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REVIEW ARTICLE

# A Systematic Review of Geographic Information Systems (GIS) in Agriculture for Evidence-Based Decision Making and Sustainability

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**Abstract**

The aim of this study was to consolidate current information on the utilization of Geographic Information Systems (GIS) and Remote Sensing (RS) in the agricultural sector, with a focus on their role in promoting evidence-based policies and practices to enhance agricultural sustainability. Additionally, this review sought to identify the challenges hindering the widespread adoption of GIS and RS applications, particularly in low- and middle-income nations. This study employed the methodology of systematic literature review. The findings indicate that the utilization of GIS technology in the agricultural sector has experienced a notable increase over the past few years. The primary areas of use for GIS that have been identified encompass crop yield estimation, assessment of soil fertility, monitoring of cropping patterns, evaluation of drought conditions, detection and management of pests and crop diseases, implementation of precision agriculture techniques, and management of fertilizer and weed control. GIS technology possesses the capacity to augment the sustainability of agriculture by incorporating the spatial aspect of agricultural practices into agricultural policies. Furthermore, the potential of GIS in facilitating evidence-based decision making is expanding. Given the escalating peril of climate change on agriculture and food security, there exists a heightened imperative to include GIS into policy formulation and decision-making processes to enhance the sustainability of agricultural practices. The findings of this study might be beneficial in informing the development of policies that effectively integrate sustainable and climate-smart practices in agriculture.

**Keywords:** GIS; Remote sensing; Agri-spatial; Decision making; Policy integration; Sustainable agriculture

## Introduction

The global demand for food has experienced a significant growth and is projected to further climb by 59-98% by the year 2050, as stated by Elferink and Schierhorn (2016). Nevertheless, there is a mounting apprehension regarding the inability of agricultural food production systems to meet the substantial demand, particularly in impoverished nations, hence exacerbating the issue of food insecurity (Bjornlund et al., 2022; Akter et al., 2023; Raihan, 2023a). The presence of inefficiencies within food production systems has been identified as a contributing factor to the issue of food insecurity (Ali et al., 2022; Viana et al., 2022; Raihan, 2023b). Effectively promoting enhanced food production while ensuring the preservation of land and water resources, energy sustainability, and environmental integrity poses a significant challenge that necessitates attention from governmental bodies and policymakers (Brgum et al., 2020; Zhang et al., 2023; Raihan, 2023c).

In numerous low- and middle-income countries (LMICs), the primary source of food production is predominantly situated in rural areas, where smallholder and subsistence farmers play a dominant role (Moustier et al., 2023; Raihan, 2024a). In order to promote the sustainability of smallholder farmers, it is crucial to empower them with practical knowledge (Raihan et al., 2022a; Ghosh et al., 2023).

This information should help farmers to make decisions based on evidence and effectively execute strategies that can enhance their farm productivity and overall sustainability (Raihan et al., 2022b). In order to address the limitations of traditional subsistence production practices, it is imperative to adopt sustainable production approaches that promote efficiency and improved agronomic practices (Raihan et al., 2022c). The strategies encompassed in this approach consist of the cultivation of crops that are resilient to climate conditions, the utilization of crop types that have high yields, the implementation of methods for predicting crop yields, the adoption of integrated pest management techniques, and the incorporation of biodiversity solutions into sustainable food production systems (Giri, 2023; Raihan et al., 2023a). In order to implement these innovative interventions effectively, it is imperative to possess complete and current datasets encompassing both spatial and non-spatial information. Additionally, the utilization of advanced GIS technologies capable of amalgamating and synthesizing various types of data, such as spatial, social, demographic, economic, and environmental, is crucial (Kross et al., 2022; Raihan et al., 2023b). The synthesis process would yield geographical knowledge that is grounded in evidence, so enhancing our comprehension of agricultural sustainability and facilitating more effective policy-making and decision-making endeavors (Raihan et al., 2023c). The current advancements in GIS, RS, and Geographic Positioning Systems (GPS) technology offer a potential avenue for obtaining and implementing high-resolution satellite imagery and digital spatial data (Trivedi et al., 2022; Raihan, 2023d). Spatial data in the field of agriculture have been essential in examining the spatial connections between social, physical, agroecological, and environmental factors, and their impact on the sustainability of agricultural practices (Raihan et al., 2023d). The utilization of GIS technology offers users a comprehensive array of tools and methodologies for managing geospatial information. This technology enables users to gather, store, merge, interrogate, present, and examine geospatial data across different levels of detail (Avanidou et al., 2023; Raihan & Tuspekova, 2022a). Remote sensing technology is utilized to obtain images and gather various data pertaining to crops and soil. This is achieved through the utilization of sensors that are installed on diverse platforms such as satellites, airborne remote sensing devices (including manned drones and unmanned aerial vehicles), as well as ground-based equipment. Subsequently, these acquired data are processed by computers to support agricultural decision-making systems (Awais et al., 2022; Raihan & Tuspekova, 2022b; Huang et al., 2023).

The examination of agriculture's geographical context can be approached by considering the varying levels of access that farmers have to livelihood capitals, local resources, and critical infrastructure and services within a certain geographic area (Wang et al., 2023; Raihan & Tuspekova, 2022c). The deconstruction of data encompassing many aspects inside a GIS can be achieved through the organization of nested spatial layers. These layers are established based on local geography, with geographic coordinates obtained through the utilization of GPS technology (Raihan & Tuspekova, 2022d; Warren et al., 2023). The geographical layers can be further subjected to processing and analysis inside a GIS platform, enabling the exploration of various aspects such as crop and soil conditions, spatial relationships, crop trend prediction, land-use change monitoring, pest surveillance, and biodiversity protection (Raihan & Tuspekova, 2022e; Taiwo et al., 2023). Furthermore, these tools can also be employed to effectively delineate and expose spatial barriers that hinder agricultural productivity, or even generate novel insights to enhance agricultural sustainability (Raihan & Tuspekova, 2022f).

In contemporary times, policymakers have shown a growing interest in exploring the potential of advanced GIS, RS, and GPS technologies to enhance agricultural productivity and optimize production practices. This interest stems from the recognition of the escalating intricacy inherent in agricultural production systems (Raihan &

Tuspekova, 2022g; Yadav et al., 2023). The utilization of GIS in the field of agriculture has witnessed a notable rise, leading to enhanced prospects for the establishment of more advanced spatially explicit frameworks. These frameworks serve to facilitate the construction of dynamic agricultural databases and interactive systems (Raihan & Tuspekova, 2022h; Chen et al., 2023). These database systems enable users to engage with farm data that is geographically referenced in real-time, offering accurate positional data and so enhancing decision-making frameworks. Emerging applications of GIS have been observed in the agricultural sector. The aforementioned areas encompass precision agriculture, crop yield forecasting, automated farm systems, climate change detection, and real-time monitoring of agricultural production (Karunathilake et al., 2023; Raihan & Tuspekova, 2022i; Khan et al., 2023). These technologies possess the potential to enhance agricultural productivity and ensure food security.

Several recent comprehensive literature evaluations have been done to elucidate and consolidate the diverse applications of GIS, RS, and GPS technologies in the agricultural sector. Systematic mapping analysis has been conducted by García-Berná et al. (2020) to examine the prevailing trajectory and emerging prospects of remote sensing techniques in the field of agriculture. The researchers observed a notable rise in the adoption of RS technologies for the collection and extraction of georeferenced information gathered from imagery from satellites and unmanned aerial vehicles (UAVs) in their investigation. Spatial data derived from these advanced technologies has been utilized in several domains such as estimating crop growth and production, extracting parameters related to cropland, detecting weeds and diseases, and monitoring the availability of water and nutrients in plants. The authors did not provide an elaboration on how this application could be used to enhance spatial-based agriculture policymaking. Moreover, Al-Ismaili (2021) emphasized the utilization of RS and GIS methodologies in the field of precision agriculture. These techniques have proven to be effective in the accurate mapping, identification, and categorization of greenhouses using aerial imagery and satellite data. The potential integration of this technique into the improvement of policymaking was not discussed. Weiss et al. (2020) conducted a meta-review that emphasized the growing advancements in RS and its relevance to several domains such as crop breeding, crop yield forecasting, agricultural land use monitoring, and biodiversity loss. Sharma et al. (2018) examined the utilization of GIS data applications in the advancement of precision agriculture. The proposed framework, referred to as "Big GIS Analytic," was put up by the authors as a means to provide guidance on the appropriate utilization of large-scale GIS data within the context of the agriculture supply chain. The framework proposed by the authors establishes a theoretical basis for enhancing the efficacy of GIS data utilization in the agricultural sector, with the ultimate goal of increasing productivity. These studies contribute to the comprehension of the advancements in the uses of GIS and RS in agricultural production systems. Nevertheless, the existing systematic evaluations appear to lack precise information on how GIS and RS technologies might effectively promote the integration of the spatial aspect of agriculture into policy frameworks and actions.

There is a growing need for evidence-based decision-making to aid policymakers in evaluating the specific requirements of farmers at the local level, enhancing production and supply value chains, and implementing spatially targeted interventions (Raihan & Tuspekova, 2022j). This study seeks to consolidate current information on the utilization of GIS and RS in the agricultural sector. The objective is to explore how these technologies might contribute to evidence-based policymaking for the enhancement of agricultural sustainability. Additionally, the review aims to highlight the challenges and barriers that hinder the widespread adoption of GIS and RS applications, with a special focus on LMICs. The present investigation explored the contemporary and prospective viewpoints regarding the incorporation of GIS into policies aimed at promoting agricultural sustainability. The primary contributions of this study are to furnish researchers and policymakers with empirical data about the utilization of GIS technology within the agricultural sector. This evidence sheds light on how GIS technology has enhanced agricultural production methods and offers insights into its potential adoption for improving evidence-based decision-making processes and policies. The results of this study could potentially contribute to the formulation of policies that successfully include sustainable and climate-smart agricultural practices.

**Methodology**

This paper aims to present a concise overview of the utilization of GIS and RS techniques in agriculture, with a focus on the most current research findings. The present study employed the systematic literature review methodology as suggested by Tawfik et al. (2019). According to Benita (2021), the systematic literature review framework is considered to be a dependable approach. A preliminary review of the literature was conducted to identify pertinent articles, validate the proposed idea, avoid redundancy with previously covered issues, and ensure the availability of sufficient articles for conducting a comprehensive analysis of the subject matter. Moreover, the focal point of the themes was to explore the application of GIS and RS across multiple agricultural segments. According to Tawfik et al. (2019), it is crucial to enhance the retrieval of results by acquiring a comprehensive understanding and familiarity with the study topic through the examination of pertinent materials and active engagement in relevant debates. This objective can be achieved by conducting a thorough examination of pertinent literature and actively participating in pertinent academic conversations.

An in-depth review was undertaken on a total of 56 scholarly articles obtained from the Scopus, Web of Science, and Google Scholar databases. The manual search results were initially enhanced and polished through the process of examining the reference lists of the included publications. Subsequently, the investigation also engaged in the practice of citation tracking, a method involving the systematic monitoring of all the scholarly works that reference each of the papers incorporated in the collection. In conjunction with the manual search, an online search of databases was also undertaken as an integral component of the comprehensive search process. The evaluation and categorization of scholarly articles were performed by taking into account their specific domains of application. The publications were categorized based on the major research topics on GIS and RS application in agriculture. Following the identification of each topic, a comprehensive review was conducted, primarily on the presented issues. The emphasis was given to the current information on the utilization of GIS and RS in the agricultural sector, with a focus on their role in promoting evidence-based policies and practices to enhance agricultural sustainability. Additionally, this review sought to identify the challenges hindering the widespread adoption of GIS and RS applications, particularly in low- and middle-income nations.

This study exclusively relied on research articles published in peer-reviewed journals, ensuring the reliability and validity of the findings. The publications were thereafter evaluated to ascertain whether their main subject matter bore a resemblance to that of the present inquiry. Priority consideration was given to papers published after the year 2010. The primary justifications for the elimination of papers are their lack of relevance, duplication, incomplete textual content, or limited presence of abstracts. The predetermined exclusion criteria were established to safeguard the researcher against potential biases that could influence their findings. Figure 1 illustrates the progression of review criteria employed for the selection of suitable documents for review analysis. Moreover, Figure 2 presents the systematic review procedure utilized in the current study. After the research topic was chosen, this study proceeded to find and locate relevant articles, do an analysis and synthesis of diverse literature sources, and create written materials for article review. The synthesis phase encompassed the collection of a wide range of publications, which were subsequently amalgamated into conceptual or empirical analyses that were relevant to the finalized research.

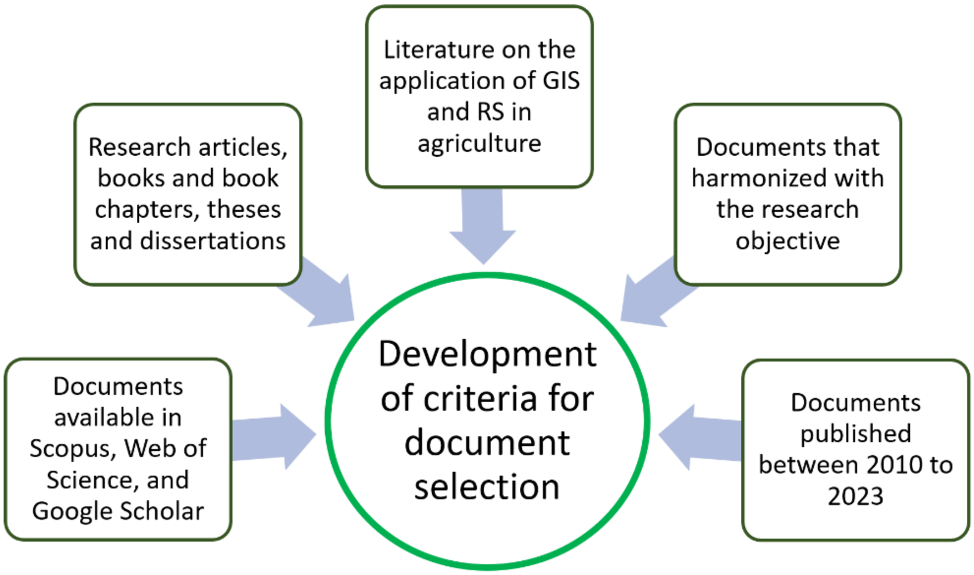


**Figure 1.** The development of criteria for the selection of documents.

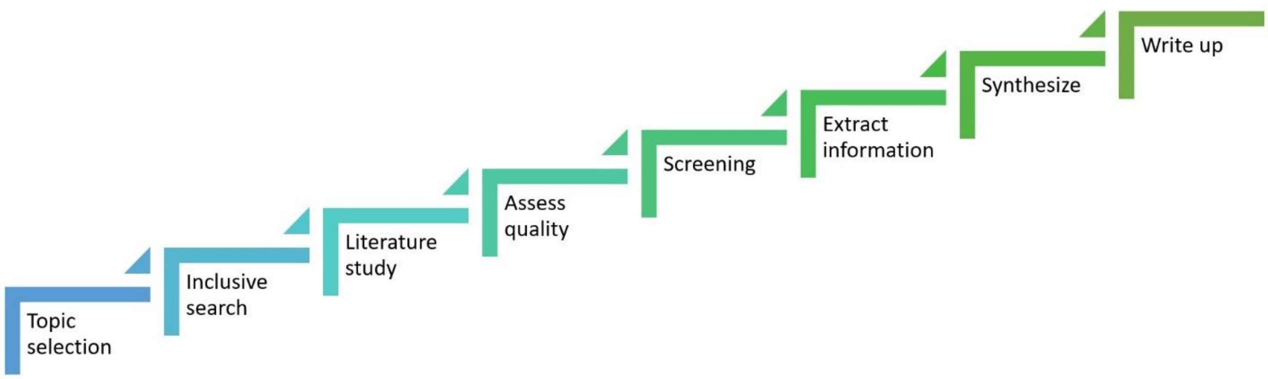


**Figure 2.** The procedure of systematic review conducted by the study.

## Results and Discussion

### GIS in agriculture and policy implications

The principal study themes within the current body of literature pertaining to the utilization of GIS in the field of agriculture are depicted in Figure 3. There are seven distinct application areas of GIS within the field of agriculture. These areas encompass crop yield estimation and forecasting, assessment of soil fertility, analysis of cropping patterns and agricultural monitoring, evaluation of drought conditions, detection and control of pests and crop diseases, implementation of precision agriculture techniques, and management of fertilizers and weeds. GIS can assist in implementing agricultural policies through several means. GIS can facilitate the enforcement of regulations and provide a visual representation of the economic consequences of policy (Boda et al., 2023; Raihan & Tuspekova, 2022k). GIS has the capability to uncover environmental health concerns as well as issues related to animal health and welfare (Niloofar et al., 2021; Raihan & Tuspekova, 2023a). GIS has the ability to mediate land use disputes (Yanbo et al., 2023; Raihan & Tuspekova, 2023b). GIS software has the capability to examine soil data and monitor the advancement of a project (Alaloul et al., 2021; Raihan & Voumik, 2022a). GIS can enhance agricultural productivity and minimize expenses by facilitating improved land resource management (Diehl et al., 2020; Raihan & Voumik, 2022b). GIS enables organizations to assess crop health by utilizing data obtained from satellite imagery, thermal sensors, and multispectral cameras (Olson & Anderson, 2021; Raihan, 2023e; Sultana et al., 2023a). GIS software aids farmers in identifying optimal sites and environmental factors for cultivating various crops (Roy et al., 2023; Sultana et al., 2023b). GIS-based models offer empirically supported approaches to enhance soil quality management (Tsegaye & Bharti, 2021; Raihan, 2023f; Voumik et al., 2022; Himu & Raihan, 2023). The subsequent sub-sections provide a description of the main research areas explored in the current body of literature pertaining to the application of GIS and RS in the field of agriculture.

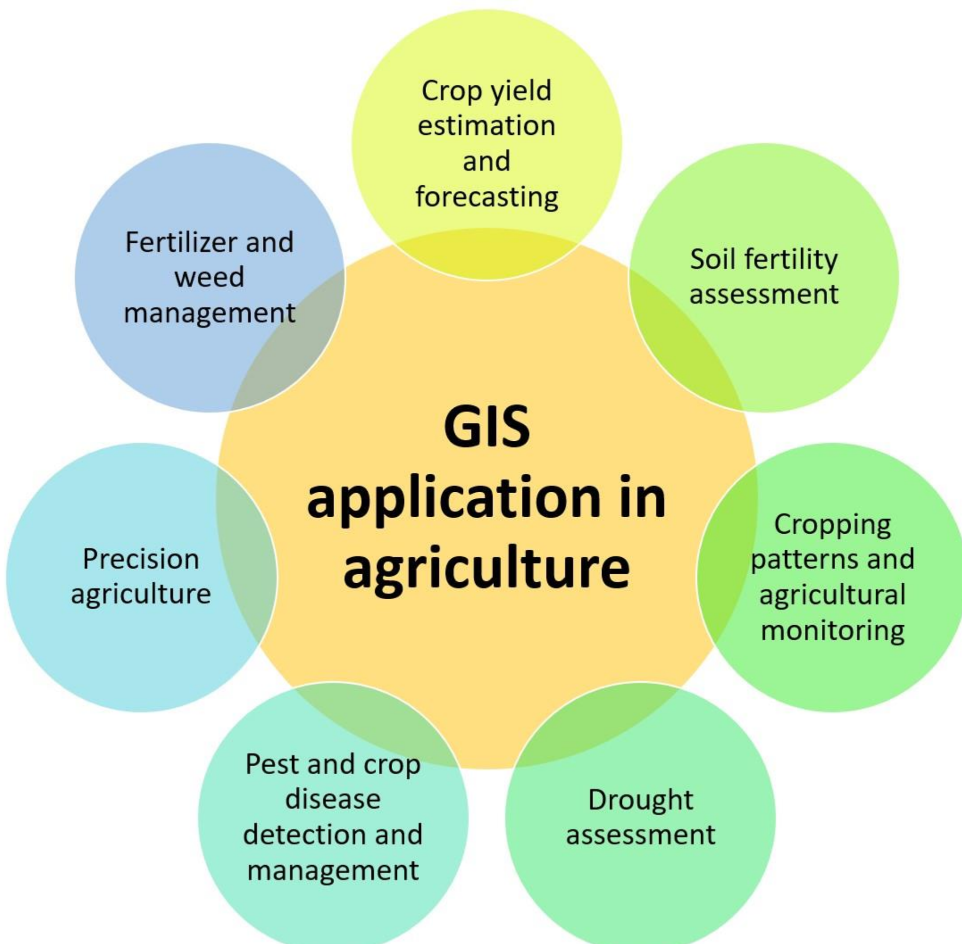


**Figure 3.** Major research topics on GIS application in agriculture.

### Crop yield estimation and forecasting

The monitoring of crop growth and the early forecasting of crop yield in agricultural fields are crucial processes for the purpose of food security planning and the prediction of agricultural economic returns (Al-Adhaileh et al., 2022; Raihan, 2023g; Voumik et al., 2023a). According to Dhanaraju et al. (2022), the ongoing progress in RS and GIS technologies has resulted in enhancements to the methods and approaches employed for monitoring agricultural development and calculating crop yields. Figure 4 depicts the utilization of remote sensing data to prepare crop yield map. Numerous research have showcased the utilization of combined GIS and RS technology for the purpose of estimating crop production. Memon et al. (2019) showcased the efficacy of integrating multispectral Landsat satellite images and comparing several remote sensing-based spectral indices in quantifying the proportion of wheat straw cover. Furthermore, the study successfully determined the impact of wheat straw cover on rice crop yields. The acquisition of knowledge can contribute to the development of long-term strategies for promoting agricultural sustainability within rice-wheat cropping systems. Hassan and Goheer (2021) indicate that it is possible to accurately estimate wheat crop yield in advance of harvesting by utilizing vegetation indices derived from moderate resolution imaging spectroradiometer satellite imagery, coupled with crop yield data and a GIS modeling approach. In a further investigation, Muslim et al. (2015) employed a GIS-based framework that linked climate modeling with environmental policy considerations. This approach offered a pragmatic solution for predicting rice crop yield. The study utilized a comprehensive model that integrated data at the regional level, including crop-level data, soil data, farm management data, and climatic data, in order to estimate geographic differences in crop production.

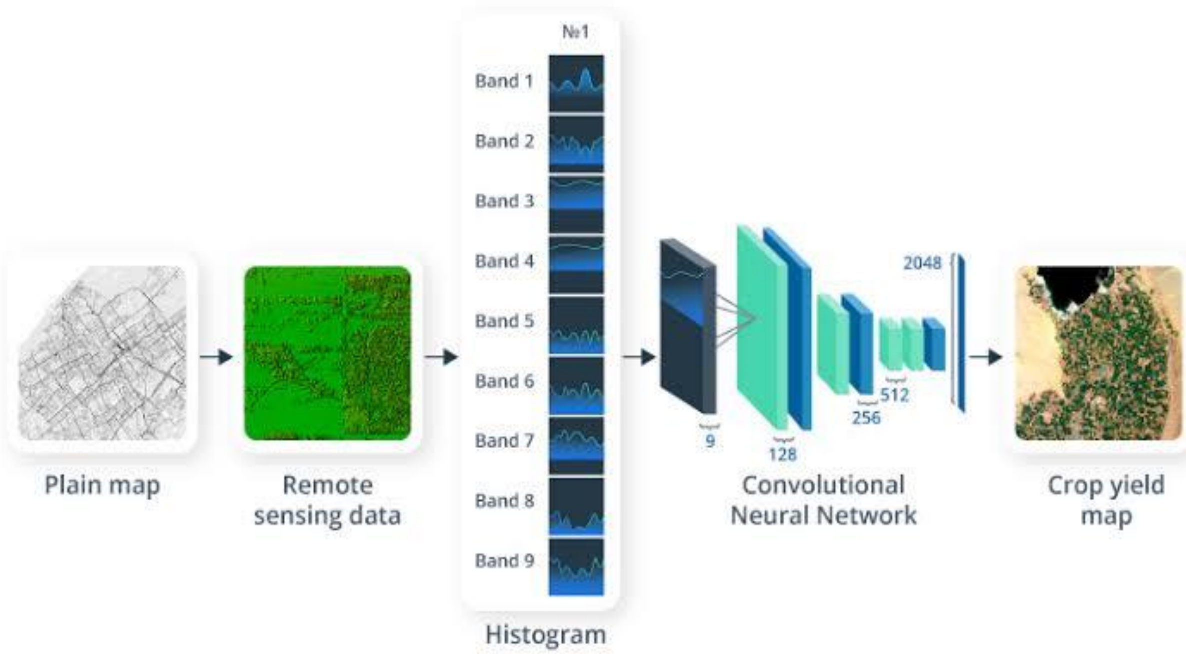


**Figure 4.** Utilization of remote sensing data to prepare crop yield map.

Similarly, Al-Gaadi et al. (2016) employed the extraction of the normalized difference vegetation index and soil-adjusted vegetation index from Landsat satellite pictures obtained throughout the various growth stages of potato plants in order to forecast the yield of potato tubers. Crop yield forecasting models that utilize GIS and RS have the potential for broader application in providing valuable insights for spatially oriented agricultural strategies. As demonstrated by the findings of these models, it is possible to develop policy interventions that target the various factors influencing crop yields, such as farm management techniques, plant health, water availability, weather conditions, terrain, altitude, and policy intervention itself (Mann & Warner, 2017; Raihan, 2023h; Voumik et al., 2023b). The ability to accurately predict crop yields well in advance of harvest is of utmost importance, particularly in a geographical area that is known for its unpredictable climate conditions. The monitoring of agricultural crop growth conditions and the forecast of prospective crop yield play a crucial role in the strategic planning and policy formulation for ensuring food security and predicting agricultural economic returns (Abhishek et al., 2023; Raihan, 2023i; Voumik et al., 2023c). One potential avenue for addressing this issue is the formulation of policies aimed at enhancing both the production and sustainability of agriculture (Pawlak & Kołodziejczak, 2020; Raihan & Said, 2022). In order to address the challenge of feeding a growing population in LMICs, it is imperative for agricultural production systems to focus on narrowing the gap between the present yields achieved by farmers and the potential yields that can be attained in rainfed subsistence farming systems. Hochman et al. (2013) aimed to resolve the discrepancy between actual and potential wheat yields. To achieve this, the researchers constructed a comprehensive model that incorporated statistical yield and cropping area data, remotely sensed data, cropping system simulation, and GIS mapping. This integrated approach allowed for the assessment and mapping of wheat yield gaps.

**Assessment of soil fertility**

The evaluation of soil quality holds significant importance in the development of sustainable agricultural strategies aimed at addressing the existing disparity between food supply and demand, hence contributing to the resolution of food security concerns (Wijerathna-Yapa & Pathirana, 2022; Raihan & Himu, 2023). The utilization of RS datasets and GIS spatial modeling approaches presents novel prospects for quantifying and assessing soil quality across various spatial extents (Guo et al., 2023; Raihan et al., 2023e). Shokr et al. (2021) devised a soil quality model that incorporates the physical, chemical, and biological attributes of soil in a spatially explicit manner. This model was further enhanced by merging a digital elevation model with a Sentinel-2 satellite image, resulting in the generation of digital soil maps. Abdelfattah and Kumar (2015) elucidate the utilization of a GIS-enabled web-based soil information system. This system offers a comprehensive soil database that incorporates descriptive, quantitative, and geographic data, all presented through a user-friendly interface. The application of the technique was utilized to assess the capacity of soils in terms of their suitability for plant cultivation and effective maintenance. Abdellatif et al. (2021) employed GIS and RS technologies to construct a spatial model aimed at evaluating soil quality. The researcher's model integrated four primary indicators of soil quality, namely the soil fertility index, soil physical index, soil chemical index, and geomorphological characteristics index. Additionally, the model employed GIS conventional kriging spatial interpolation techniques to provide a comprehensive map of the soil quality index. The utilization of these GIS-based models offers empirically supported approaches for enhancing soil quality management (Raihan et al., 2023f). The implementation of this approach would provide decision-makers, policymakers, land-use planners, and agricultural professionals with the means to effectively oversee soil resources and promote the sustainable utilization of agricultural lands based on their inherent capabilities (AbdelRahman et al., 2021; Tunçay et al., 2021; Raihan et al., 2023g). Therefore, the evaluation of soil quality indicators holds significance in the context of sustainable agricultural policies and practices, as well as in the pursuit of food security.

**Analysis of cropping patterns and agricultural monitoring**

In the context of climate variability, the utilization of agricultural crop monitoring analysis has the potential to assist governmental officials and farmers in formulating strategic approaches for crop planning and designing that are responsive to fluctuations in water resources (Njoya et al., 2022; Raihan et al., 2023h). Agricultural monitoring systems incorporate various geographic data sets and cropping system models into computational algorithms in order to spatially calculate and simulate optimal scenarios for site-specific conditions in crop production (Luo et al., 2023; Raihan et al., 2023i). Shafi et al. (2020) have created a crop monitoring system that combines geospatial data acquired through high-resolution remote sensing with a web-based GIS geoportal interface. The existing literature provides evidence for the distinctiveness of integrating GIS and RS into a tool designed for crop selection and rotation analysis at the farm level, with the aim of enhancing decision-making in crop management (Kumar & Babu, 2016; Raihan et al., 2023j). The modeling of cropping patterns is influenced by the availability of irrigation water, which is, in turn, influenced by climate variations and policy regarding the extraction of irrigation water. Wang et al. (2011) integrated GIS with irrigation water availability simulation models in order to examine cropping patterns. This analysis was conducted by utilizing forecasts of irrigation water availability. According to Kumar and Babu (2016), the implementation of a GIS that is accessible through the web can serve as a valuable tool for farmers at the individual farm level. This system would enable farmers to obtain pertinent information and make informed decisions aimed at enhancing agricultural productivity. Singha et al. (2020) assert that this system possesses a broader range of potential applications in facilitating agronomic decision-making processes, such as the optimization of land and labor efficiencies, the promotion of increased cropping intensities, and the generation of improved crop yields. This practice has the potential to enhance agricultural yield and optimize crop management practices, particularly in terms of precision irrigation management, over an extended period of time. Figure 5 presents the usage of Internet of Things (IoT) and smart sensors for agricultural monitoring.

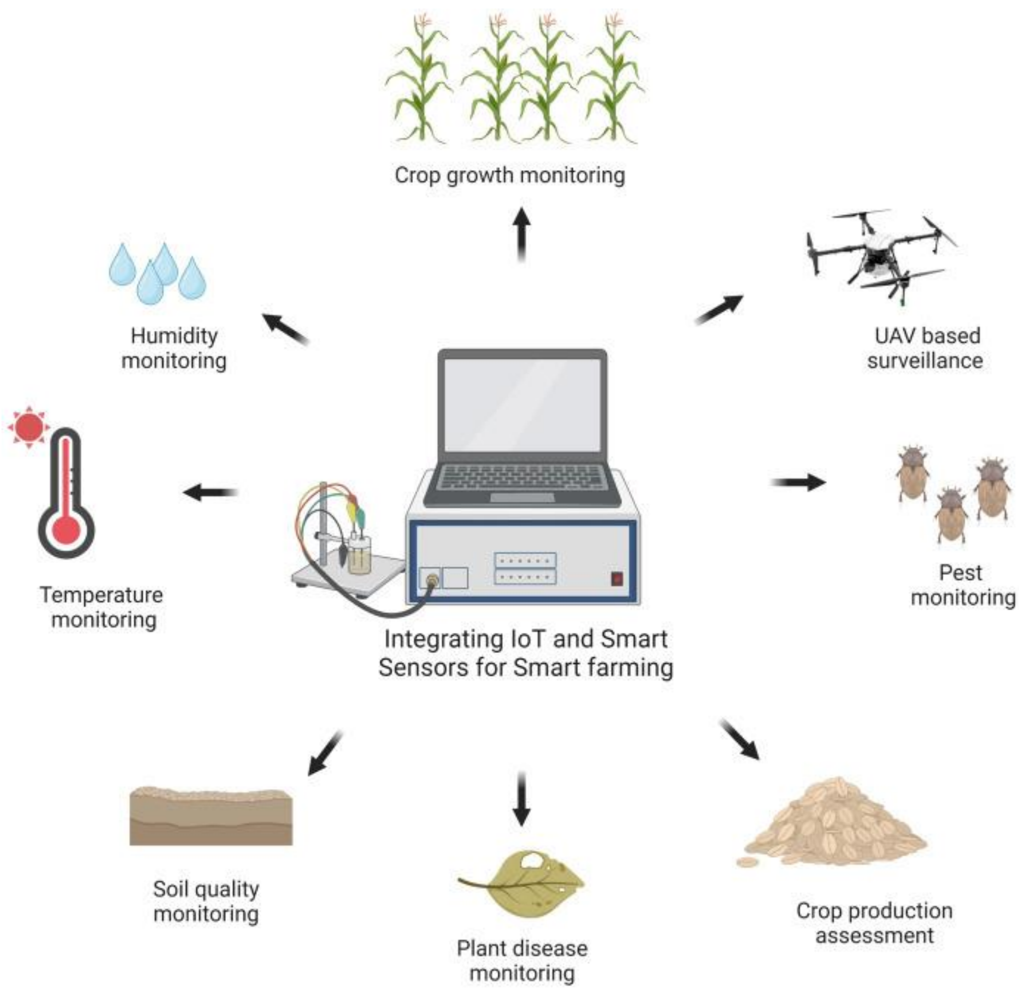


**Figure 5.** The usage of IoT and smart sensors for agricultural monitoring (Rajak et al., 2023).

### Evaluation of drought conditions

The utilization of spatial datasets derived from satellite RS and GIS technology provides valuable insights for evaluating and modeling agricultural drought-risk patterns, monitoring drought conditions, and generating maps depicting drought vulnerability (Mullapudi et al., 2023; Raihan et al., 2023k). Hoque et al. (2021) involved the integration of geospatial methodologies and fuzzy logic in order to create a complete spatial drought risk inventory model that can be utilized for effective operational drought management. The model effectively detected and characterized the geographical boundaries and patterns associated with agricultural drought vulnerability. Sehgal and Dhakar (2016) employed GIS and high-resolution RS data to create indicators of crop sensitivity. These indicators were then utilized to establish a technique for evaluating and mapping the primary biophysical elements that contribute to vulnerability to agricultural drought, specifically at a local level. According to Aziz et al. (2022), policymakers can utilize drought risk maps to develop policies that are geographically specific for mitigating and intervening in drought situations. Furthermore, the utilization of vulnerability maps can serve as a valuable tool in identifying areas that need prioritization for socioeconomic development policy initiatives (Isfat & Raihan, 2022; Saha et al., 2023; Raihan & Bijoy, 2023).

### Detection and control of pests and crop diseases

Ahmad and Sharma (2023) assert that ongoing advancements in geospatial tools and techniques are being made with the aim of assisting farmers in their efforts to control and manage crop diseases. Several research have demonstrated the pragmatic utilization of satellite RS data and Geospatial techniques in the context of detecting and managing crop diseases in a sustainable manner (Roberts et al., 2021; Raihan et al., 2018; Pande & Moharir, 2023). RS technology, specifically the utilization of airborne and satellite imagery during the periods of crop growth, has been employed for the purposes of early detection and mapping of certain crop diseases, as well as for managing the recurrence of diseases in subsequent seasons and evaluating the economic impact resulting from frost damage (Jaafar et al., 2020; Sishodia et al., 2020; Raihan et al., 2019; Wu et al., 2023). Santoso et al. (2011) employed high-resolution QuickBird satellite images to successfully identify regional distributions of oil palm plants afflicted with basal stem rot disease. Six vegetation indicators were employed, which were generated from satellite imagery's visible and near-infrared bands, in order to effectively differentiate between oil palms that were healthy and those that were sick. Yang (2020) demonstrated the successful implementation of site-specific fungicide applications for disease management through the utilization of precision agriculture technologies and remotely sensed imaging. In the forthcoming years, novel methodologies that employ geoinformation technology for the purpose of monitoring and managing pest and crop disease detection have the potential to mitigate the environmental impact of pesticides and herbicide chemicals.

### Precision agriculture

Automated geospatial analysis and decision support algorithms in the field of precision agriculture have the potential to offer policymakers significant scientific insights, hence enhancing the creation of agriculture policies (Raihan et al., 2021a; Saliu & Deari, 2023). The utilization of integrated GIS, RS, and GPS technology has led to the increasing recognition of precision agriculture methods. These practices have demonstrated their effectiveness in enhancing crop output, enabling site-specific crop management, and minimizing the use of agrochemicals (Karunathilake et al., 2023; Raihan et al., 2021b). Toscano et al. (2019) showcased the efficacy of utilizing Sentinel-2 and Landsat-8 imagery for representing the spatial heterogeneity of wheat production within a given field. This information is crucial for the implementation of precision farming methodologies. This offered a prospective alternative to conventional farming methods through the enhancement of site-specific management and agricultural yield. García et al. (2020) conducted an investigation to evaluate the efficacy of remote-sensing drones in serving as mobile gateways for facilitating Wi-Fi data transfer between sensor nodes and the gateway in precision agriculture systems. The authors aimed to provide insights into the ideal drone parameters that would ensure successful data transmission in this context. The research effectively showcased the utilization of drones as a remote sensing instrument for collecting data from field-deployed nodes to facilitate crop monitoring and management. The drones operated at a minimal pace, maintained a height of 24 m, and were equipped with an antenna providing a coverage range of 25 m. This had the potential to enhance the uptake of precision agriculture among smallholder farmers.

Segarra et al. (2020) had a specific objective of comprehending the characteristics of the twin Sentinel-2 satellites belonging to the European Space Agency, as well as their utilization in the field of precision agriculture. The research conducted emphasizes the significant advancements brought about by Sentinel-2 in the field of agricultural monitoring and crop management. It has greatly enhanced the detection of abiotic and biotic stresses, improved the accuracy of crop yield estimation, facilitated more precise crop type classifications, and offered a range of other valuable applications in the agricultural sector. Various factors contribute to the augmentation of precision agriculture, resulting in enhanced agricultural management and environmental sustainability (Elahi et al., 2022; Raihan, 2024b). The utilization of satellite image-based solutions for the extraction of plantation rows plays a crucial role in various aspects of precision agriculture, including crop harvesting, pest management, and projections of plant growth rates. Fareed and Rehman (2020) conducted a study in which they employed GIS and RS techniques to develop an automated approach for extracting plantation rows from a digital surface model derived from drone-based picture point clouds. The technique of automatic extraction of plantation rows can be employed for the purpose of quantifying damage assessment in precision agriculture pertaining to plantation rows. Figure 6 presents the technologies involved in precision agriculture.

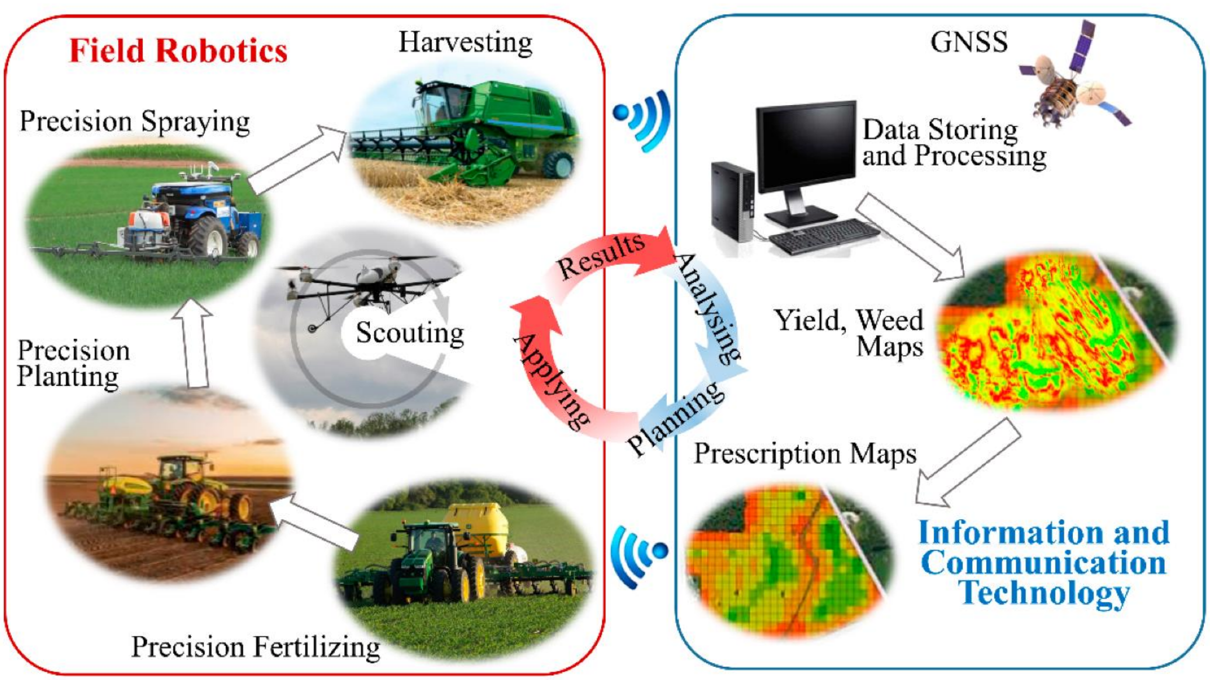


**Figure 6.** Technologies involved in precision agriculture (Gonzalez-de-Santos et al., 2020).

### Weed and fertilizer management

The implementation of precise mapping techniques for weed distribution has the potential to significantly improve the effectiveness of weed management strategies. This can lead to a reduction in weed-related losses, as well as a decrease in the expenses associated with herbicide application and the optimization of fertilizer usage (Chaudhari et al., 2022; Raihan et al., 2022d). GIS technologies were employed to generate precise maps depicting the distribution of weeds inside rice farms, which enhanced input application efficiency, reducing the utilization of inputs such as herbicides, fungicides, and labor expenses associated with weeding (Dunaieva et al., 2018; Raihan et al., 2022e). Consequently, this led to a decrease in weed damage and a reduction in the overhead expenditures associated with crop production. The utilization of GIS in the creation of a GIS-based Fertilizer Decision Support System (FDSS) has been shown in the literature (Xie et al., 2012; Raihan et al., 2022f). This was achieved through the integration of RS data, field surveys, and expert knowledge. The researchers successfully developed a soil spatial database on the SuperMap platform, which proved to be valuable for effective crop management systems. The employment of FDSS in agricultural production has been found to yield several advantages, including enhanced efficiency in fertilizer utilization, thus leading to a reduction in production costs.

### Challenges in implementing GIS in agricultural policy and practice

In general, the utilization of GIS and RS technology is not a universally effective solution for achieving evidence-based policy and practice, and it is not without its drawbacks. The efficacy of geospatial technology application is contingent upon its appropriate utilization, the availability of high-quality data, and the allocation of substantial resources for its management (Raihan et al., 2022g). In nations experiencing limited resources, such as LMICs, the widespread utilization and acceptance of technology are hindered by the associated expenses and insufficient proficiency in relevant competencies (Raihan et al., 2022h). The task of simulating crop yield generation poses inherent challenges owing to the diverse array of cropping systems and the varying degrees of technological advancement employed (Abbasi et al., 2022; Raihan et al., 2022i). In order to achieve a precise evaluation of crop production gaps, it is imperative to enhance the quality of input data. This entails obtaining precise meteorological parameters, improving soil characterization, and acquiring geographically dispersed land use data (Schils et al., 2022; Raihan, 2024c). Additionally, the implementation of instrumented geo-referenced validation sites would be necessary in order to provide full survey data that can be used to feed a continuous improvement cycle for assessing yield gaps (Tantalaki et al., 2019; Raihan, 2023j). Therefore, the advancement of remote sensing technologies and the refinement of integrated cropping systems models would result in enhanced precision for yield gap estimation in the future.

In the field of drought vulnerability assessment and mapping, a majority of research documented in scholarly literature have demonstrated a preference for employing aggregated geographical data at broader spatial scales, such as national or regional levels. However, there has been a notable absence of use of finer-scale data, specifically at the local level (Raihan, 2023k). Given that the impact of drought hazards is predominantly experienced and demonstrated at the local level, conducting a comprehensive mapping of drought risks at a more precise scale necessitates the utilization of high-resolution remote sensing techniques and the incorporation of locally relevant indicators. This approach is crucial in order to obtain a comprehensive understanding of susceptibility in relation to drought (Raihan, 2023l). This would be of more significance to policymakers who are aiming to develop and execute mitigation initiatives at the local level. Given the anticipation of heightened and more frequent drought occurrences, as well as the escalating risks posed by climate change, the integration of all spatially explicit risk factors into drought risk mapping would constitute a valuable and effective addition to measures aimed at mitigating drought impacts (Raihan, 2023m). There is a need for further acquisition of skills and knowledge pertaining to the application of geospatial techniques in the context of agricultural drought risk.

In the domain of agricultural disease identification, there persist issues pertaining to the accurate mapping of such diseases through the utilization of aerial or satellite imaging (Raihan, 2023n). While satellite imaging has proven effective in detecting and mapping several crop diseases, it is important to note that each disease possesses unique characteristics that necessitate distinct approaches for detection and management. Yang (2020) asserts that the identification of certain diseases poses challenges, particularly when there are several biotic and abiotic factors that have similar spectral features within a given field. The identification of recurring diseases necessitates the utilization of consistent historical images and spatial-temporal data, whereas the detection of developing diseases poses greater challenges. Yang (2020) asserts that there is a need for the development of more sophisticated RS imaging sensors and image-processing systems in order to effectively distinguish diseases from other factors that may cause confusion. In underdeveloped nations, there is a limited number of farmers possessing the requisite expertise for utilizing RS technologies in the generation of prescription maps, the execution of disease control strategies, and the administration of site-specific fungicides (Raihan, 2023o). Further investigation is warranted in the advancement of integrated geospatial analytical approaches and technologies to assist farmers in identifying various crop diseases.

The utilization of precision agriculture technologies has the potential to enhance crop optimization and support decision-making in agricultural management, thereby addressing the issue of food insecurity in LMICs (Raihan, 2023p). However, the successful implementation of precision farming necessitates the adoption of geospatial technology and the acquisition of substantial quantities of high-resolution spatiotemporal data (Raihan, 2023q). The deficiency in proficiency in using GIS and RS technologies in LMICs can be addressed by the widespread distribution and adoption of realistic geospatial technology from more industrialized nations (Roberts et al., 2021; Raihan, 2023r). Nevertheless, the successful implementation of precision agriculture methods in LMICs requires substantial investments in information and communication technology (ICT) infrastructure.

The evaluation of soil fertility is widely recognized as a crucial parameter in precision farming and the sustainable management of agricultural lands based on their inherent capabilities (Raihan, 2023s). The establishment of a comprehensive soil information system is necessary. Nevertheless, as asserted by Abdelfattah and Kumar (2015), a significant portion of the global population lacks access to comprehensive soil quality data. In LMICs, there is a notable increase in the fragmentation of agricultural land into smaller plots that are economically unviable, accompanied by the adoption of unsustainable farming practices (Raihan, 2023t). Further investigation is warranted to explore the potential of active remote sensors in assessing soil quality within a dynamic and evolving context.

One of the challenges hindering the utilization and acceptance of GIS and RS in the agricultural sector is to the absence of universally recognized standards for data interoperability (Raihan, 2023u). Despite the growing accessibility of spatial data utilization in LMICs, a significant challenge arises from the inherent susceptibility of these data to errors (Raihan, 2023v). Furthermore, the collection and storage of such data in LMICs may involve disparate spatial units, formats, metadata, as well as variations in time and space intervals (Raihan, 2023w). These factors render certain data impractical for use, impede the integration of spatial data, and impede the comprehensive analysis of data, particularly when it is acquired from several sensors and platforms (Raihan, 2023x). There is a necessity to establish universally accepted protocols for the development of standardized rules pertaining to geographical data in the field of agriculture (Raihan, 2023y). It is of utmost importance to provide training to academics, practitioners, and farmers on the proper methods for collecting spatial data that is both high in quality and accuracy, ensuring its usability across several platforms. Enhancing the interoperability of spatial data repositories has the potential to facilitate data integration and enhance the efficacy of data analysis.

Crowdsourced data collecting has promise as a valuable contribution towards the development of cost-effective agri-spatial data repositories.

## Conclusions and Policy Implications

This study has examined diverse methods in which GIS technology has been incorporated within the agricultural sector to enhance decision-making processes and inform policymaking efforts. GIS and RS technologies offer more effective methodologies for analyzing spatial elements that impact agricultural production in comparison to methods that lack geographically explicit data. When effectively utilized, the spatially integrated knowledge offered by GIS and RS can be utilized to augment agricultural policy and evidence-based interventions aimed at enhancing agricultural sustainability. Despite the potential of GIS technology to enhance agronomic practices, their utilization in many LMICs is limited. This is concerning, as many countries are in urgent need of upgrading their agriculture and food production techniques. In order to optimize the utilization of GIS and RS technologies, it is imperative for governments and farmers in LMICs to enhance their understanding and possible application of spatial data pertaining to agricultural practices. Advancements in geoinformatics methods and computing infrastructure have the potential to facilitate a more collaborative framework among various stakeholders, including scientists, researchers, policymakers, academics, crop consultants, extension employees, and agricultural machinery and chemical dealers. This framework aims to provide practical guidelines for the effective management of crop production estimations, fertility of the soil, cropping patterns and monitoring, drought risks, as well as fertilizer and weed management.

To bolster evidence-based agricultural policy, government entities and policymakers necessitate robust empirical data that facilitates a comprehensive comprehension of the intricate and interrelated elements influencing agricultural productivity. Consequently, this would facilitate the development of specific intervention techniques. Moreover, it is imperative for a diverse range of stakeholders and professionals in the field of agriculture to have access to geographically relevant agricultural data in order to effectively implement a multitude of strategies aimed at enhancing agricultural productivity. Similarly, it is crucial for smallholder farmers to have access to synthesized information in order to empower them to make educated decisions based on evidence. This knowledge is also necessary for them to effectively undertake practical activities that can enhance agricultural productivity. The aforementioned statement highlights the growing need for the integration of GIS in the processes of formulating and implementing agricultural policies.

GIS and RS technologies possess considerable potential in the evaluation, preservation, manipulation, and generation of agricultural data. The data holds potential value in several applications such as precision agriculture, site-specific farming, and disease detection, with the overarching goal of enhancing agricultural food production and addressing food security concerns. Regrettably, the absence of reliable spatial data in numerous local government entities persists as a hindrance to decision-making processes, policy development, and the subsequent execution thereof. In instances where such data is available, there is a prevailing deficiency in the proficiency of individuals in utilizing GIS and RS spatial analytical tools. The attainment of agriculturally integrated policies that encompass geographical dimensions necessitates the use of comprehensive and current spatial datasets, as well as improved methodologies that effectively amalgamate and analyze intricate data from diverse origins in order to generate valuable insights. This would require both national and local governments to implement methodologies, approaches, and methodologies that enable the gathering and examination of various agricultural datasets, thereby offering comprehensive insights to policymakers, planners, farmers, and a wide range of stakeholders involved in the agricultural industry. GIS offers a promising avenue for obtaining comprehensive and current spatial datasets, as well as improved spatial analytic techniques capable of effectively evaluating intricate data to generate valuable insights. If appropriately adopted and implemented, GIS has the potential to increase the spatial decision support system, hence boosting the efficiency and efficacy of agriculture policy development and planning. However, the implementation of policy change necessitates the presence of both public and political will in order to effectively lead and stimulate actions. Consequently, the implementation of GIS technology in the policymaking process necessitates the allocation of public monies by local government entities to establish the necessary software, hardware, supportive infrastructure, and staff training. Future research endeavors may prioritize the examination of how GIS and RS technologies might facilitate the establishment of a collaboration framework among scientists, policymakers, researchers, and extension agriculture officers. This collaborative framework aims to enhance the promotion of sustainable and climate-smart farming methods, with a particular emphasis on LMICs.

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