on the surface, including their area, location, shape, and pattern.

5.Agro Metrological Application

Strong climatic and metrological effects on agriculture. The metrological data are gathered using various point station observation networks in space. The ability of conventional agro metrological techniques to use their data for forecasting yields and real-time agricultural monitoring is severely constrained. The use of satellite metrology has made it possible to measure evapotranspiration, solar radiation, and rainfall accurately and frequently. The main inputs for the agro meteorology model included minimum and maximum temperatures, considerable rainfall occurring at biweekly intervals, and so on. The use of geostationary satellites for weather and climate remote sensing is regarded as the single most important development in the last 25 years for tracking the Earth's vegetation, weather, and climate. These satellites measure ocean temperatures and terrestrial vegetation.

6. Pest Infestation

Uses of remote sensing technologies are a crucial and efficient way to spot diseased, infested, and invader-infested areas. The analysis of biological invasion trends is challenged by regional variability, but due to its broad scope, remote sensing can give the essential information (Joshi et. al., 2004). Applications for remote sensing include data that is crucial for identifying and mapping defoliation, characterizing pattern disruptions, and more. If these changes can be connected, categorized, and interpreted, the remote sensing application in monitoring and analyzing insect defoliation has been utilized to relate variation in spectral responses to chlorosis, yellowing of leaves, and foliage decrease during a specific time period. Different flying altitudes can produce varying spatial resolutions for airborne remote sensing.

7. Water Resource Management

Recent decades have seen a global and regional decrease in the availability of water resources, which calls for judicious management using cutting-edge technology. Remote sensing is one of the most effective tools for analyzing and tracking water resources. Hyper spectral remote sensing is emerging as a more comprehensive method of examining spatial, spectral, and temporal variations in order to generate more precise estimations of information needed for water resource applications. With the advent of microwave remote sensing, it is now possible to measure soil moisture availability using distant sensing data. Groundwater is a significant natural resource that promotes human health, ecological variety, and economic development. Our ecosystems and the survival of future generations are in danger due to the excessive use of this essential resource. The use of RS and GIS technology in groundwater hydrology has received less attention. Watersheds, watershed sources, terrain surfaces, land uses, land covers, rainfall, temperature, humidity, soil conditions and composition, geology, atmospheric conditions, human activities, environmental data, and so on all necessitate a thorough understanding of the physical world and the spatial data that surrounds it.

8. Crop development and damage assessment

The amount of land penetration can be assessed by employing Remote Sensing technology. A proportion of crops that have progressed and those that have been harmed on farmlands.

9. Analysis of cropping systems and horticulture

Planting systems of different crops can be examined by employing Remote Sensing technology. The horticultural sector can also use these technology for flower growth through which, with the aid of numerous analyses, we may forecast and examine the pattern of flower growth.

10. Crop identification

Variety of crops can be identified with the aid of Remote Sensing technology. We must keep an eye on our crops if they exhibit any odd traits. Additionally, the data that was gathered was brought to labs to examine various facets of crops and crop culture.

11. Crop acreage estimation

Using remote sensing technologies, we may calculate the amount of agricultural area on which to grow our crop. Whenever we estimate agricultural lands manually, the process is usually quite large because of the enormous acreages involved.

12. Evaluation of crop health and stress detection

With the use of remote sensing technologies, we are able to evaluate both the health and stress of crops. Moreover, the crop's quality can be determined using these statistics.

13. Dates for planting and harvesting

Farmers can now forecast the seasons or dates for planting and harvesting each crop by employing remote sensing technology to observe a wide range of factors, such as soil types and weather patterns.

14. Crop yield estimation and modeling

Experts and farmers can use remote sensing technologies to estimate the projected crop yield for a given piece of land by analyzing the crop's quality and size.

15.**Disease and pest identification**

We can identify agricultural pests and provide information on effective pest management techniques by employing remote sensing technologies. in order to eradicate the pests and this disease from the land.

16. Estimation of soil moisture

We can estimate the moisture content of the soil by utilizing remote sensing technologies. These technologies enable us to obtain data on soil moisture, which is useful in estimating the amount of moisture present in the soil and the kind of crop that may be planted there.

Integration of GIS and remote sensing

GIS functions as a framework for overseeing, examining, and illustrating the spatial data acquired using remote sensing techniques (Evsahibioğlu and Özdikililer., 2015). Analysis integration enhances the accuracy and comprehensiveness of analysis by incorporating spatial context into data obtained through remote sensing techniques (Wang,et.al., 2016) The integration of GIS with remote sensing provides farmers and decision-makers with powerful spatial data to enhance agricultural practices, manage resources effectively, and promote sustainability (Lakra, et.al.,2024).

The Relationship between GIS and Remote Sensing

GIS and remote sensing technologies frequently augment each other. GIS offers a framework for effectively handling, examining, and representing geographical data acquired by remote sensing methodologies. By combining the detailed images from remote sensing with the spatial analysis tools of GIS, enhanced analytics make it possible to fully evaluate agricultural landscapes. Integration of GIS and ATV technologies: ATVs, fitted with GPS and sensors, travel through agricultural areas to gather precise spatial data on soil qualities, moisture levels, and crop conditions (Sivakumar, et.al.,2023). ATVs may travel fields with precision by integrating with GPS and using GIS-generated maps. This integration allows for focused operations like soil sampling, irrigation, and pesticide application (Qin et.al., 2017)

Challenges and limitations

The utilization of remote sensing, geographic information systems (GIS) and precision farming methodologies for agricultural resource management is experiencing rapid growth, primarily driven by advancements in space science and bolstered by computer and communication technologies. To effectively leverage these technologies, several challenges must be confronted (Dige, 2020, Patil et al., 2002).

Data complexity and integration: Data interoperability in remote sensing is hindered by the presence of many sensor kinds, resolutions, formats, and calibration methodologies. These problems prevent the smooth compatibility of the system because of variations in wavelengths, radiation characteristics, and distortions. In order to attain data interoperability, it is necessary to implement harmonization, standardization, and metadata enrichment. Data silos impede the accessibility, cooperation, and integration of data, resulting in inefficiency in resource use, compatibility problems, and security risks. Methods to enhance efficiency include the establishment of standardized data, improvement of interoperability, and implementation of secure protocols for data sharing (Helder, et.al.,2018)

Technology interoperability and standardization: Remote sensing encounters compatibility issues arising from variances in sensor properties, resolutions, and data formats. These problems restrict the sharing and analysis of data across different platforms. Essential components include reliable data conversion tools, generally recognized formats, and collaborative initiatives. Advanced machine-learning techniques may fix these issues. Technical challenges comprise various aspects such as image processing algorithms, limitations in data storage and transmission, mitigating

air interference, resolving spatial and spectral resolution concerns, implementing precise calibration and validation methods, and monitoring sensor deterioration (Ball,et.al., 2017)

Costs and investments: Remote sensing encounters financial obstacles, including regulatory obstacles, initial expenses for satellite launches and sensor enhancements, and guarantees of data quality. Fluctuations in market demand can have a significant impact on the sustainability of an organization. The complex nature of remote sensing data is a challenge when integrating it with the existing financial models (Padhiary and Roy 2024). However, the possibility of economical solutions in infrastructure, environmental monitoring, and agriculture has sparked interest. Resource limitations, such as a scarcity of high-resolution data and insufficient financing, have a direct impact on the accuracy and availability of data. Challenges are being tackled through the utilization of technology improvements, worldwide collaboration, and inventive algorithms (Kadhim, et.al., 2016)

Data privacy and security concerns: Ensuring the security of remote sensing data involves addressing issues such as safeguarding privacy, controlling access to sensitive information, and preventing data breaches. In order to tackle these issues, a comprehensive strategy that incorporates ethical considerations, technological advancements, and legal frameworks is required (Chandra and Bhatia 2020.) Remote sensing is susceptible to cyber security vulnerabilities such as tampering, illegal access, and data interception. Engaging in collaboration with various parties heightens the probability of experiencing security breaches. The situation is further complicated by the limited availability of encryption alternatives and the necessity to safeguard satellite communication networks and IoT devices. Strong encryption methods, ongoing surveillance, and effective coordination among relevant parties are crucial (Barik, et.al., 2023).

Training and adoption challenges: The evaluation of remote sensing data encounters constraints such as geometric imperfections, air disturbances, and a scarcity of high-quality data. Continuous skill growth and multidisciplinary knowledge are necessary due to the emergence of ethical and data privacy concerns (Padhiary and Roy 2024). The limited accessibility of technology, high costs, complex data processing, and defined protocols are obstacles that hinder adoption rates. The dearth of information and training, particularly in economically disadvantaged nations, exacerbates the disparity. To tackle these difficulties, it is necessary to enhance education and training programs, address infrastructural shortcomings, implement cost-effective solutions, and promote stakeholder engagement (Pettorelli, et.al.,2014).

Regulatory and policy frameworks: The legislation governing remote sensing encounters difficulties in safeguarding personal information, upholding national security, determining data ownership and accessibility, and assuring worldwide consistency. In order to achieve a balance between protecting interests and promoting innovation, it is necessary to provide adaptable and customizable frameworks. For ethical and responsible deployment of remote sensing technology, it is crucial to have collaboration among different disciplines, clear and transparent legislation, and active involvement of stakeholders (Zhang, et.al.,2022). Ethical considerations encompass concerns over the protection of data, potential violations of privacy, and ensuring equitable access to data. The extensive accessibility of high-resolution images gives rise to issues over privacy, while safeguarding data security is essential to prevent any potential misuse or exploitation. Ensuring fair access to remote sensing data and technology is crucial to preventing worsening social inequalities. Prudent ethical consideration and adherence to regulations are essential in order to strike a balance between these issues and the advantages of using remote sensing for environmental monitoring, disaster relief, and urban planning (Bennett, et.al.,2024).

Table 1: Performance metrics and applications of GIS and remote sensing in precision agriculture

Performance Metric	Description	Methods Used	References	Applications
Data accuracy	Measure of the correctness of collected data with an accuracy of 85%	Satellite imagery, GPS, drones	Nie and Yang ,2021	Ensuring accurate mapping and monitoring of agricultural fields
Temporal resolution	Frequency of data collection over time	Satellite imagery, aerial photography	Bahrami, et, al., 2022	Monitoring crop growth stages and detecting changes
Remote sensing detection rate	Detection accuracy of 92% for environmental and crop conditions	NDVI, multispectral imagery	Khanal,et.al.,2020	Monitoring crop health and detecting stress factors
Spatial resolution	Detail level of spatial data	Satellite imagery, drones	Alphonse,et.al.,2023	High-resolution mapping of fields for precision agriculture

Spectral resolution	Ability to capture data in multiple wavelengths	Spectral indices, thermal imaging	Kior, et.al., 2021	Assessing crop health and detecting stress using NDVI and other spectral indices
Analytical capabilities	Capacity to perform complex spatial analyzes	GIS spatial analysis tools	Gudowicz andPaluszkiewicz,2021	Conducting terrain modeling, interpolation, and suitability analysis
Decision support	Effectiveness in providing actionable insights	GIS-based decision support systems	Xia,et.al., 2014	Supporting farmers in making informed decisions regarding crop management and resource allocation
Data interoperability	Ability to integrate various data formats (30% of interoperability cases)	Data integration software	Amiri-Zarandi,et.al., 2022	Combining diverse datasets (soil, weather, crop yield) for comprehensive analysis
Cost efficiency	Cost-benefit ratio of technology implementation and 40% reduction in workforce expenses with automation	Cost analysis tools, ROI calculations	Radočaj, et.al.,2022	Evaluating the economic viability and benefits of adopting GIS and remote sensing technologies
Real-time monitoring	Ability to provide live updates on field conditions	IoT sensors, drones, satellite imagery	Popescu, et.al., 2020	Immediate assessment and response to changing field conditions
Environmental impact	Assessment of technology's effect on the environment	Environmental impact assessment tools	Oguntola and Simske,2023	Measuring and minimizing the ecological footprint of farming practices

The way forward

In the future of precision farming, the key thrust involves advancing the integration of Geographic Information Systems (GIS), Global Positioning Systems (GPS) and Remote Sensing technologies. This synergy aims to address the challenges posed by global population growth and the need for sustainable productivity in agriculture. The trajectory of precision farming will be shaped by refining data analytics, machine learning and artificial intelligence to effectively utilize the wealth of information generated by GIS, GPS and Remote Sensing. This evolution is expected to bring forth more advanced sensor technologies, improved connectivity and widespread access to data-driven insights. Ultimately, this convergence is set to propel agriculture towards a future marked by enhanced efficiency, sustainability and productivity.

CONCLUSION

In recent years, there has been a significant surge in the application and recognition of RS, GPS and GIS in agriculture. This can be attributed to the development of digital technologies that have made RS and GIS as tools for problem solving and decision making. These tools has been used for evaluating crops, soils, and their surroundings. This can be attributed to evaluating the development of digital technologies, which have made GIS a vital tool for crops, soils, and their surroundings. The integration of GIS, GPS and remote sensing technologies has ushered in a new era for precision agriculture, offering solutions to the challenges posed by climate change and burgeoning population demands. The applications of these technologies in crop monitoring, disease management and resource optimization underscore their transformative impact on Indian agriculture. Despite the progress made, challenges such as automation, cost reduction and skill development persist, requiring collaborative efforts from stakeholders. The future trajectory of precision farming envisions advanced sensor technologies, improved connectivity and widespread access to data-driven insights, promising increased efficiency and sustainability. Immediate, mid-term and long-term strategies are proposed to address current issues and foster the widespread adoption of precision agriculture. As the

agricultural landscape continues to evolve, the synergy of GIS, GPS and remote sensing remains integral to mapping the future of agriculture and ensuring food security in a changing climate.
Additionally, progress in remote sensing and blockchain technologies will guarantee more precise insights and safe data transfers. Highlighting regenerative and sustainable practices underscores the crucial role of these integrated technologies in tackling climate change and advancing environmental stewardship. As we progress through these technological developments, it becomes crucial to promote open platforms, establish standards, and encourage collaborative ecosystems. To fully harness the benefits of integrated agricultural technology, it is essential to engage in collaborative endeavors that provide farmers with the necessary skills and knowledge. This will enable the achievement of a more sustainable, efficient, and productive future in agriculture.

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