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5. Application of GIS

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Abstract:

Geographic Information Systems (GIS) have transformed how farmers manage their crops and come to informed choices, becoming vital tools in the area of agriculture. Using GIS, farmers may analyze and see complex linkages and trends by integrating different geographical data layers, such as soil parameters, weather patterns, and crop performance. Farmers may boost output and lessen their impact on the environment by using GIS to optimize their practices for pest management, fertilizer application, and irrigation. GIS-based precision agricultural methods provide focused interventions to ensure resource efficiency. Additionally, GIS supports land suitability studies, assisting farmers in determining the best sites for particular crops. The abstract emphasizes the transformational influence of GIS in agriculture, emphasizing its function in encouraging sustainable practices, improving crop management, and raising overall agricultural production.

Keywords:

Agriculture, geographic Information systems, geographical data, soil, sustainable.

5.1 Introduction:

With the projected global population reaching close to 9.1 billion by 2050, there is a pressing need to increase food production by approximately 50% compared to 2013 levels in order to meet the growing demand [1]. In order to meet our food production targets while facing the challenges of climate change, limited arable land expansion, and diminishing water resources, it is essential to implement sustainable practices that preserve soil health, conserve water, and protect biodiversity [2]. To tackle these issues, it is important to monitor crop growth and health efficiently and intervene promptly to enhance productivity while minimizing resource waste. Fortunately, advancements in sensor technology, communication systems, computational capabilities, and data analytics provide us with the necessary tools to address these tasks effectively. The adoption of technologies that promote efficient use of agricultural inputs and reduce environmental losses is crucial for ensuring food security. A range of tools and technologies, including Geographic Information System (GIS), Global Positioning System (GPS), remote sensing (RS), Artificial Intelligence (AI), Big Data Analytics, and Internet of Things (IoT), play a pivotal role in achieving these objectives by enabling accurate monitoring of crops and soils. By integrating these technologies with other sources of information, we can obtain data-driven insights for targeted and site-specific crop management, leading to increased productivity [3]. Geographic Information System (GIS), GIS, in particular, is a powerful system that facilitates the collection, storage, retrieval, analysis, transformation, and visualization of spatial data for specific purposes [4].

It acts as a foundational technology, providing spatial context and information on various features through data layers. The use of GIS in agriculture has expanded significantly in recent years, not only at local and regional scales but also at national and global levels. By combining GIS with remote sensing, GPS, and data analytics, we can gain a comprehensive understanding of farms and regions, enabling targeted interventions and corrective measures for crops and soils. GIS finds application in various domains, including geography, environmental sciences, natural resources, forestry, agriculture, food, banking, and health services. In the past few decades, there has been a notable rise in the use of GIS tools in agriculture, spanning various scales from local to global. These applications commonly integrate GIS with complementary technologies like remote sensing, GPS, and data analytics. The aim is to gain a comprehensive understanding of specific farms or regions, enabling interventions and corrective measures for crops and soils. This integration of technologies facilitates in-depth analysis and provides valuable insights for effective agricultural management. GIS is often referred to as the "brain" of Precision Agriculture due to its role in collecting, storing, retrieving, and analyzing data related to features and locations. It plays a crucial role in enabling data-driven solutions, particularly in site-specific management [5].

Digital agriculture, regarded as the fourth revolution in farming, has completely revolutionized agricultural practices by leveraging advancements in geospatial technologies, sensors, artificial intelligence, robotics, and other tools and technologies. This transformation has enabled the accurate identification of issues in cropland and the monitoring and management of every stage in the agriculture value chain, necessitating the integration of image and non-image data within a spatial context. Although GIS has been employed in agricultural applications for a considerable period, recent technological progress has led to a significant surge in its usage. Below, a few of the most popular and cutting-edge applications are covered.

5.2 Planning for The Use of Land and Determining Its Suitability Land:

In today's world, we are confronted with the daunting task of feeding a growing global population while the availability of fertile land is diminishing. To address this challenge, it becomes crucial to optimize the utilization of natural resources in order to maximize their benefits. Geographic Information System (GIS) serves as a valuable platform for evaluating land quality and determining suitable land use applications [6]. Among researchers, the most commonly preferred approach for land use planning is the Multi-criteria decision-making (MCDM) method based on GIS. Researchers leverage various GIS features such as soil type distribution, soil texture maps, underground water level distribution, soil fertility distribution, soil pollution distribution, hydraulic conductivity of soil, depth to water-table, slope, electrical conductivity of ground water, climate conditions, topography, and satellite data. By analyzing the interactions, dependencies, and impacts of these factors on sustainable land use, researchers gain insights for effective decision-making. The integration of remote sensing and GIS has demonstrated its effectiveness in evaluating the suitability of land. A study utilized a GIS-based two-step Analytic Hierarchy Process (AHP) to assess the suitability of land for crop cultivation [7]. The study emphasized the importance of carefully selecting relevant evaluation factors and highlighted the need to consider features that exhibit substantial differences. Furthermore, the researchers emphasized the significance of controlling land use and avoiding causal relationships. By incorporating these considerations, the assessment of land suitability can be enhanced in terms of accuracy and reliability.

5.3 Management of Water Resources:

Sufficient water supply is a fundamental requirement for meeting the increasing global food demand as the population grows [8]. To identify potential groundwater zones, the combination of GIS and remote sensing techniques has been utilized. By analyzing lineament and hydro-geomorphologic maps derived from remote sensing images, groundwater potential zones were delineated. The results of this delineation process showed consistency with well-yield data, indicating a synergy between the two [8]. In further study, he integration of GIS and remote sensing data was employed to assess sub-watershed level runoff and sediment yield, reducing data processing time while yielding reliable outcomes in comparison to actual measurements [9]. In regions with water scarcity, such as the UAE, a comprehensive assessment of irrigation suitability considered non-renewable sources like desalination and treated sewage effluent (TSE). To optimize water resource management, factors such as land management, topography, climate conditions, soil capabilities and water potential were incorporated into an analytical hierarchical process (AHP) GIS model. The study determined that the land was unsuitable for cereals and vegetables, but recommended the cultivation of sorghum, jojoba, fruits like date palm, and forage [10]. This research showcased the potential of GIS technology in maximizing the utilization of fertile land in water-scarce regions. Therefore, GIS technology has the power of addressing the challenges associated with water scarcity and enabling efficient land and water management for sustainable agriculture.

5.4 Evaluation and Remediation of Biotic and Abiotic Damage:

Extensive research has highlighted the substantial yield losses, ranging from 15% to 70%, resulting from biotic crop damage caused by pests like insects and fungi [11, 12]. This not only disrupts the demand and supply chain but also has severe repercussions on farmers' livelihoods. The shifting weather patterns further exacerbate the vulnerability of crops to pest infestations and diseases. While crop protection methods exist, the lack of timely information on pest and disease outbreaks hampers effective mitigation efforts.

Nonetheless, the integration of GIS technology offers significant prospects for targeted management of pests and diseases. Remote sensing and GIS-based early warning systems play a vital role in preventing yield losses and economic setbacks. By providing accurate forecasts of pest and disease occurrences, these systems empower farmers to implement timely control measures, thereby reducing production costs.

Furthermore, pest population density maps assume a critical role in identifying high-risk areas and providing valuable guidance to farmers. Such maps facilitate the formulation of comprehensive management strategies by farmers, agricultural experts, and policymakers to combat future pest infestations.

5.5 Monitoring Crop Health and Yield Forecasting:

For managing food security and evaluating economic returns, accurate crop growth, health, and yield forecasting is crucial. It has been discovered that conventional techniques of agricultural yield estimation are insufficient, resulting in subpar evaluation and erroneous crop area appraisal [13,14]. Furthermore, these methods need a significant amount of data collecting on crops and yields and are expensive, labor-intensive, and time-consuming. however, the integration of remote sensing (RS), GPS, and GIS technologies brings significant advantages by enabling the evaluation of temporal and spatial variations in crop dynamics and yield outcomes [15]. The combination of RS and GIS, complemented by other inputs, provides an efficient solution for monitoring crop health and developing models to predict yields at different spatial scales. Yield monitors, utilized in various crops such as corn (Zea mays), wheat (Triticum aestivium), soybeans (Gylycine max), potatoes (solanum tuberosum), and cotton (Gossypium herbaceum), play a crucial role in monitoring crop yield. These monitors employ sensors to measure the mass or volume of crops, providing accurate measurements within +/-3% of the actual harvested amount, albeit requiring regular calibration to maintain precision [16]. The recorded measurements, along with harvester travel speed, crop moisture, harvester width, and GPS data, are stored in an on-board computer and transferred to a desktop GIS for processing, visualization, and analysis. While yield monitors generate valuable data during harvesting, it is in a GIS where this data is transformed into actionable insights for decision-making. GIS technology plays a crucial role in collecting, storing, retrieving, and visualizing geographically linked data. Furthermore, it integrates remotely sensed geospatial data acquired from satellites, aircraft, or unmanned aerial vehicles (UAVs) to gather detailed information on crop features and soil characteristics that support crop growth. This integration facilitates the assessment of crop health and provides valuable insights for agricultural management. Yield monitors are valuable during harvesting as they gather a significant amount of data. However, the critical decision-making information derived from this data emerges after processing it in a GIS. GIS transforms the data obtained from yield monitors into actionable insights for management decisions, such as creating management zones, applying variable rates, and conducting targeted soil sampling. By delineating management zones in a GIS, fields can be managed based on their specific variations. Each zone can be sampled to identify deficiencies and manage them in a targeted manner, rather than applying inputs uniformly. The separate management zones enable farmers to accurately diagnose problems and compare management records across different years [17]. GIS technology plays a vital role in collecting, storing, retrieving, and visualizing geographically linked data. It also integrates remotely sensed geospatial data acquired from satellites, aircraft, or unmanned aerial vehicles (UAVs), providing valuable information on crop characteristics and soil attributes that support crop growth. Assessing crop health often involves determining vegetation indices calculated from surface reflectance measurements obtained from crop canopies at multiple wavelengths. Various vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Difference Vegetation Index (DVI) and Chlorophyll Vegetation Index (CVI) are available for evaluating vegetation extent, vigor, growth dynamics, and stress caused by biotic or abiotic factors [18]. In a study multiple vegetation indices, including NDVI, GNDVI, DVI and CVI were utilized to assess crop health and variations in health conditions [19].

5.6 Bio-Energy Potential Assessment:

The utilization of renewable energy sources is vital in achieving climate change and sustainability objectives. Agricultural residues offer great potential as a biomass-based energy source, and their demand is rapidly growing worldwide. However, efficiently harnessing agricultural residues for energy production poses challenges due to their seasonal availability and widespread geographic distribution. To overcome these challenges and optimize biomass-based energy generation, a solution is needed that can address the spatio-temporal variability and seasonal fluctuations in biomass supply, as well as facilitate the identification and transport of residues to power plants. A powerful tool in addressing these requirements is the combination of Geographic Information Systems (GIS) and remote sensing technologies. By leveraging GIS and remote sensing, precise identification and assessment of crop residues from existing agricultural practices can be achieved, which becomes even more advantageous as farmers transition from conventional to smart farming approaches [20]. The estimation of bio-energy potential through GIS-based approaches offers a technologically advanced solution for effectively utilizing agricultural residues. In a study conducted in a rural area of India, rice croplands were mapped using WorldView-2 satellite images. The resulting map, combined with agricultural production statistics, was analyzed in a GIS environment to assess the availability of rice straw as a potential feedstock for bio-energy generation [21]. Additionally, the study estimated the annual rice straw availability and the electrical power that could be generated from it, providing valuable information for energy developers and policymakers to aid in planning and decision-making processes.

5.7 Selective Soil Sampling:

The success of crop production heavily relies on the quality and characteristics of the soil. Achieving optimal soil conditions is essential for maximizing crop yields and ensuring a favorable return on investment. Farmers who possess a deep understanding of their operating environment are better equipped to make informed decisions that enhance profitability while minimizing negative environmental impacts. Historically, before the industrialization and mechanization of agriculture, farmers worked on smaller fields that allowed them to manage the inherent variability within their plots [22]. However, with the advent of mechanization, larger fields became more common, making it challenging to effectively address the variability present within them. Farmers now have access to more comprehensive soil property information, which empowers them to make more precise and cost-effective management decisions. Within the targeted soil sampling management technique, Geographic Information Systems (GIS) plays a vital role. This technique encompasses two main methods: grid sampling and zone sampling. Both methods involve the utilization of GIS software in combination with Global Positioning System (GPS) technology to establish field boundaries and divide them into smaller segments for detailed analysis. Using GIS software, farmers can create field boundaries and delineate zones or grids, which can be conveniently viewed on laptops or handheld computers.

These visual aids assist farmers in efficiently navigating to specific sampling sites within the field. By integrating GIS and GPS technologies, farmers can accurately pinpoint locations for soil sampling, ensuring representative samples are collected from various segments of the field. By utilizing GIS in targeted soil sampling, farmers can reduce costs by optimizing input usage and increase profits by maximizing productivity.

This technology empowers farmers to make site-specific management decisions based on accurate soil information, leading to more efficient resource allocation, improved crop health, and enhanced overall agricultural sustainability.

5.8 Remote Sensing:

Remote sensing, similar to yield monitoring and site-specific soil sampling, serves as a valuable tool for gathering information in precision farming. Its potential lies in its ability to monitor changes in spectral and spatial patterns at high resolution over time [22].

By providing aerial views of farmers' fields through airborne sensors, remote sensing offers unique perspectives that aid in field analysis. When integrated into a Geographic Information System (GIS), remotely sensed data can unveil valuable insights into soil characteristics such as organic matter content and moisture levels, as well as overall crop health. Despite being the least adopted precision agriculture tool among farmers at present, remote sensing holds immense potential due to its ability to rapidly gather extensive information using plane-based or satellite-based sensors, requiring minimal labor.

By capturing data about soil and crops from a distance, remote sensing eliminates the need for direct contact. The collected data can range from basic color photographs to measurements of the electromagnetic energy emitted by crops.

The provision of near real-time information empowers farmers to make prompt management decisions, addressing issues before they escalate beyond recovery. Moreover, remote sensing enables the collection of data across entire fields, surpassing the limitations of traditional scouting methods. It can be performed at multiple intervals throughout the growing season, facilitating the monitoring of both positive and negative trends in crop development.

The challenge for farmers lies in effectively analyzing and processing the collected data to extract meaningful information that can inform management decisions, increase productivity, optimize resource utilization, and minimize risks. Sensors used in remote sensing focus on measuring infrared energy reflected or emitted by plants in the non-visible spectrum, as most objects emit electromagnetic radiation outside the visible range [22].

Electromagnetic radiation is released by all things, and the majority of it is produced at wavelengths outside the visual range. When light strikes a plant, it either reflects, transmits, or is absorbed. Depending on the qualities of the plant, each one will reflect or emit light in a distinct manner. This response of plant to the light is known as spectral response. The spectral response of healthy plants differs from that of less healthy plants. By examining a limited area of the electromagnetic spectrum, remote sensing tries to identify the distinctive responses that can be used to gauge crop quality.

5.9 Site Specific Application:

To ensure the cost-effectiveness of agricultural inputs like pesticides, herbicides, fertilizer, and labor, it is crucial to utilize them accurately and efficiently. Additionally, farmers have employed a uniform approach, applying chemicals or nutrients at a constant rate across their fields. This approach reduces labor costs and ensures even distribution of inputs [23]. However, it overlooks the fact that different areas within a field may have varying requirements for deficiency correction, herbicide treatment, or pesticide application. Some areas may need higher levels of treatment, while others may require none at all. Variable rate application (VRA) addresses this issue by utilizing field-specific information to apply inputs only where they are needed. By adopting a variable rate instead of a constant rate, farmers can reduce input and labor costs, optimize productivity, and minimize the environmental impact of over-application. Prior to implementing VRA, farmers must determine the basis for application decisions [24].

For instance, nitrogen application decisions are often based on average yields from previous years, while fertilizer and lime application decisions rely on information obtained from targeted soil sampling. Aerial imagery or soil maps from organizations like the Natural Resources Conservation Service (NRCS) can also be used to divide the field into management zones, allowing for individualized treatment of each area.

A Geographic Information System (GIS) plays a crucial role in VRA, as it facilitates data analysis and the creation of application maps. All the relevant data needed for generating application maps initially resides within the GIS. Farmers can enhance resource optimization and mitigate soil and environmental harm by applying inputs at rates that optimize productivity for each specific area. The goal is not to maximize inputs for every plant, but rather to manage small areas with similar productivity levels in a site-specific manner. With the aid of GIS technology, farmers gain the capability to establish management zones based on historical field productivity. By defining zones categorized as low, medium, and high productivity, farmers can create application maps that seamlessly integrate with the on-board GIS and controller units of their application equipment. However, to truly maximize productivity, it is crucial that the appropriate amount of input is applied to each individual area.

5.10 Conclusion:

In order to sustain profitability in the face of declining crop prices and increased competition from abroad, farmers are seeking every available option. Precision agriculture technologies, enhanced by geographic information system (GIS), offer a valuable solution by providing farmers with crucial information for making informed management decisions. While adopting these technologies requires significant investment in terms of time, money, and dedication, they offer numerous benefits in maximizing production. Precision agriculture encompasses various tools, ranging from yield monitoring to targeted application of inputs, allowing farmers to optimize their operations. The advantages of precision agriculture extend beyond production enhancements. By utilizing GIS-enabled technologies, farmers can improve their record-keeping practices, leading to more accurate and streamlined accounting processes.

Furthermore, the adoption of precision agriculture minimizes the potential negative environmental impacts associated with excessive use of pesticides, herbicides, and other inputs. With site-specific application techniques, the risk of over-application is reduced, promoting sustainable and responsible farming practices.

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